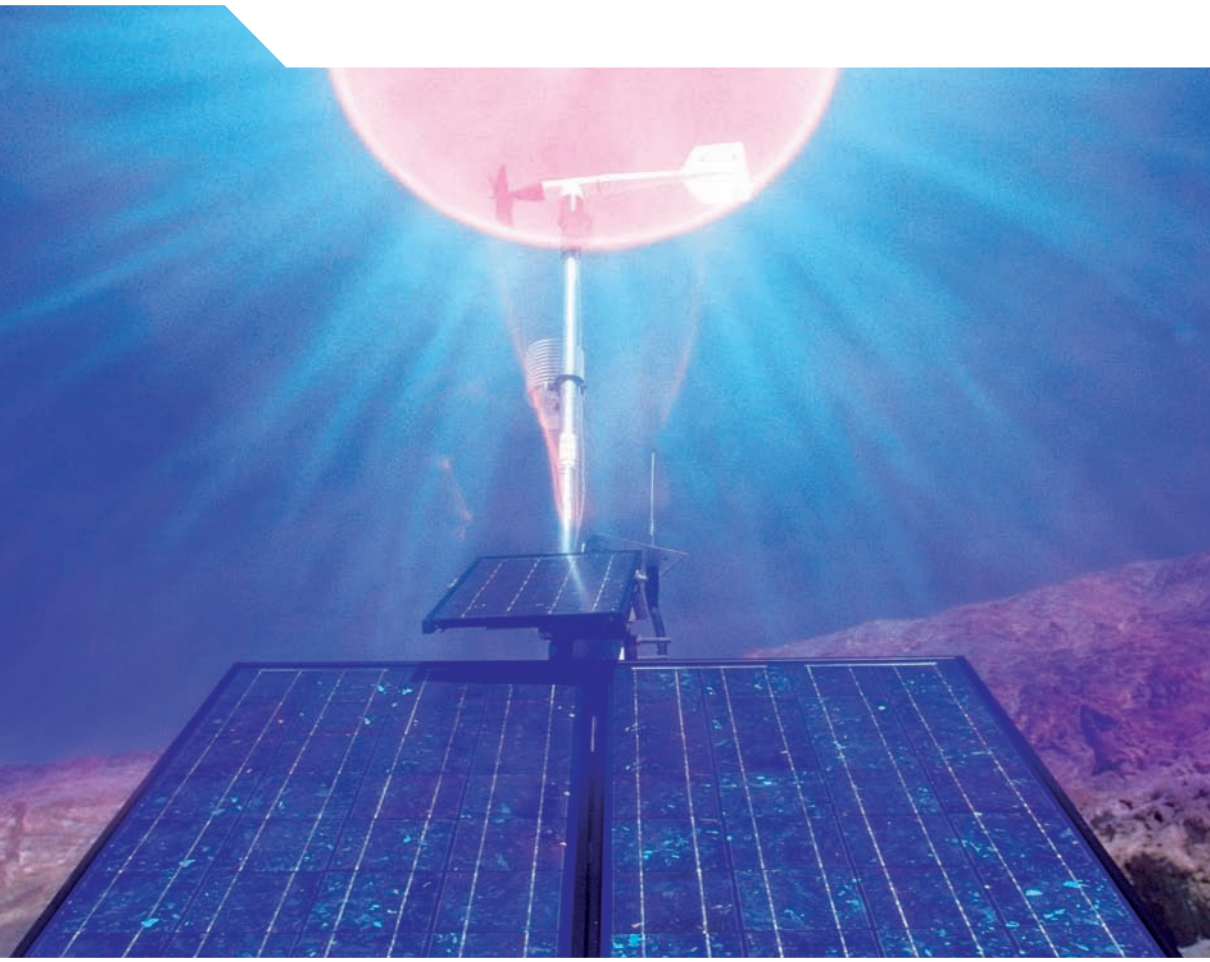
OECD Studies on Environmental Innovation

Better Policies to Support Eco-innovation



OECD

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Foreword

This report was developed as part of the OECD Programme of Work and Budget on eco-innovation. One of its objectives is to identify best practices in order to support the development and the deployment of eco-innovation. This work builds on the OECD Innovation Strategy which was released in May 2010. It complements other work on eco-innovation at the OECD, which includes assessing the impact of environmental policies on eco-innovation and the role of eco-innovation in pursuing green growth.

The report builds on analytical work of the last two years, which includes:

- A review of eco-innovation roadmaps developed by European countries under the aegis of the European Commission's Environmental Technology Action Plan. It complements country profiles on policies to support eco-innovation in eight non European OECD members developed by the OECD Secretariat [ENV/EPOC/GSP(2008)12/FINAL]. The review was undertaken by a team of experts from the Austrian Institute of Economic Research (WIFO) and managed by Andreas Reinstaller and Daniela Kletzan-Slamanig.

- Case studies on selected technologies undertaken to explore how certain policies interfere with contextual features of the development and diffusion of eco-innovation. The following technologies were selected: electric cars (in Canada and Germany), micro combined heat and power (in Germany), combined heat and power generation (in Canada and Germany), carbon capture and storage (in Canada), solar tiles (in Portugal), biopackaging (in France). Philippe Larrue and Nicolas Turcat, Technopolis Group, undertook the case study on micro combined heat and power. Jon van Til, Technopolis Group, carried out the case study on solar tiles. Gilles Le Blanc, CERNA/Mines Paris Tech, was responsible for the case studies on carbon capture and storage, combined heat and power, electric cars and biopackaging.

- Case studies on selected public-private partnerships. The studies present lessons for policy makers on the design of innovative and efficient forms of public private co-operation. Two partnerships were selected: The Carbon Trust in the United Kingdom and

Sustainable Development Technology Canada (SDTC), in Canada. Michal Miedzinski and Nelly Bruno (Technopolis Group) carried out the first case study and Gilles Le Blanc (Cerna/Mines Paris Tech) the second.

- A Global Forum on Environment focused on eco-innovation, organised in November 2009 in Paris. Its objective was to share experience on policy issues related to the development and diffusion of eco-innovation, and to fine-tune messages on how to make environment and innovation policies mutually supportive. A special focus was on emerging and developing countries. All relevant information, including proceedings and papers released in the OECD Environmental Working Papers series, is available at *www.oecd.org/environment/innovation/globalforum*.

Xavier Leflaive co-ordinated the project and was responsible for the synthesis report.

An informal technical workshop was organised in June 2010, with the authors of the case studies, external experts (Carlos Montalvo, TNO; Jens Horbach, University of Applied Sciences, Anhalt), the European Commission (Aurelio Politano, ETAP) and the OECD Secretariat (Tomoo Machiba, Directorate for Science, Technology and Industry; Ivan Hascic, Environment Directorate).

The report benefited from comments by delegates to the OECD Working Party on Global and Structural Policies and the Working Party on National Environment Policies at various meetings in 2009 and 2010.

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ACRONYMS AND ABBREVIATIONS

ADENE	Energy Agency (Portugal)
AFVs	Alternative fuel vehicles
ARRA	American Recovery and Reinvestment Act of 2009
BMU	Federal Environment Ministry (Germany)
CCS	Carbon capture and storage
CDM	Clean Development Mechanism
CHP	Combined heat and power generation
DHC	District heating and cooling
DOE	Department of Energy (US)
EC	European Commission
ECAs	Enhanced capital allowances
EEG	Renewable Energy Sources Act (Germany)
EPA	Environmental Protection Agency
ESCO	Energy service company
ETAP	Environmental Technology Action Plan
ETS	Emissions trading system
EU	European Union
FC	Fuel cell
FCCJ	Fuel Cell Commercialization Conference of Japan (Japan)
ICE	Internal combustion engine
IEA	International Energy Agency
GWe	Gigawatt electric

HFP	Hydrogen and Fuel Cell Technology platform (Europe)
IGCC	Integrated gasification combined cycle
IPRs	Intellectual property rights
KTNs	Knowledge transfer networks
kWe	Kilowatt electric
MCFC	Molten carbonate fuel cells
Mt	Million tonnes
MWe	Megawatt electric
MWh	Megawatt hour
NAO	National Audit Office (United Kingdom)
NIP	National Hydrogen and Fuel Cell Technology Innovation Programme (Germany)
NGOs	Non-governmental organisations
NOW	Nationale Organisation Wasserstoff und Brennstoffzellen Technologie Gmbh (Germany)
PAFC	Phosphoric acid fuel cell
PEMFC	Proton exchange membrane fuel cell
PPP	Public-private partnership
PV	Photovoltaic
R&D	Research and development
SDTC	Sustainable Development Technology Canada
SOFC	Solid oxide fuel cells
TWh	Terawatt hour
USEPA	US Environmental Protection Agency
VC	Venture capital
VPP	Virtual power plant
WIFO	Austrian Institute of Economic Research
WWF	Worldwide Fund for Nature

Executive summary

Innovative products, services, processes or business models can benefit the environment by reducing pressure on natural resources and/or the emission of pollutants. At the same time, environmentally friendly innovation can foster economic development. The environmental goods and services industry is growing fast in OECD and non-member countries alike. Like information technologies a few decades ago, it can enhance the competitiveness of other industries. This explains why a number of OECD governments see environmentally friendly innovation (hereafter eco-innovation) as a major driver of green growth.

Market mechanisms alone will not provide an appropriate amount of eco-innovation at the right time. This is because innovators may not reap all of the benefits of their innovations and because environmental benefits may not be appropriately valued by markets. Policy intervention is therefore a must. From a policy perspective, the question is: What is the best way to support the development and diffusion of eco-innovation? More specifically, from an environmental policy perspective, the issue is to stimulate innovation that will benefit the environment.

This perspective has consequences. First, it acknowledges that eco-innovations may originate in a variety of contexts and that environmental performance may not be the initial driver. Second, non-technical innovation matters (for instance, the on-demand bicycle service in Paris relies little on technology and heavily on a sophisticated business model and appropriate organisation). Third, the way innovations are used (that is, whether more or less competently) matters.

This report explores how these consequences help to shape eco-innovation policies. It complements previous OECD work on eco-innovation, which generally focused on the impact of market failures on the amount of environmental inventions and on the instruments and policy packages that can remedy such failures. It also complements ongoing studies

of business approaches to eco-innovation and empirical analyses of the changes in industrial structure required to achieve green growth.

National strategies for eco-innovation have strengths and limitations

Most OECD countries have developed national strategies to support eco-innovation. In Europe, the Environmental Technology Action Plan (ETAP) has invited EU members to develop eco-innovation roadmaps and to report initiatives taken at national and/or local level to support eco-innovation. Outside Europe, a number of OECD countries have similar initiatives; in particular, Korea and the United States have designed explicit strategies to stimulate eco-innovation.

National strategies address a variety of objectives: bridging the gap from the demonstration phase to commercialisation (*e.g.* in the field of carbon capture and storage or micro combined heat and power generation), improving consumer awareness (*e.g.* of biopackaging), defining technical standards (*e.g.* for electric cars), and building a critical mass (*e.g.* for combined heat and power generation). They cover a wide range of policies, from environment to science and technology, industry, transport, competition, and energy policies. They mix very diverse tools and initiatives, from support for research and development (R&D) to market creation and export promotion. They involve initiatives by public authorities at both national and local levels and offer lessons regarding an appropriate split of responsibilities between them. Roadmaps provide a framework to assess the coherence of these policies.

More could be learned from these strategies if standardised measurement references could be used to assess the impact of specific eco-innovation policies in national contexts. This would require:

- more systematic information on the contextual features of the country, including industry structure and domestic market size, key environmental challenges, the knowledge base as regards eco-innovation, and the strength of the domestic venture capital industry;
- qualitative information on the design of instruments that underpin eco-innovation policies.

It is not clear how national strategies support the development of eco-innovations when alternative technological trajectories abound (see Box 0.1). There is a risk that a strategy, when too narrowly or strictly focused, will restrict the scope of technological options that will be explored

and impinge on the development of alternative trajectories. Timing is essential.

Box 0.1. Technological trajectory, defined

The concept of technology trajectory refers to a single branch in the evolution of a technological design of a product or service. Movement along the technology trajectory is associated with research and development.

The economic literature argues that only a small fraction of the possible directions a technology could have taken materialises. Owing to the institutionalisation of ideas, markets and professions, development of a technology can get "stuck" in one trajectory, with firms and engineers unable to adapt to ideas and innovation from outside. Alternatively, technological trajectories for a given product or service may proliferate, eventually fragmenting markets into segments that substitute poorly for one another. Independent technological trajectories are characterised by limited demand substitution and R&D scope economies.

The concept is useful for analysing the pattern of linkages across submarkets on both the demand (substitution) and technological (R&D scope economies) sides. To address this issue, Sutton (1998) suggested introducing the notion of distinct technological trajectories, each associated with a distinct submarket. When products in submarkets are close substitutes, a firm advancing along one trajectory with a large R&D effort will manage to win market share from firms operating on other trajectories and submarkets. Alternatively, when products in different submarkets are poor substitutes, the market becomes separable into a number of independent submarkets, and a superior R&D effort in one will have little impact on the others.

The concept usefully allows for a distinction between markets in which innovation progresses along a single trajectory, and those marked by a continuous proliferation of technological trajectories. This distinction has significant implications for the analysis of the respective roles of market forces and public policies. Moreover, it is an invitation to take account of the customer side and to evaluate the potential benefits of an eco-innovation in light of existing substitutes and the nature of market competition. The concept also has methodological consequences. To assess competition between distinct technological trajectories as well as the potential for product substitution and R&D economies of scope, empirical investigations should not be restricted to a particular eco-innovation, but should consider other alternatives and the associated industries.

Source: Adapted from an unpublished methodological note by Gilles Le Blanc for the OECD Global Forum on Environment focused on eco-innovation, November 2009.

Moving from green technologies to the environmental benefit of innovation-in-use

The case studies examined in this report highlight the long history of selected eco-innovations (such as combined heat and power generation and electric cars) and note that they often originated outside the environmental domain. For example, carbon capture and storage combines a set of commercially available component technologies from the oil, chemical and power generation industries. Furthermore, a number of eco-innovations are not regarded as particularly high technology: for example, biopackaging can improve the environmental performance of the food, drink, cosmetics and pharmaceutical industries, using mundane resources and mature techniques.

A number of policy messages derive from these observations:

- making mature technologies more market-friendly is as important as producing new knowledge;
- technical and non-technical innovations matter equally;
- capturing innovations originating in non-environmental domains opens a large spectrum.

It follows that eco-innovation policies interact with policies developed in other domains. This raises issues of consistency, governance and monitoring. In particular, from an environmental policy perspective, monitoring could focus on the environmental benefit of innovation-in-use.

Eco-innovation policies are linked to industrial and competition issues

When considering the trajectories along which eco-innovations are developed and brought to the market, innovative industries reveal two opposing patterns which may require policy makers to consider a number of concepts, instruments and indicators when developing eco-innovation policies.

The first pattern is one of R&D economies of scope and market substitution, which lead to escalation along a single technical trajectory and potentially to a high level of concentration. Typically, only one combined heat and power generation (CHP) technology is used in the market for a given size of applications. In such cases, public R&D expenditure benefits all players in the field; similarly, all firms potentially benefit from market

creation mechanisms (*e.g.* performance standards, labels, green procurement).

The second pattern emerges when there is no economy of scope for R&D and when demand is split among non-substitutable goods and services. For instance, the electric car industry may be characterised by the coexistence of separate trajectories (*e.g.* hybrid, full electric), with little (if any) economies of scope for R&D, and non-substitutable market segments. In such a context, there is a risk that public R&D expenditure and market creation mechanisms will only benefit one cluster of industries, at the expense of others.

This links eco-innovation policies to industrial and competition issues. When facing a proliferation of possible technical trajectories, should a government concentrate R&D efforts and budgets on one technological trajectory or encourage a diversity of solutions by simultaneously supporting alternate routes? The first option focuses public support but may generate lock-in effects. The second option fragments R&D efforts and markets, potentially delaying diffusion. The CHP case study shows that Germany and Canada adopt different strategies in this area and have different policy priorities.

Co-ordination is needed across time, layers of government and the public and private sectors

As the case studies make clear, eco-innovation policies need to be co-ordinated in many ways.

First, policies to support eco-innovation generally develop and evolve over long periods, and coherence can be difficult to maintain over time. In addition, priorities and needs evolve and instruments have to be revised and adapted. For instance, policies to support micro-CHP in Germany have developed over 30 years; the initial emphasis was on R&D and has led to important developments and a fragmented marketplace; since 2005, the major instrument is NOW, a joint initiative of several federal ministries, which mainly aims to develop applied research and field tests. Policy makers would benefit from a better understanding of when and how to introduce an instrument, and when and how to phase others out.

Second, sub-national authorities actively support eco-innovation. They have developed capacities to address environmental concerns at their level, and they consider environmental goods and services as new engines for growth. Co-operation built on a better understanding of the respective roles of the different layers is needed across levels of government.

Third, co-ordination between research and industry is essential. Deployment matters just as much as development of new knowledge. The private sector is the main vehicle for deployment, both domestically and internationally (through trade and foreign direct investment). This means that:

- demonstration is essential, and governments can bridge the gap between research and industry when markets fail;
- knowledge transfer networks, incubators and other forms of partnerships can help to circulate information between research and industry;
- public-private partnerships can contribute to effective governance in support of eco-innovation.

Fourth, when markets are uncertain, (international) co-operative research can pool development risks and share information. The case study on carbon capture and storage identifies opportunities for international co-operation (*e.g.* on common regulation; on policies to transport and store carbon in neighbouring countries; on R&D and demonstration subsidies). More could be learned on the appropriate instruments, timing and risks related to (international) co-operation for eco-innovation, taking account of environmental, science, industry and competition perspectives.

Eco-innovation calls for focused technology transfer models

To reap the full environmental benefit of available products, services, and processes, the transfer of eco-innovations is essential. Transfers to developing countries topped the policy agenda on climate change mitigation at the Conference of the Parties 15 in December 2009 in Copenhagen.

Recent research shared at the 2009 OECD Global Forum on Environment suggests that international co-operation mechanisms are more effective when they strengthen developing countries' own capacities to grow or adapt existing eco-innovations. This requires flows of underlying and tacit knowledge (know-how and know-why). This is not limited to higher education: low-skill jobs may be required.

The report inventories viable models for a more focused, needs-based approach to building eco-innovation capabilities in developing countries.

Résumé

Les innovations dans les produits, services, processus ou modèles d'activité peuvent être bénéfiques pour l'environnement car elles peuvent réduire la pression exercée sur les ressources naturelles et/ou l'émission de polluants. Parallèlement, des innovations favorables à l'environnement peuvent stimuler le développement économique. Le secteur des biens et services environnementaux connaît une croissance rapide dans les pays membres de l'OCDE comme dans les pays non membres. Tout comme les technologies de l'information il y a quelques décennies, ce secteur peut accroître la compétitivité d'autres secteurs. C'est la raison pour laquelle un certain nombre de pays de l'OCDE voient dans les innovations favorables à l'environnement (appelées ci-après éco-innovation) l'un des principaux moteurs de la croissance verte.

Les mécanismes de marché ne fourniront pas, à eux seuls, la quantité appropriée d'éco-innovation au bon moment, car il y a un risque que les inventeurs ne touchent pas les dividendes de leurs innovations et que les marchés ne valorisent pas correctement les bénéfices environnementaux d'une innovation. Par conséquent, les pouvoirs publics doivent intervenir. Du point de vue des politiques publiques, la question est de savoir comment soutenir au mieux le développement et la diffusion de l'éco-innovation. Plus spécifiquement, du point de vue des politiques environnementales, le problème est de stimuler des innovations qui seront bénéfiques pour l'environnement.

Cette perspective a des conséquences. Premièrement, elle reconnaît que l'éco-innovation peut émerger dans toute une série de contextes, pour des raisons qui ne sont pas nécessairement liées à la recherche d'une meilleure performance environnementale. Deuxièmement, l'innovation non technique importe autant que l'innovation à caractère technologique (à Paris, par exemple, le système de vélos en libre-service repose moins sur la technologie que sur un modèle d'activité complexe et une organisation appropriée). Troisièmement, la manière (plus ou moins compétente) dont l'innovation est utilisée, importe.

Le rapport analyse comment les politiques de soutien à l'éco-innovation peuvent prendre en compte ces considérations. Il complète les travaux précédents de l'OCDE sur l'éco-innovation, qui se concentrent principalement sur l'impact des défaillances du marché sur le nombre d'inventions liées à l'environnement et sur les instruments et programmes d'action susceptibles de remédier à ces défaillances. Il complète également les études en cours sur l'attitude des firmes au sujet de l'éco-innovation et l'analyse empirique des changements de structure industrielle que requiert la croissance verte.

Les stratégies nationales en faveur de l'éco-innovation ont des avantages et des inconvénients

La plupart des pays de l'OCDE ont élaboré des stratégies nationales de soutien à l'éco-innovation. En Europe, le Plan d'action en faveur des écotechnologies (ETAP) a invité les membres de l'Union européenne à élaborer des feuilles de route pour l'éco-innovation et à rendre compte d'initiatives prises au niveau national et/ou local pour soutenir l'éco-innovation. En dehors de l'Europe, un certain nombre de pays de l'OCDE ont pris des initiatives similaires ; en particulier, la Corée et les États-Unis ont conçu des stratégies visant explicitement à stimuler l'éco-innovation.

Les stratégies nationales s'attaquent à des objectifs variés : créer un lien entre la phase de démonstration d'une technologie et sa commercialisation (par exemple en matière de micro cogénération ou de piégeage et de stockage du carbone), sensibiliser davantage les consommateurs (par exemple en matière de « biopackaging »), définir des normes techniques (pour les voitures électriques, par exemple) et atteindre une masse critique (dans le cas de la cogénération). Elles couvrent un large éventail de politiques, de l'environnement à la science et à la technologie, à l'industrie, aux transports, à la concurrence et aux politiques énergétiques. Elles mélangent des outils et des initiatives très divers, du soutien à la recherche et au développement (R-D) jusqu'à la création de marchés et à la promotion des exportations. Les initiatives sont prises par les responsables publics tant au niveau national que local et cela pose des questions sur la manière de partager au mieux les responsabilités entre ces niveaux d'administration. Les feuilles de route fournissent un cadre pour évaluer la cohérence de ces politiques.

On pourrait tirer davantage d'enseignements de ces stratégies si l'on pouvait utiliser des indicateurs normalisés pour évaluer l'impact de politiques spécifiques de soutien à l'éco-innovation dans les contextes nationaux.

Cela suppose :

- une information plus systématique sur les contextes nationaux, notamment sur la structure industrielle et la taille du marché intérieur, les principaux défis environnementaux auxquels le pays est confronté, la base de connaissances en matière d'éco-innovation, et la force du capital risque dans le pays ;
- une information qualitative sur les instruments qui sous-tendent les politiques d'éco-innovation.

On ne sait pas bien comment les stratégies nationales appuient le développement de l'éco-innovation lorsqu'elles sont confrontées à un foisonnement de trajectoires technologiques dans un domaine donné (voir encadré 0.1). Le risque est qu'une stratégie ciblée de manière trop étroite ou stricte restreigne le champ des options technologiques qui seront explorées et nuise au développement de trajectoires alternatives. Le timing est essentiel.

Il s'agit de passer des technologies vertes au bénéfice environnemental de l'utilisation des innovations

Les études de cas examinées dans ce rapport soulignent que certaines éco-innovations mettent beaucoup de temps à émerger (comme la cogénération ou la voiture électrique). Elles rappellent que, bien souvent, ces innovations trouvent leur origine en dehors du domaine de l'environnement. Le piégeage et le stockage du carbone, par exemple, associent un ensemble de technologies du secteur pétrolier et chimique et du secteur de la production électrique qui sont déjà sur le marché. De plus, un certain nombre d'éco-innovations ne relèvent pas particulièrement de la haute technologie : le biopackaging, par exemple, peut améliorer les performances environnementales des industries agroalimentaires, cosmétiques et pharmaceutiques, en n'utilisant que des ressources simples et des techniques bien maîtrisées.

Un certain nombre de considérations de politique économique découlent de ces observations :

- il est aussi important d'adapter des technologies mures aux besoins du marché que de produire de nouveaux savoirs ;
- l'innovation technique et l'innovation non technique sont également importantes ;

Encadré 0.1. Trajectoire technologique : une définition

Une trajectoire technologique est une branche unique dans l'évolution de la conception technologique d'un produit ou d'un service. Le déplacement le long d'une trajectoire technologique découle des efforts de recherche et de développement.

La littérature économique montre que seule se matérialise une infime partie de toutes les directions qu'une technologie aurait pu prendre. En raison de l'institutionnalisation des idées, des marchés et des professions, le développement d'une technologie peut être « bloqué » dans une trajectoire donnée, entreprises et ingénieurs étant incapables de s'adapter aux idées et aux innovations venant de l'extérieur. Dans d'autres cas, les trajectoires technologiques d'un produit ou d'un service donné peuvent proliférer, fragmentant au bout du compte les marchés en segments qui se substituent mal les uns aux autres. Des trajectoires technologiques indépendantes se caractérisent par des économies de gamme limitées en matière de R-D et une faible substitution de la demande.

Le concept de trajectoire technologique est utile pour analyser la forme des relations qui lient les segments de marché du point de vue de la demande (substitution) et de la technologie (économies de gamme en matière de R-D). Pour s'attaquer à ce problème, Sutton (1998) a proposé le concept de trajectoires technologiques distinctes, dont chacune est associée à un segment de marché particulier. Lorsque les produits sur ces segments sont facilement substituables, une entreprise faisant des efforts de R-D au sein d'une trajectoire donnée peut gagner des parts de marché sur les entreprises opérant selon d'autres trajectoires et sur d'autres segments. En revanche, lorsque les produits sur différents segments de marchés sont peu substituables, le marché se fragmente en segments indépendants, et un effort de R-D sur l'un des segments n'aura guère d'impact sur les autres.

Le concept permet de distinguer entre les marchés sur lesquels l'innovation suit une trajectoire unique et ceux marqués par une prolifération continue de trajectoires technologiques. Cette distinction a des implications importantes pour l'analyse des rôles respectifs des dynamiques de marché et des politiques publiques. De surcroît, elle invite à prendre en compte la perspective du consommateur, pour évaluer les avantages potentiels d'une éco-innovation face à ses substituts existants, dans un contexte concurrentiel donné. Le concept a également des conséquences en termes de méthode : pour évaluer la concurrence entre des trajectoires technologiques distinctes mais aussi pour évaluer le potentiel de substitution et les économies de gamme sur la R-D, les investigations empiriques ne doivent pas se limiter à une éco-innovation particulière mais prendre en compte les alternatives et les secteurs industriels associés.

Source: Adapté d'une note méthodologique non publiée, rédigée par Gilles Le Blanc pour le Forum mondial sur l'environnement, ciblé sur l'éco-innovation, novembre 2009.

- les innovations nées en dehors du champ de l'environnement offrent de larges perspectives.

Il s'ensuit que les politiques de soutien à l'éco-innovation interagissent avec les politiques élaborées dans d'autres domaines, ce qui pose des problèmes de cohérence, de gouvernance et de suivi. En particulier, du point de vue des politiques d'environnement, le suivi pourrait se focaliser sur le bénéfice environnemental de l'utilisation d'une innovation.

Les politiques de soutien à l'éco-innovation sont liées aux politiques industrielles et de concurrence

Lorsque l'on considère les trajectoires le long desquelles les éco-innovations se développent et arrivent sur le marché, deux schémas opposés apparaissent ; chacun de ces schémas impose aux responsables politiques des concepts, instruments et indicateurs spécifiques pour concevoir des politiques de soutien à l'éco-innovation.

Le premier schéma combine des économies de gamme en matière de R-D et des segments de marché substituables. Il conduit au développement d'une trajectoire technique unique et mène potentiellement à un niveau élevé de concentration. À titre d'illustration, le marché n'utilise qu'une seule technologie de cogénération pour une taille d'équipement donnée. Dans ce schéma, les dépenses publiques de R-D bénéficient à tous les acteurs du champ ; de même, toutes les entreprises peuvent bénéficier des mécanismes de soutien de marché (normes de performance, labels, ou achats publics verts).

Le second schéma se distingue par l'absence d'économie de gamme pour la R-D et une demande fragmentée entre des biens et des services pour lesquels il n'y a pas de substitution possible. Le secteur de la voiture électrique, par exemple, se distingue par la coexistence de trajectoires distinctes (voiture hybride ou entièrement électrique) offrant peu, voire pas d'économies de gamme pour la R-D et des segments de marché non substituables. Dans ce schéma, il est probable que les dépenses publiques de R-D et les mécanismes de création de marché ne profitent qu'à une grappe d'industries au détriment des autres.

Les politiques de soutien à l'éco-innovation sont donc liées aux questions industrielles et de concurrence. Face à une prolifération de trajectoires techniques, un État doit-il concentrer ses efforts et ses budgets de R-D sur une trajectoire particulière ou encourager un éventail de solutions en soutenant simultanément plusieurs trajectoires ? La première

option concentre l'effort public mais limite l'exploration de trajectoires alternatives. La seconde fragmente les efforts de R-D et les marchés, ce qui risque de retarder la diffusion des meilleures technologies. L'étude de cas de la cogénération montre que l'Allemagne et le Canada mettent en œuvre des stratégies différentes dans ce domaine, qui résultent de priorités différentes dans des contextes spécifiques.

Il faut coordonner les initiatives dans le temps, entre niveaux de gouvernement et entre secteurs public et privé

Les études de cas démontrent la nécessité de coordonner les politiques de soutien à l'éco-innovation de multiples façons.

Premièrement, les politiques visant à soutenir l'éco-innovation se développent et évoluent généralement sur des périodes longues et leur cohérence peut être difficile à maintenir dans la durée. En outre, les priorités et les besoins évoluant, les instruments doivent être révisés et adaptés. En Allemagne, par exemple, les politiques de soutien à la micro cogénération se sont développées sur 30 ans ; l'accent mis initialement sur la R-D a conduit à des développements importants et à une fragmentation du marché ; depuis 2005, le principal instrument est une initiative conjointe de plusieurs ministères fédéraux (NOW), qui vise principalement à développer la recherche appliquée et les tests sur le terrain. Les décideurs auraient avantage à mieux comprendre quand et comment introduire un instrument, et quand et comment en éliminer progressivement d'autres.

Deuxièmement, les collectivités locales soutiennent activement l'éco-innovation. Elles ont développé des capacités pour s'attaquer, à leur niveau, aux défis liés à l'environnement. Elles voient dans les biens et services environnementaux de nouveaux relais de croissance. Une coopération entre les différents niveaux de gouvernement est nécessaire, s'appuyant sur une meilleure compréhension de leurs rôles respectifs.

Troisièmement, une bonne coordination entre la recherche et l'industrie est essentielle. L'exploitation des innovations existantes compte autant que le développement de nouveaux savoirs. Le secteur privé est le principal vecteur de cette exploitation, tant au niveau national qu'international (à travers le commerce et l'investissement direct étranger). Par conséquent :

- la phase de démonstration est essentielle et les États peuvent créer des liens entre la recherche et l'industrie en cas de défaillance des marchés ;

- les réseaux de transmission de savoirs, pépinières d'entreprises et autres formes de partenariat peuvent aider à faire circuler l'information entre la recherche et l'industrie ;
- les partenariats public-privé peuvent contribuer à une gouvernance efficace pour soutenir l'éco-innovation.

Quatrièmement, lorsque les marchés sont dans l'incertitude, une coopération (internationale) en matière de recherche peut mener à un partage de l'information et des risques liés au développement. L'étude de cas sur le piégeage et le stockage du carbone identifie des possibilités de coopération internationale (par exemple, pour une réglementation et une politique communes pour le transport et le stockage du carbone dans les pays voisins ; pour les aides à la R-D et à la démonstration). Il serait utile de mieux comprendre les instruments appropriés, le timing et les risques liés à une coopération (internationale) pour l'éco-innovation, en prenant en compte les perspectives de l'environnement, de la science, de l'industrie et de la concurrence.

L'éco-innovation requiert des modèles de transfert de technologie adaptés

Le transfert d'éco-innovations est essentiel pour profiter pleinement du bénéfice environnemental dont elles sont porteuses. A la 15ème Conférence des Parties de décembre 2009, à Copenhague, les transferts à destination des pays en développement figuraient en tête du programme d'action sur l'atténuation du changement climatique.

Les résultats de recherches récentes partagés lors du Forum mondial 2009 de l'OCDE sur l'environnement donnent à penser que les mécanismes de coopération internationale sont plus efficaces lorsqu'ils renforcent les capacités propres des pays en développement à développer ou à adapter les éco-innovations existantes. Cela suppose des flux de savoirs sous-jacents et tacites (« know-how » et « know-why »). Ces flux ne concernent pas que l'enseignement supérieur : des emplois peu qualifiés peuvent être concernés.

Le rapport inventorie des modèles viables pour renforcer les capacités d'éco-innovation dans les pays en développement de manière plus ciblée et mieux adaptée aux besoins.

Part I

Policy issues for eco-innovation: An overview

Introduction

Eco-innovation is an elusive concept, and it is hard to give a robust definition. An inventory of eco-innovation policies in OECD countries unveils a variety of definitions across countries (and sometimes across authorities in a single country).

According to the OECD *Oslo Manual*, innovation comprises technologically new or significantly improved products or processes; it includes organisational and marketing innovations as well, although their definitions are still evolving.

Eco-innovation can be identified by its favourable impact on the environment. However, this is not straightforward. For instance, an environmentally friendly product may result in rebound effects and thus create an environmental problem. The European Commission therefore defines eco-innovation as all forms of innovation that reduce environmental impacts and/or optimise the use of resources throughout the lifecycle of related activities. Following from these considerations:

- Eco-innovation compares favourably with relevant alternatives.
- It applies to goods, services, manufacturing processes or business models. In the United States, the concept includes innovative regulatory approaches for environmental protection as well.
- It includes, but is not limited to, green technologies. It does not necessarily originate in the environmental field or have a technological component.
- Eco-innovation can be radical and systemic (*e.g.* substituting polluting goods by environment-friendly services), or incremental (*e.g.* enhancing the resource efficiency of a particular product).

Eco-innovation can be associated with various concepts, such as eco-efficiency (defined as producing more goods and services with less energy and fewer natural resource), cleaner production (a strategy to continuously reduce pollution and waste at the source) and eco-design (*i.e.* the re-design

of a product or process to reduce its environmental impacts throughout its life cycle).

Most OECD countries consider eco-innovation an important element of the response to contemporary challenges, including climate change and energy security. In addition, many countries and firms see eco-innovation as a potential source of competitive advantage in the fast-growing environmental goods and services industry. Eco-innovation is viewed as a major driver of green growth.

However, market mechanisms will fail to deliver the optimal amount of eco-innovation at the appropriate time. This is so for two reasons. As with any kind of innovation, spillover effects (such as those resulting from information flows or imitation) may deprive innovators from the full benefits of their efforts. This is compounded by the fact that the market may not adequately value the environmental benefit for the community. Eco-innovation is therefore likely to suffer from insufficient and potentially misdirected investment.

It follows that governments legitimately support eco-innovation. The OECD Secretariat has inventoried policies and programmes put in place by OECD countries to promote eco-innovation. A number of policy issues have emerged from that work. They are discussed in a document entitled *National Approaches for Promoting Eco-Innovation: Policy Issues,* which confirmed that eco-innovation policies adopt a variety of instruments. They have to adjust to features of the domestic economy, in particular the knowledge base, the size of domestic markets and the vigour of the venture capital industry.

This report moves the analysis ahead. Taking account of the conditions under which eco-innovation policies are developed and operate, it explores how these policies interact with contextual features such as other policies, market forces or industry structures. It endeavours to identify good practices to support the development and deployment of eco-innovation. It develops policy messages on a number of issues: the benefits (and limitations) of national strategies to support eco-innovation; a shift in focus from green technologies to the environmental benefit of innovation-in-use; eco-innovation policies and competition issues; means of co-ordination across time, layers of government and public and private sector; opportunities for international co-operation and new models for technology transfer.

Chapter 1

Towards eco-innovation: The role of policy

Eco-innovation does not necessarily involve new knowledge or new technologies, and it may not originate in the environmental domain. For this reason, the spectrum of eco-innovation policies is very broad. Their measurement requires a complex set of indicators, including those on environmental impact. The co-ordination and stability of jurisdictions and policy instruments are essential. A comprehensive national reference document can facilitate co-ordination and enhance consistency, especially if it is based on good information. The most efficient policy design takes account of the development pattern of an eco-innovation, which generates opportunities for co-operation, economies of scope and scale, and/or competition.

The value of a strategic approach: Eco-innovation roadmaps

Most OECD countries have developed national strategies to support eco-innovation. These and related instruments are reported in a series of reference documents. In Europe, the Environmental Technology Action Plan (ETAP) has invited EU members to develop eco-innovation roadmaps to account for initiatives taken at national level to support eco-innovation. Similarly, the OECD Secretariat has compiled country profiles for eight non-EU OECD members (Australia, Canada, Japan, Korea, Mexico, New Zealand, Turkey and the United States) and for China.

Lessons can be learned from the systematic comparison of these policy documents. A project has been undertaken, with the financial support of the European Commission, to assess the ETAP roadmaps with regard to their eco-innovation potential. Country profiles of non-EU members have been used as a benchmark. This section reports on the messages that emerge from this project. The methodology is presented in Annex 1.A1.

Characterisation of roadmaps

Roadmaps can be characterised along three dimensions: governance, steering role and balance.

Governance

Governance describes the structure and processes in place in each country to set priorities, co-ordinate the initiatives of the various agencies involved in policies to support eco-innovation, monitor and assess the initiatives, and revise the roadmap.

The analysis of the ETAP roadmaps shows that countries differ in many respects with regard to governance. The data show that in most countries the two ministries principally in charge of the measures listed in the ETAP roadmap are the ministries in charge of environmental policy and the ministries with economic affairs, innovation and technology policy in their portfolio. This reflects the dual character of the ETAP roadmaps as an instrument of the industrial policy embedded in the Lisbon agenda, and as an instrument to address environmental policy issues.

The country profiles of eight non-EU OECD members made it clear that public resources are increasingly channelled via departments not directly in charge of environment policies (*e.g.* those in charge of energy, agriculture and transport), making inter-agency co-operation even more necessary.

In several OECD countries, ministries dealing with regional development or public works are in charge of measures to support eco-innovation. This is often the case in the new EU member states. Depending on the design of the national innovation system, research support agencies are also often in charge of measures listed in the national eco-innovation strategy. This is the case in the Nordic countries.

Thus, different governance models exist across OECD countries. It is not clear whether the observed patterns are related in any meaningful way to a country's eco-innovation potential and performance.

Steering role

The question is whether national eco-innovation roadmaps are used as reference documents to steer eco-innovation policies. A roadmap can be compared with the main initiatives taken since it was devised and made public. The question is only relevant for well-developed roadmaps.

The review of ETAP roadmaps indicates that they have usually not spurred new policies: rather, they have been a vehicle to gather and share information and to reorganise measures. For new EU member states, they have also been a way to initiate a policy dialogue on eco-innovation policies.

Some roadmaps are being assessed (Germany) or updated (Austria, Romania, Sweden, possibly Cyprus,[1] Denmark, Hungary, Ireland, Poland and Portugal).

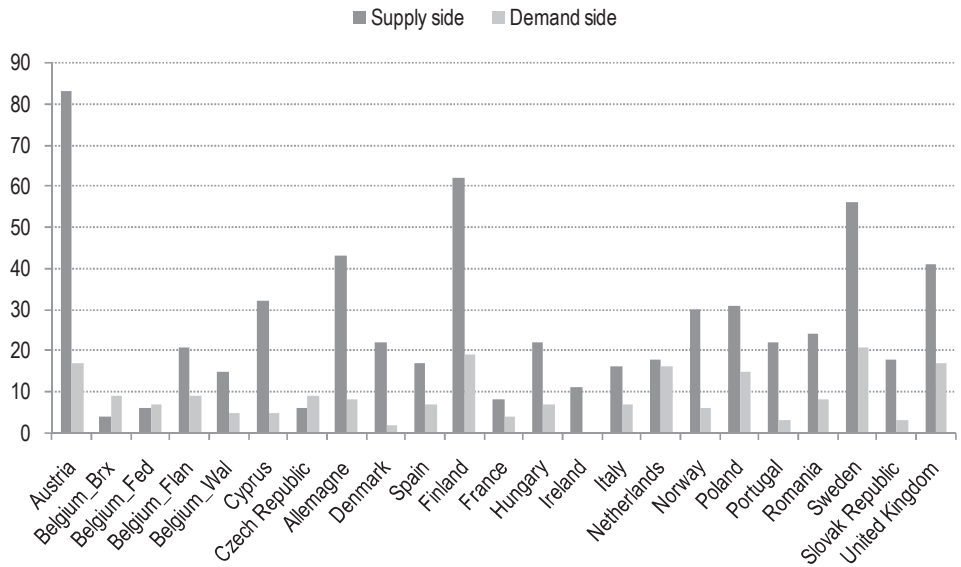
Balance

There is growing recognition that effective and efficient policies to support eco-innovation combine investment in innovation activities (technology-push or supply-side measures) and incentives to create markets for innovative products and services (market-pull or demand-side measures; see the following section). It follows that eco-innovation roadmaps can be characterised according to their ambition to combine supply-side and demand-side measures.

The balance of instruments reported in ETAP roadmaps indicates a bias towards supply-side instruments. They emphasise R&D support, the support of networks and partnerships, demonstration and commercialisation; among demand-side measures, information services are most common. The only exceptions are two regions in Belgium and the Czech Republic. Austria, Denmark, Germany, Finland, Norway, Sweden and the United Kingdom are the countries with the greatest difference between the number of supply-side and demand-side measures (Figure 1.1). At the same time, Austria, Finland,

Sweden and the United Kingdom have also deployed quite a sizeable number of demand-side instruments. The Netherlands reports a more balanced policy portfolio.

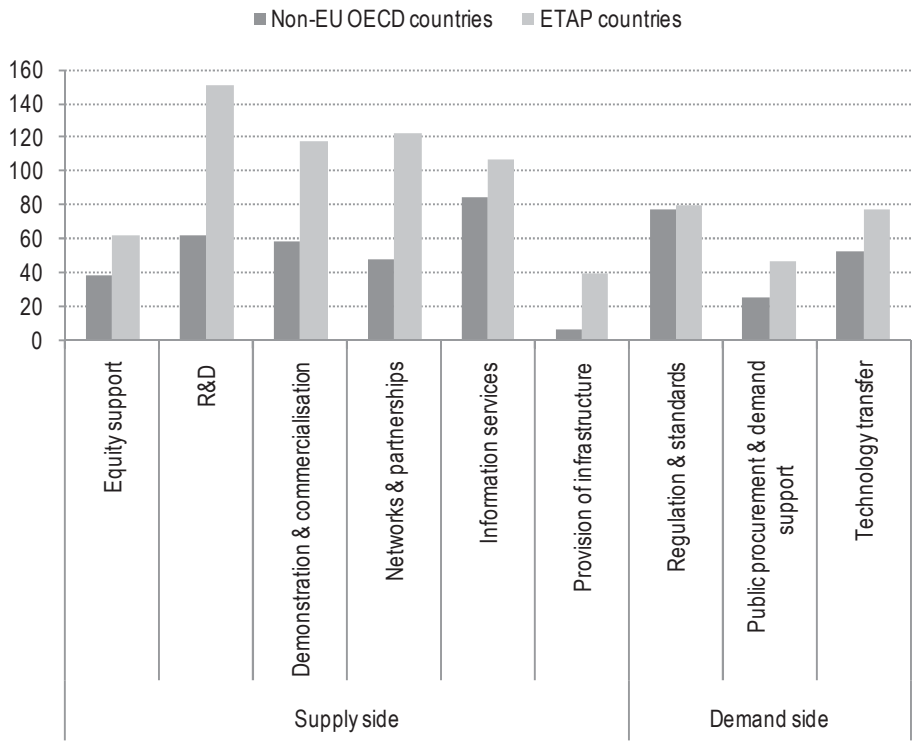
Figure 1.1. Balance between supply and demand side instruments



Source: Kletzan-Slamanig *et al*. (2009), "Assessment of ETAP Roadmaps with Regard to their Eco-innovation Potential", Report commissioned by the OECD Environment Directorate to the Austrian Institute of Economic Research (WIFO), Vienna, *http://ec.europa.eu/environment/etap/files/env-map_projektt2_finalreport_maindocument_final_030910.pdf*.

In the profiles of the eight non-EU OECD countries, policies supporting eco-innovation focus on supply-side measures as well, even though the emphasis differs slightly (Figure 1.2). Information services are quoted more often than R&D support or measures to support demonstration and commercialisation. Another major difference with ETAP roadmaps is the importance of regulations and standards: in terms of the absolute number of reported measures, such instruments play a less prominent role in ETAP countries.

Figure 1.2. Contrast between EU and selected non-EU OECD countries



Source: Kletzan-Slamanig *et al*. (2009), "Assessment of ETAP Roadmaps with Regard to their Eco-innovation Potential", Report commissioned by the OECD Environment Directorate to the Austrian Institute of Economic Research (WIFO), Vienna, *http://ec.europa.eu/environment/etap/files/env-map_projektt2_finalreport_maindocument_final_030910.pdf*.

Of course, the number of measures or instruments is not correlated with effectiveness.

Assessing the fit between national roadmaps and contextual features

A preliminary analysis of policies to support eco-innovation in EU and selected non-EU OECD countries (OECD, 2008) has suggested that the context in which these policies evolve can be described in terms of three dimensions which are relevant from a policy perspective:

- The size of the domestic market for environmental goods and services. A large domestic market can be attractive for investors; in

such a context, a policy (*e.g.* a standard) may be geared towards satisfying the needs of that particular country; smaller markets may not offer strong enough incentives for technology developers to invest in tailored innovations.

- The knowledge base of a particular economy as regards eco-innovation. The knowledge base of a particular economy is a key capacity on which policies to support eco-innovation can build. Countries with a smaller knowledge base may be more likely to adopt innovations developed abroad.

- The vigour of the country's venture capital industry. Venture capital (VC) is a key resource for developing green technologies. Among non-EU OECD countries, the United States is a particular case in point; Korea has taken specific action to stimulate VC for green technologies.

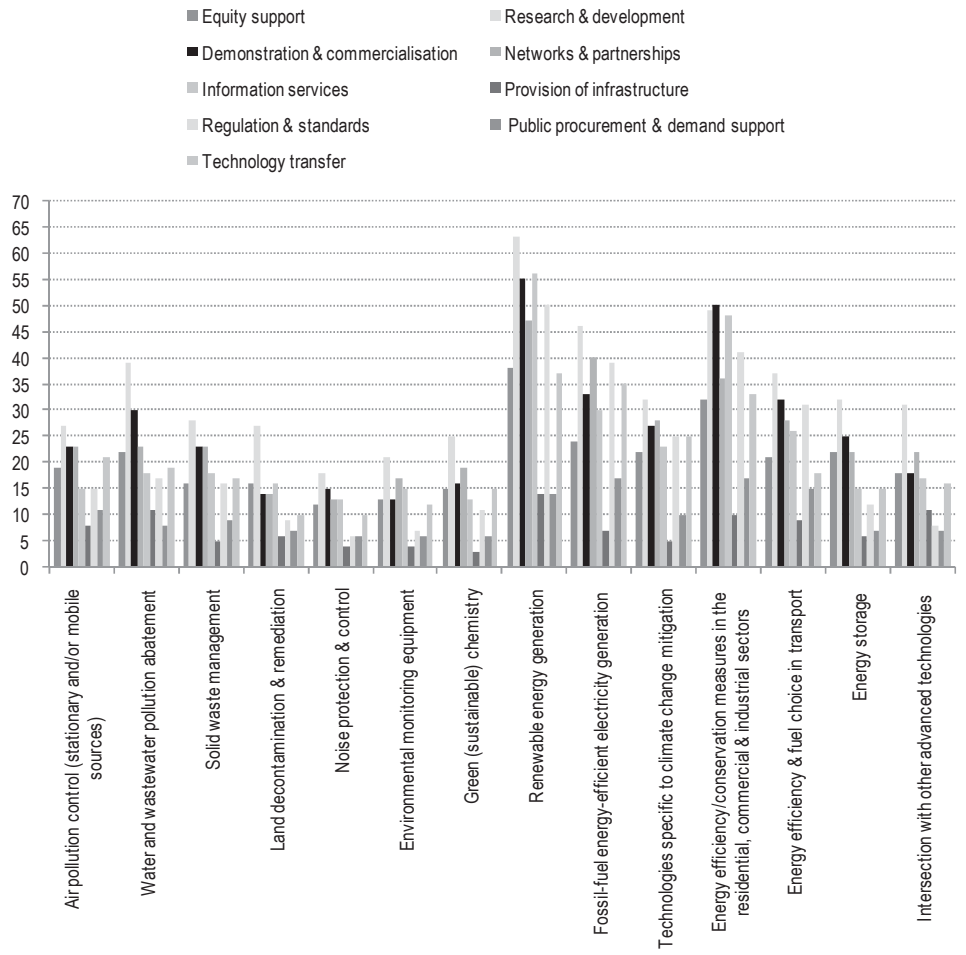
Additional contextual features can be considered, *e.g.* the environmental context of the country; environmental priorities (*e.g.* air, water, waste, etc.); policy areas that receive more attention.[2]

In the project on the assessment of ETAP roadmaps, a classification of countries was developed based on indicators of innovation potential, environmental challenges and framework conditions; a summary list of the countries that reported an ETAP roadmap is appended.

The systematic review of ETAP roadmaps indicates that environmental policy priorities are well reflected in the eco-innovation priorities reported in the roadmaps. Nevertheless, there is a strong bias towards climate change mitigation and (renewable) energy generation. For some countries, environmental priorities in air emissions, waste management, or wastewater treatment are less well reflected in ETAP roadmaps (Figure 1.3).

The review indicates that the choice of instruments to support eco-innovation is related to a country's innovation potential and level of development. Countries with a higher potential for innovation (Group 1 in Figure 1.4) tend to focus mostly on supply-side measures to support eco-innovation and favour R&D support. Less advanced countries (Group 3 in Figure 1.4) tend to rely more on demand-side instruments, such as standards and regulations or technology transfer. This reflects their technological capability and their emphasis on the diffusion and adaptation of technologies developed abroad (spillover effect, when regulations in one country spur innovation in other countries). This also suggests that eco-innovation policies will not bridge technological gaps.

Figure 1.3. Instruments reported in the roadmaps, by technological area

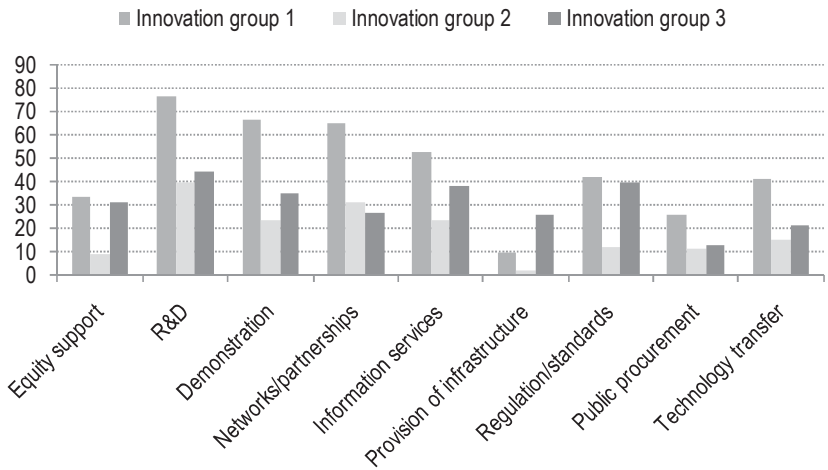


Source: Kletzan-Slamanig *et al*. (2009), "Assessment of ETAP Roadmaps with Regard to their Eco-innovation Potential", Report commissioned by the OECD Environment Directorate to the Austrian Institute of Economic Research (WIFO), Vienna, *http://ec.europa.eu/environment/etap/files/env-map_projektt2_finalreport_maindocument_final_030910.pdf*.

The OECD Innovation Strategy also suggests that countries with small domestic markets or less innovation/knowledge capacity could also develop targeted strategies and focus on specific areas of innovation, such as wind industry in Denmark or water technologies in the Netherlands. They do not need to adopt innovations developed elsewhere.

Figure 1.4. Principal instruments in ETAP roadmaps by innovation group

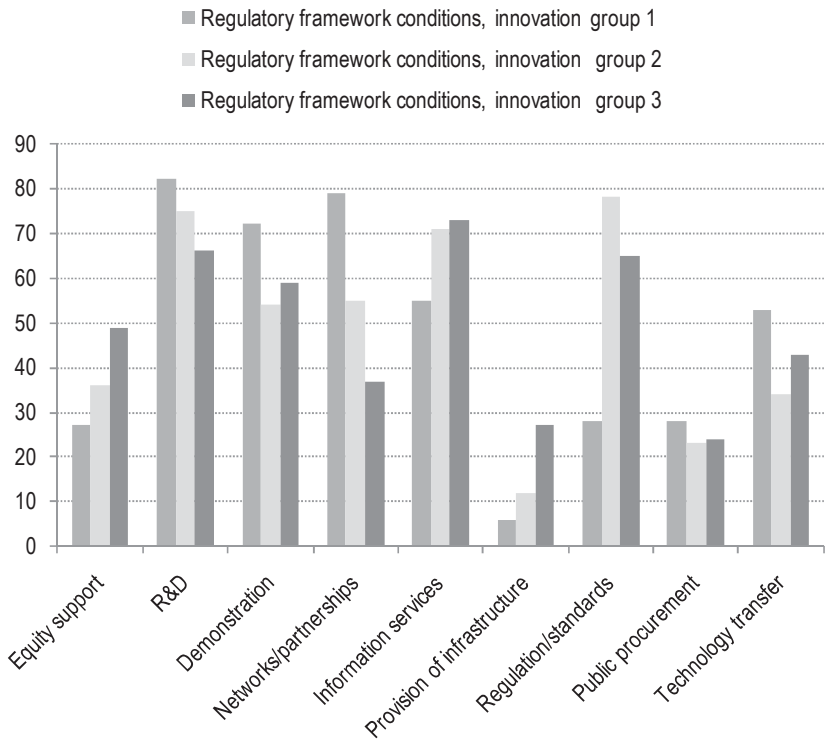
By classification of innovation potential



Source: Kletzan-Slamanig *et al*. (2009), "Assessment of ETAP Roadmaps with Regard to their Eco-innovation Potential", Report commissioned by the OECD Environment Directorate to the Austrian Institute of Economic Research (WIFO), Vienna, *http://ec.europa.eu/environment/etap/files/env-map_projektt2_finalreport_maindocument_final_030910.pdf*.

Finally, the review suggests that countries with the most stringent, most flexible and most transparent environmental regulations (Group 1 in Figure 1.5) rely more heavily on supply-side measures, whereas countries with less stringent environmental policy regimes and less developed financial markets (Group 3 in Figure 1.5), on average, more frequently use information services, the provision of infrastructures, and regulations and standards to support eco-innovation. The countries in Group 2 have a more business-friendly, competitive institutional environment with more sophisticated financial markets; they predominantly rely on R&D support, information services, standards and regulations.

Figure 1.5. Principal instruments in ETAP roadmaps by regulatory framework conditions



Source: Kletzan-Slamanig *et al*. (2009), "Assessment of ETAP Roadmaps with Regard to their Eco-innovation Potential", Report commissioned by the OECD Environment Directorate to the Austrian Institute of Economic Research (WIFO), Vienna, *http://ec.europa.eu/environment/etap/files/env-map_projektt2_finalreport_maindocument_final_030910.pdf*.

These features can explain why particular policies may be appropriate and effective in particular contexts and why some policies may be irrelevant or difficult to replicate in other contexts. Although objectives are not explicitly stated in roadmaps, the analysis of contextual features suggests that eco-innovation policies have a variety of objectives, which do not necessarily coincide, *e.g.* addressing a domestic environmental challenge or building a competitive industry (which may be export-driven). The case studies illustrate some objectives of eco-innovation policies: bridging the gap of the demonstration phase (carbon capture and storage, micro-CHP), improving consumer awareness (biopackaging), defining the most relevant technical trajectory and standard (electric car), or building a critical mass

(CHP). These objectives relate to choices in timing and instruments for public intervention.

How to make the most of national roadmaps

National strategies to support eco-innovation provide opportunities to co-ordinate a policy dialogue on this complex and multifaceted issue in a whole-of-government approach. Typically, in Europe, ETAP has been a vehicle for systematising and reorganising existing measures in the participating countries. For countries that have been exposed to the European convergence process more recently, ETAP has also been a means to start a policy debate on issues related to eco-innovation.

National strategies are useful as benchmark documents. The knowledge base made from roadmaps (for EU members) and country profiles (for non-European OECD members) has proven very useful. However, some information is missing on policy measures that would make the assessment and benchmarking even more useful. For instance, more qualitative information on the status and design of instruments would be needed to characterise them further and assess their potential impact on eco-innovation; additional information on target, budget (annual or total when appropriate) would be useful as well. In addition, it would be useful for countries to report on policies that were successful and lessons that have been learned from the use of particular policies.

OECD countries could benefit from updating these reference documents and completing the missing information.

Combining technical and non-technical innovation: From clean technologies to eco-innovation

Like innovation in general, eco-innovation is a multifaceted term, which cannot be subsumed under environmental technologies. A more systematic coverage of its scope and focus is of consequence from a policy perspective. In the vein of the discussions at the Global Forum on Environment focused on eco-innovation, this section proposes a balanced approach and emphasises the importance of the pace of diffusion and of alternative patterns of technological trajectories. Policy messages derive from these considerations.

Issues of scope and focus

Two points are emphasised here. First, enhanced environmental performance may derive from innovations in other domains. The case of carbon capture and storage shows how eco-innovation combines a set of

component technologies from the oil, chemical and power generation industries that already exist and are commercially available. According to René Kemp, who led the project Measuring Eco-Innovation in Europe, eco-innovation research and data collection should not be limited to products from the environmental goods and services sector or to environmentally motivated innovations but should cover all innovations with an environmental benefit, with research inquiring into the nature of the benefit and the motivation for it. Attention should be broadened to include innovation in or oriented towards resource use, energy efficiency, greenhouse gas reduction, waste minimisation, reuse and recycling, new materials (for example nanotechnology-based) and eco-design. It follows that eco-innovation potentially covers generic technologies, which may not be directly acknowledged as environmental technologies. From a policy perspective, a broad portfolio of investments is required.

Second, enhanced environmental performance may derive from a range of complementary changes and investments, new production processes, systems or organisations. In a contribution to the Global Forum on Environment focused on eco-innovation, René Kemp proposes that invention be carefully differentiated from innovation. Too often the two are used as synonyms, especially in innovation studies that rely on patents as the only source of information. Patents are a measure of invention, which may or may not lead to innovation, whereas the majority of innovations are not based on inventions that were developed within the innovating firm itself.

Bleischwitz *et al.* (2009) present three categories of eco-innovations:

- A process innovation is the implementation of an improved production or delivery method; it includes organisational innovation but can also involve tweaking configurations of existing equipment or experimenting with existing processes. It is closely linked to learning. It is associated with such concepts as cleaner production, zero emissions or waste, or material efficiency.

- A product innovation leads to a significantly improved product or service. It may involve eco-design, environmental technology and the dematerialisation of products.

- System innovations are concerned with technological systems, disruptive technologies, as well as all types of system changes. It is associated with life-cycle analysis, cradle-to-cradle, material flow analysis, integrated environmental assessment, closed loop, factor 4 or 10, user-oriented systems, etc.

Box 1.1. Take-home messages from the study of policies to support biopackaging

Biopackaging is a business-to-consumer sector in which products have a short life cycle. The denomination masks a proliferation of techniques.

This area attracts very little public intervention. Development in this area essentially relies on initiatives from industry, *i.e.* retailers and agro and liquid producers.

The deployment of biopackaging technologies requires high upfront investment in stores and in logistics. In such a competitive market, replacing existing products hardly makes business sense, as higher production costs can neither be reflected in final pricing nor be recouped through revenues from recycling. Return depends on a long-term perspective.

Incentives are very few, except in specific cases where the packaging contributes to product definition, or when the industry anticipates regulation.

In the short term, the most appropriate government initiatives relate to the recycling stage and enhance the business case for biopackaging.

Source: OECD case study on biopackaging, see Chapter 6.

Many of these innovations are usually not patentable. In the case of carbon capture and storage, the required skills are not all new but derive from skills in a variety of fields. The issue really is to build on such existing skills to meet additional need for carbon capture and storage.

Issues of scope and focus are of some consequence from a policy perspective. Some considerations follow.

Impact, diffusion and pace as features of eco-innovation policies

Reid and Miedzinski (2008) claim that eco-innovations should aim to reduce material flows. This may be restrictive (qualities of the flows matter just as much), but points at a feature of eco-innovations and policies that support them: the objective is not to spur new technologies (eventually measured through patents), but to accelerate the improvement of environmental performance (through innovation). The benefits of innovation for the environment only materialise when the innovation is taken up by users and delivers the expected performance.

An implicit assumption made in much of the innovation literature is that more innovation-related activity is always better than less. This may not necessarily be true, especially if it means unnecessary duplication of research efforts. It is at least as important to ask whether optimal use is

being made of the existing stock of knowledge as it is to ask how that stock can be expanded (Jaumotte and Pain, 2005). In the current economic context, budgetary constraints and fiscal consolidation add power to this view. It is even more important in the case of eco-innovation, as more eco-innovation does not necessarily lead to improved environmental performance; for instance, Doornbosch and Steenblick (2007) show how eco-innovation can have unintended negative environmental consequences (*e.g.* growing crops to make biofuel can lead to deforestation and increased greenhouse gas emissions). The case of carbon capture and storage also illustrates how the deployment of this technology may conflict with policies to support renewables in Germany.

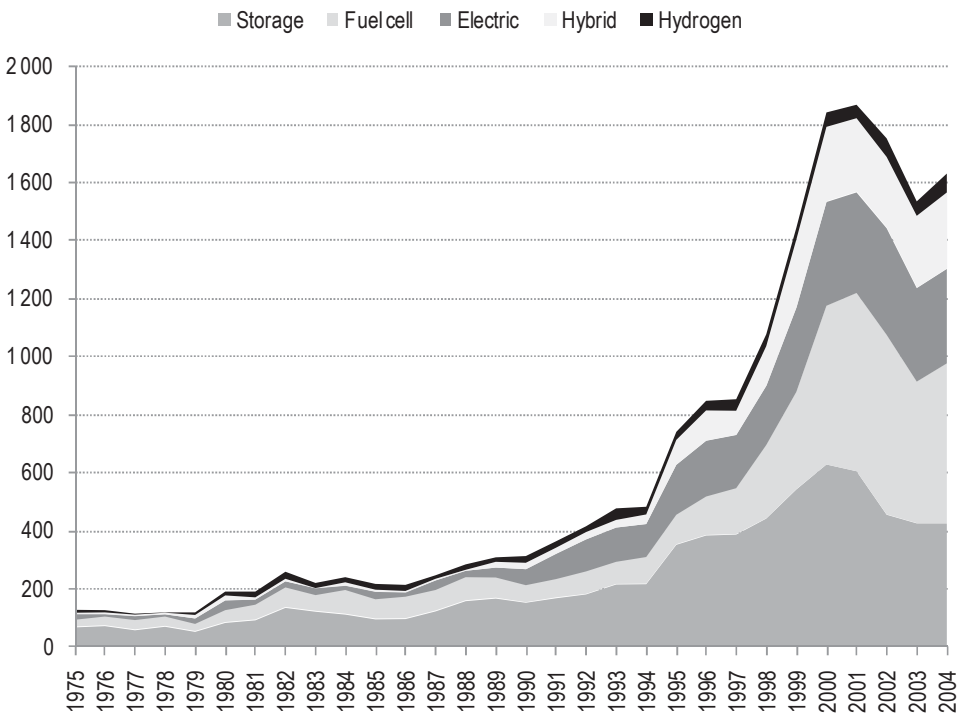
Also, research outputs are not all of equal value. This is particularly true from an environment policy perspective. What is important is to obtain adequate environmental benefits from the resources being used in the research process and to address any market or policy failures that may be holding back the level of research that takes place. As an illustration, recent OECD research on patents for alternative fuel vehicles (AFVs) indicates that there are more patents on fuel cells (Figure 1.6), although hybrid vehicles dominate this market segment. This shows that the number of patents is an indication neither of policy relevance, nor of market success or environmental benefit.

In other words, when it comes to eco-innovation, the issue is not so much to stimulate innovation, but to make sure that new technologies will deliver a certain level of environmental performance, on time. In a number of environmental areas (water, climate, eco-system services), time matters and there is some urgency. The pace of eco-innovation diffusion may be critical, in particular when countries face precise deadlines, *e.g.* access to safe water supply according to the Millennium Development Goals (MGDs) or emission reduction targets under the Kyoto protocol, or when urgent action is required.

Time is thus an issue: How much time does it take to develop an innovative process, product or service, deploy it, and see the environmental benefit? From a policy perspective, the issue then is: What policy mix can best shorten that delay? Time here does not necessarily refer to the creation of new knowledge. It more aptly refers to the deployment and diffusion of eco-innovations. This explains why policies to support micro-CHP in Germany have shifted from long-term perspectives to closer-to-market applications.

Figure 1.6. Development of inventions with respect to AFVs

Claimed priorities worldwide, 1975-2003



Source: Johnstone, N. and I. Hascic (2008), "Preliminary Indicators of Eco-innovation in Selected Environmental Areas", ENV/EPOC/WPNEP(2008)7, internal working document, OECD, Paris.

Two policy issues derive from these considerations:

- Effective eco-innovation policies deal with speeding up innovation delivery and the uptake of innovative technologies; diffusion and delivery of environmental performance are key dimensions of eco-innovation policies. In many areas, innovative technologies are already available and need to be brought together in appropriate demonstration projects (*e.g.* Smart Energy Home, F3 Factory for the future for sustainable chemistry in Europe).
- Policies to support eco-innovation must be evaluated against tight timelines for delivering solution and achieving enhanced environmental performance.

These considerations are explored below.

Box 1.2. Take-home messages from the study of policies to support combined heat and power generation (CHP)

CHP is a proven technology that has been on the market for more than four decades. It is an example of technological variety, segmented by size and users. The alternative technologies do not compete with one another.

The main challenge in this area is return on investment. The latter is essentially driven by input and output prices, hence the uncertainty that derives from erratic oil prices and the relevance of feed-in tariffs as a policy instrument.

CHP is at the crossroad of a number of policy goals: development of renewable energy sources, reduction of carbon emissions, and development of business opportunities (typically for biogas CHP technologies). It was initially developed to produce heat and now is seen as a technology for reducing carbon emissions and ensuring energy security. This can lead to possible contradictions, unintended consequences or inconsistencies.

CHP is a cost-effective technology, the diffusion of which is hindered by a market failure. There is a conflict of interest between energy users and suppliers *vis-à-vis* CHP. Command and control (*i.e.* make the use of heat mandatory when energy is produced) may be appropriate to remedy this market failure.

Canada supports CHP at a generic level, through wide, non-specific instruments; the absence of a targeted federal policy leads to fragmentation of the field and suboptimal arrangements. In Germany, CHP benefits from a variety of instruments, in combination with incentives for renewables (biomass). Germany uses precise and targeted instruments (*e.g.* feed-in tariffs tailored to the size of the equipment, the fuel used). This requires additional information.

Source: OECD case study on combined heat and power generation, see Chapter 2.

Policy mixes that induce the diffusion of eco-innovation

Very little is known about induced innovation diffusion. Diaz-Rainey (2009) defines it as any intervention that aims to alter the speed and/or total level of adoption of an innovation, and notes that the concept remains elusive. The literature is sparse, although it is mostly focused on environmental innovation.

From a theoretical perspective, induced diffusion may not be desirable. For instance, as reported by Diaz-Rainey, subsidies for technology adoption may not increase welfare. Therefore, it is only desirable to accelerate the

diffusion of eco-innovations that will increase welfare for the wider community.

Empirical research indicates that diffusion can be induced. This may be of importance from an environmental policy perspective, as the environmental benefit of eco-innovation will depend on the pace and level of diffusion. Case studies of selected eco-innovations point at several factors which hinder the deployment of mature technologies: conflict of interests (in the case of combined heat and power generation), market uncertainties and network externalities (in the case of electric cars). Here, policy makers can mobilise a broad array of instruments to induce the diffusion of eco-innovation. Empirical evidence reviewed by Diaz-Rainey suggests that command and control instruments may be just as effective as market-focused instruments in terms of speeding up eco-innovations.

To decide on the most appropriate mix, one needs to take account of the heterogeneity of adopters of the innovations and to better understand their environment. Exploratory methods, including case studies, may be best suited to discover the non-economic barriers to adoption and the detailed interaction between instruments that support the diffusion of eco-innovation. A refined analytical framework may help to cluster technologies into homogenous types and to adjust policy responses.

Looking for a complex combination of indicators

As flagged by an expert from the US Environmental Protection Agency (USEPA) at the Global Forum on Environment focused on eco-innovation, investments in environmental innovation are intended to satisfy multiple policy objectives. For example, economic growth and job creation are critical outcomes for all programmes being funded under the American Recovery and Reinvestment Act of 2009 (ARRA, the so-called "Recovery Act"). Combined heat and power generation contributes to heat production, reduction of carbon emissions and energy security.

One environmental innovation currently under development in the United States is the Recovery through Retrofit initiative, which is intended to reduce energy costs for middle class families through residential weatherisation and energy efficiency, while creating jobs and reducing greenhouse gases. Integrating the programmes of several US government agencies, the initiative will establish standardised methods of measuring and reporting home energy efficiency, develop financing mechanisms to stimulate demand for weatherisation activities, and standardise workforce and entrepreneurial training to support implementation of the initiative. The measurement and reporting components of this initiative are central to achieving the multi-goal objectives. With more than USD 100 billion of

green investments contained in the Recovery Act, there are many other examples of multi-objective environmental innovations.

At the same time, there remain many gaps in the measurement system that will need to be filled in order to realise economic revitalisation and environmental sustainability. These gaps exist because many organisations investing in environmental innovation were not set up to measure environmental outcomes. Analysis of market demand and penetration, the linking of behavioural change to environmental outcomes, and *ex ante/ex post* estimation of environmental impacts will all be important investments in support of a robust system of environmental innovation.

The Irish Environmental Protection Agency (EPA) has echoed this view. Stated objectives of eco-innovation policies in Ireland include: supporting the continued development of the environmental goods and services sector; contributing to environmental protection by delivering applicable and relevant solutions, information and knowledge; and promoting the integration of eco-innovation into all relevant sectors. This suggests that measurement systems for eco-innovation can only be useful if they are flexible, robust and multi-dimensional. The Irish EPA has outlined some practical outcomes in the areas of environmental technologies and innovation in its recent report *Innovation for a Green Economy – Environment and Technology: A win-win story*. Indicators used in the report reveal the interests of policy makers and the many dimensions of policies that support eco-innovation. In a similar vein, Environment Canada is developing and assessing environmental performance indicators used (or to be used) by federally supported environmental technology programmes.

For measuring eco-innovation, no single method or indicator is likely to suffice. In general, different methods need to be combined. In particular, more effort could be devoted to direct measurement of innovation output. The advantage is that it measures environmental performance rather than innovation inputs (such as R&D expenditures) or an intermediary output measure (such as patents). Innovation can also be measured indirectly through changes in resource efficiency and productivity. These two avenues are underexplored and could receive more attention, in order to augment the existing knowledge base (see OECD, 2010a, in particular Chapter 4). The way the UK Carbon Trust reviews and communicates its results is interesting as it covers some of these dimensions, including the reduction in carbon dioxide (CO_2) emissions (see Box 1.3).

Box 1.3. Measurement of the impact of eco-innovation policies by the UK Carbon Trust

According to the Carbon Trust's assessments, the organisation has contributed to saving over 23 Mt CO_2 as of 2009, delivering costs savings of around GBP 1.4 billion (Carbon Trust, 2009). It has helped drive around GBP 1 billion of additional investment into the development and deployment of low-carbon technologies, markets, products and services. The organisation supported the development of over 250 new low-carbon technology projects and companies in the United Kingdom. The Carbon Trust Footprinting Company has certified the carbon footprints of over 2 500 products and awarded the Carbon Reduction Label to more than 2 000.

Over the financial year 2008/09, the Carbon Trust has supported 30 000 customers, saving companies up to GBP 227 million in direct costs and cutting up to 2 million tonnes of CO_2 from their annual emissions. The Trust leveraged some GBP 300 million of private investment in carbon reduction and low-carbon technology projects and delivered carbon savings cost effectively at GBP 4-6 per tonne of carbon saved. The organisation has offered GBP 22.3 million in interest-free energy efficiency loans to businesses and the Carbon Trust Standard Company has certified 71 companies to the Carbon Trust Standard.

The Carbon Trust also launched three major projects to accelerate the deployment of low-carbon energy technologies, including a GBP 30 million flagship project with the offshore wind industry (Technology Accelerator) to cut the cost of offshore wind energy by 10%. It has signed a contract with the China Energy Conservation Investment Corporation to set up a joint venture company to help businesses that have decided establish a presence in Chinese low-carbon technology markets.

The satisfaction of clients is taken into consideration as well. Out of all Carbon Trust customers who received specific guidance or advice between April 2005 and March 2006 80% were satisfied with the service received (NAO, 2007). Over three-quarters of respondents considered that they had received sufficient advice to reduce their CO_2 emissions. Among respondents, 76% said that they would not have implemented the same level of energy or carbon savings without the intervention of the Carbon Trust, while 20% said they would have made the same changes anyway.

Source: OECD case study on the Carbon Trust, see Chapter 8.

Technological trajectories and market fragmentation

The technological landscape of eco-innovation is quite complex and often covers a large variety of distinct technical solutions. Two opposing patterns emerge in high-technology and innovative industries. The first combines economies of scope for R&D and demand substitution. It is a

pattern of R&D escalation along a single technical trajectory, leading to a high level of concentration. The second involves the impossibility of demand substitution. It is a pattern of proliferation of technical trajectories and their associated submarkets. Sutton illustrates the two cases with the aircraft industry (escalation in the 1920-30s along the technical trajectory defined by the DC3 design from a very diverse landscape of plane types) and the flow-meter industry (specific applications for particular types of buyers limit the scope of demand substitution and, despite a high-level of R&D intensity, allow for a large number of submarkets and of specialised firms, and fragmentation of the industry). Among the case studies developed in this project, micro-CHP tends to follow a single trajectory; carbon capture and storage follows three trajectories, with some common elements; in the case of combined heat and power generation, technological variety is segmented by size and users; the electric car and biopackaging are marked by technology proliferation, with no (or very few) common elements.

These patterns are of consequence from a policy perspective. When products in submarkets are close substitutes, one firm advancing along one trajectory with a large R&D effort will manage to win market shares from firms operating with other trajectories and submarkets; similarly, public support for R&D will benefit a wide community. According to the same logic, when products in different submarkets are poor substitutes and R&D efforts in one area do not benefit other submarkets, fragmented and independent submarkets develop, and a superior R&D effort in one submarket will have little impact on the others; this raises irreversibility issues for public support or for firms' R&D effort. Among other things, it calls for a qualification of the indicator for public R&D expenditures. In some contexts, it may be too aggregate to be meaningful from a policy perspective; for instance, in the case of electric and hybrid vehicles, an aggregate figure for R&D efforts may be misleading, as expenditures in one technology area do not benefit others. This reflects Sutton's notion of distinct technological trajectories, each associated with a distinct submarket (Sutton, 1998).

This framework potentially has significant implications for the analysis of the respective roles of market forces (demand, supply) and public policies in the development and deployment of eco-innovations. The development of alternative technologies may lead to a suboptimal level of innovation, as it adds to the uncertainty firms have to cope with. The case of electric vehicles suggests that policy responses may include experimentation (to produce information and real innovation) and standardisation (to reduce uncertainty). Timing is crucial, as too early a response may generate competition biases, and too late a one may result in irreversible effects and the duplication of efforts.

Box 1.4. Take-home messages from the study of policies to support electric cars

This is a business-to-consumer industry, marked by the proliferation of vehicles and technological trajectories (hybrid, fully electric cars). It is characterised by large uncertainties on a variety of dimensions: technological, regulatory, consumer behaviour and economic. In addition, the sector faces high network externalities; in such a context, the winner takes all and the losers lose heavily. This results in suboptimal levels of innovation.

A number of consequences follow, from a policy perspective:

- experimentation is required to produce some of the missing information and real innovation;
- a balance has to be found between inertia and the costs of switching from traditional combustion to electric cars;
- the electric car relates to smart grids (because it takes a smart grid to access the sophisticated pricing system needed);
- a critical size is required, to generate positive network externalities.

The case highlights how initial conditions drive the ways in which experimentation is organised. In Canada, provincial and municipal authorities are demonstrating leadership to stimulate the development of demand and infrastructure for electric vehicles, often in close collaboration with industry (*e.g.* car manufacturers and utilities). This is leading to experimentation and demonstration at the local and regional scale that could later be applied more broadly. In Germany, initiatives are taken by car manufacturers, including newcomers. In France, initiatives follow a national plan, co-ordinated by the central government; the plan sets domestic targets and essentially supports one manufacturer.

The case highlights timing issues as well. Because of uncertainty and the variety of competing trajectories, standardisation is required, which may generate positive externalities. The question is: When is the best time to set standards? Setting standards too early can raise competition issues; setting standards too late may lead to irreversible effects, wastage of financial resources and duplication of efforts.

Source: OECD case study on electric cars, see Chapter 5.

As suggested by Le Blanc in a contribution to the Global Forum on Environment focused on eco-innovation, this line of reasoning requires a definition of overall utility in the market considered, a comprehensive identification of the various technical solutions available to answer this need, including environmental ones, and a careful examination of

substitution and scope for R&D economies between them. It calls for a refinement of demand-side measures to support eco-innovation: the structure of markets, based on more or less substitutable technologies and market segments, is important. Governments would benefit from a better understanding of what drives the development patterns identified above as this may condition the effectiveness and costs of policies to support eco-innovation.

Joining up an array of policies: Co-ordination needs

This section analyses the need for co-ordination to drive the effectiveness and efficiency of eco-innovation policies. It first emphasises policy accumulation during long periods of time. It looks next at the combination of national and local initiatives. It then turns to the joining of research and industry; particular attention is paid to policies to support new firms, as they play a particular role in the development and deployment of eco-innovation. Finally, it considers the role of public-private partnerships.

From the design of policy instruments to the review of policy accumulation

ETAP roadmaps and country profiles developed by the OECD Secretariat confirm that countries implement a variety of policies to stimulate eco-innovation. This is justified on two grounds. First, different policies are needed at different stages of the innovation process; for instance, pricing mechanisms and taxes are more likely to stimulate market-ready innovation (OECD, 2010b). Second, different policies are needed to address different market failures; for instance, basic R&D provided by public research institutions can be used when the outcome cannot be appropriated by a private firm.

This makes the design of eco-innovation policies complex. Optimising the design of individual instruments makes more sense in the context of policy packages. Moreover, as eco-innovation policies accumulate over long periods of time, one cannot presume that such accumulation is consistent. This vein of reasoning is explored below.

Combining policy instruments into effective packages

Recent modelling work on endogenous directed technological change confirms that the most efficient policies to spur a low-carbon economy combine a portfolio of instruments, involving carbon pricing, R&D support for green innovations, removal of non-market barriers to ease the shift from dirty to green technologies, and subsidies for transfers of clean technology

to developing countries (Acemoglu *et al.*, 2010). Typically, pricing the externality should be combined with long-term investment by governments and firms if technological change is too costly, too risky, too-long term or cannot be appropriated by firms.

The case studies on selected technologies reveal the diversity of policy instruments in use. For instance, policies to support micro-CHP in Germany combine research programmes, demonstration projects, field tests, feed-in tariffs, regulations, upfront investment and financial support, planning, and governance. This diversity should be comprehensively reviewed to evaluate the impact of public policies on innovation creation and diffusion. One size does not fit all and the final outcome crucially depends on the composition, relevance and coherence of the policy mix implemented in each case.

A lot of attention has been paid to the design of the policy instruments that will best support eco-innovation. Less work has been devoted to the design of policy packages. Montalvo (2002) claims that policy packages are specific to the goal, subject and context and have a limited lifespan. Braathen (2007) considers how such mixes can stimulate environment-related innovation. While market-based instruments can provide important incentives for research and innovation, it may also be useful to introduce complementary measures to promote technological innovation directly. For example, in the area of non-point sources of water pollution, the provision of financial support to develop better feedstuffs for animals has played an important role in addressing nutrient run-off in Denmark and the Netherlands, in combination with their respective nutrients accounting systems. Similar conclusions derive from recent OECD research on environmental taxation (OECD, 2010b): in cases of split incentives, it is necessary to know the impact of changes in taxes and additional measures such as regulation and/or information campaigns.

Braathen argues that the efficiency and effectiveness of instrument mixes depend upon proper targeting of financial support programmes. For instance, providing subsidies for R&D may undermine the environmental effectiveness and economic efficiency of the instrument mix, if these subsidies are not properly designed and targeted. It is important to ensure that financial support provides an incentive for technological innovations with a positive return for society as a whole, and that these innovations would not have occurred otherwise. It is noteworthy that the better targeting of measures can also entail significant additional administrative costs: there is a trade-off here.

Timing and policy accumulation as driving features of eco-innovation policies

Timing, a critical dimension

The case studies on selected eco-innovations suggest that timing is critical. The case study on micro-CHP in Germany provides a good illustration. In 2002, a CHP law introduced a feed-in tariff for electricity produced through CHP; the tariff includes a bonus supported by the government. According to Cames *et al.* (2005), as fuel cells are still at the stage of product development and field testing, this bonus will not be sufficient to lift fuel-cell-based micro-CHP technology over the breakeven point and facilitate market entry. On the contrary, some boiler developers claim that the current difference between feed-in tariffs (output) and the price of natural gas (input) is sufficient to cover the high acquisition costs over the expected lifetime of the system. The case studies of selected eco-innovations thus highlight a number of timing issues: When to shift from demonstration to market support (*e.g.* micro-CHP)? At what time should standards be introduced to generate positive externalities while avoiding competition biases and/or replication of efforts (*e.g.* electric cars)?

Box 1.5. Take-home messages from the study of policies to support micro-CHP generation

The case describes comprehensive policy mixes which may not be coherent: incentives may be inconsistent, and elements may be missing. Typically, poor governance has limited the development of the sector in Germany; the NOW programme reflects the new priority given to interactions between stakeholders.

Micro-CHP remains a risky technology. It is a case for a stable (and sustainable) policy framework: in Germany, CHP law and feed-in tariffs give long-term confidence to investors.

Policies in this area are marked by two shifts: from long-term to short-term (closer to market) applications; from a single stage to a multistage approach (looking for breakthrough technologies).

The case also shows the operational issues related to timing: When does the demonstration phase end and when does market support begin?

Source: OECD case study on micro-CHP generation, see Chapter 3.

It follows that the effectiveness and cost efficiency of the tariff policy depends on its timing with the development of technological options.

Inappropriate timing can increase the cost of public support. Green public procurement can be very costly and quite ineffective if there is only a limited supply of greener goods and services. The micro-CHP case study suggests that more work is needed to improve the co-ordination of policy packages over time.

Taking account of policy accumulation

Policy packages are supposed to be designed in a coherent way. They do not account for cases in which a variety of instruments accumulates over long periods of time. Chappin *et al.* (2009) suggest investigating policy accumulation and the implementation of "a mixture of policy instruments with a variety of underlying mechanisms to enable the achievement of policy goals". Attention should be paid to the growing variety of instruments, the (in)consistencies between the associated mechanisms, and the temporal aspect (continuity or change, potential clustering of instruments in a short period of time). Their empirical application to the case of CHP adoption in the Dutch paper and board industry over a 40-year period demonstrates the differentiated role of policies in different time periods. The results reveal different effects: some instruments reinforce each other, new instruments disturb situations originating from earlier policy instruments, and negative risk-adverse firm behaviour is triggered by several instruments implemented in a short time span.

The case study on micro-CHP in Germany indicates that policies have developed over 30 years. The initial emphasis was on R&D. It covered a wide array of topics and did not systematically focus on fuel cells and micro-CHP: systems analysis, analytics, production engineering, electrochemistry, modelling and simulation, catalysis and reaction engineering, or process and system engineering. At the turn of the century, micro-CHP benefited from a wider programme targeted at hydrogen technologies (ZIP programme); the programme facilitated fuel cell development, including for micro-CHP applications. This has led to important developments and a fragmented field: different norms, technologies and partnerships coexisted and hindered further development and market entry. In that context, developers and energy suppliers understood the need to have a large, co-ordinated programme: since 2005, the major instrument to develop the fuel-cell-based micro-CHP technology is NIP (National Hydrogen and Fuel Cell Technology Innovation Programme), a joint initiative of several federal ministries which focuses mainly on developing applied research and field tests.

Unintended consequences of policies are just as relevant as intended ones.

Combining national and local efforts

The country profiles flag the numerous initiatives taken at local, sub-sovereign level to support eco-innovation. Sub-national entities are involved, because some environmental problems require local responses. This is the rationale for Korea's regional environmental technology development centres. Universities, administrative agencies, research institutes, industries and non-governmental organisations constitute regional environmental technology development centres which attempt to solve unique local environmental problems collectively. The responsibilities of each centre include analysis and study of local environmental pollution, development of environmental technology, environmental education and technical support to enterprises coping with environmental management problems, dissemination of new environmental technologies, and promotion and education regarding new environmental technologies to local people.

Box 1.6. Take-home messages from the study of policies to support solar tiles in Portugal

Solar tiles are a niche of the solar photovoltaic domain. These products fit well into Portuguese traditions in architecture and construction, but still face a number of technical challenges. A specific type of tiles is being developed by a Portuguese consortium that comprises industry (ceramics), research (from the ceramics, photovoltaics and coating sectors) and the government. The Energy Agency initiated the consortium as part of a portfolio of initiatives to support renewables; it will see that knowledge produced by the consortium is disseminated at the end of the project. Users are imperfectly represented in the consortium (photovoltaic market).

Building on accumulated knowledge in related fields, the project aims to develop a proof of concept. This stage of the project benefits from generic innovation incentives (via the National Strategic Reference Framework of Portugal, the Ministry of Economy and Innovation, and the Energy Agency). At later stages, other instruments will be available, with a view to engaging industry further and to stimulating demand (including feed-in tariffs and tax exemptions). Current standards regarding renewable energy in buildings are technology-prescriptive and tend to favour alternative options; members of the consortium claim that the standards should be revised and become more flexible as regards the technology. The demand side of the market will need to be mobilised further.

The stakes are high as regional authorities see opportunities to stimulate the tiles industry, for domestic markets and exports in the Mediterranean.

Source: OECD case study on solar tiles, see Chapter 7.

Sub-national authorities also actively support eco-innovation because they have developed capacities to address environmental concerns at their level and because they consider the development of environmental goods and services as a new engine for growth. Illustrations abound: regional economic development is one of the rationales for public support for solar tiles in Portugal; the German *Länder* join with the federal government to fund R&D for fuel cells and micro-CHP; Ontario supports the development of electric cars by car manufacturers located in the province. In the United States, states take a number of initiatives with or without federal support: they have a (limited) capacity to finance R&D directly. They also take initiatives essentially to bridge the gap between research and markets, often in collaboration. Important measures, increasingly in use at local and state level, have to do with performance standards such as requirements for green buildings or portfolio standards for renewable energy.

It is not clear when and how national and local initiatives come together. Additional research in this area would be useful, in particular in the context of fiscal consolidation (when public finance is particularly scarce) and of green growth policies: What is the role of central/federal governments *vis-à-vis* local initiatives? What national framework is particularly capable of inducing co-ordinated local action?

Joining research and industry

The eight country profiles of non-EU OECD members indicate that the role of research organisations is being redefined to intensify linkages with the private sector and stimulate the development of marketable outputs. In the United States, the Department of Energy runs the Technology Commercialization Fund (TCF) to complement angel investment or early-stage corporate product development. The Fund brings the DoE's national laboratories and industry together to identify technologies that are promising but face the "Valley of Death" of commercialisation. It makes matching funds available to private-sector partners who wish to deploy the identified technologies. Incubators in the United States and the National Institute of Advanced Industrial Science and Technology's (AIST) Technology Licensing Office in Japan illustrate innovative arrangements in this area.

Attracting private funds to finance environmental R&D is another major policy orientation. The main issue is to reduce risks for private investors investing in environmental R&D projects, while making sure that public money is used effectively and does not crowd out private initiatives. A variety of funds have been established to reduce risks to private investors (*e.g.* Sustainable Technology Development Canada), or incubators (*e.g.* The Clean Energy Alliance in the United States, the Environmental Technology

Business Incubator in Korea). Measures are taken to stimulate the venture capital industry and to provide incentives for environment-related projects; this is the role of the Environmental Venture Fund in Korea (see below).

Box 1.7. The performance of knowledge transfer networks in the United Kingdom

During 2008 a review of the knowledge transfer networks was carried out to assess their current effectiveness and scope. The comprehensive review, which obtained views from 2 100 KTN users and R&D-intensive businesses, strongly confirmed the value of the networks: 75% of business respondents rated KTN services as effective or highly effective. Over 50% have developed, or are developing, new R&D or commercial relationships with people met through a KTN and 25% have made changes to their innovation activities as a result of their engagement. The most highly rated functions of KTNs, according to the survey, are monitoring and reporting on technologies, applications and markets; providing high-quality networking opportunities; and identifying and prioritising key innovation-related issues and challenges. The review also emphasised the strong benefits brought to the KTN programme by links with a wide range of partners. KTNs engage with trade associations, technology providers, research councils, regional development agencies and devolved administrations to deliver benefits to businesses of all sizes.

The review highlighted an opportunity to refocus the work of the KTNs, by optimising the coverage of business and technology sectors and by creating a more targeted, comprehensive and accessible range of network resources to help accelerate innovation. Plans are also advanced to establish new KTNs in some areas, for example energy generation and supply.

Source: Proceedings of the Global Forum on Environment on Eco-innovation, November 2009, *www.oecd.org/dataoecd/36/7/45375531.pdf*.

Knowledge transfer networks (KTNs) are an interesting way to bring research and industry together. In the United Kingdom, a knowledge transfer network is a group of individuals/organisations with a shared interest in an area of emerging technology. It provides an easy means of acquiring and sharing knowledge, and hence, participating in shaping the future of a strategically important technology in the United Kingdom. KTNs have been set up and are funded by government, industry and academia. They bring together diverse organisations and provide activities and initiatives that promote the exchange of knowledge and the stimulation of innovation in these communities. There are currently 25 KTNs with a membership of around 45 000, now funded by the Technology Strategy Board. KTNs are playing an increasingly important role in the development of the Technology

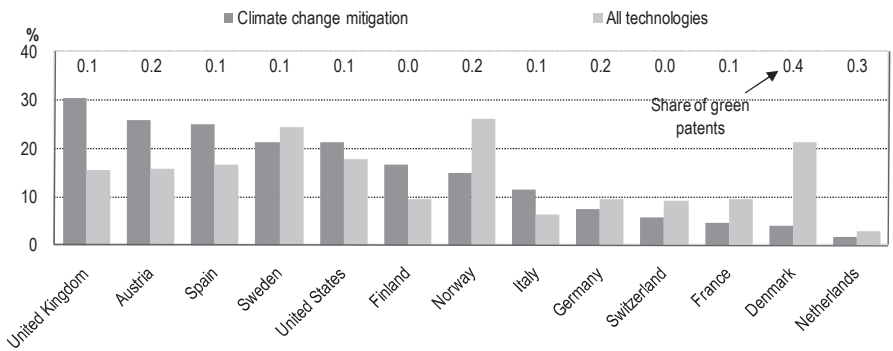
Strategy Board's future direction with a view to improving the United Kingdom's innovation performance by increasing the breadth and depth, or the knowledge transfer, of technology in UK-based businesses and by accelerating the rate at which this process occurs. The Global Forum on Environment focused on eco-innovation has been an opportunity to share experience on KTNs and the results of a recent review of their performance (see Box 1.7).

Eco-innovation comes from new firms as well

The ETAP roadmaps and the country profiles of non-EU OECD countries show that countries devote a lot of attention to the creation and development of new firms. In particular, various initiatives encourage venture capital and direct it towards investments in green technology and eco-innovation. The United States paves the way. Australia, Korea and the European Commission have taken actions to stimulate (or compensate) less dynamic venture capital industries.

This is appropriate, as eco-innovation comes from new firms as well. Figure 1.7 gives an indication of green entrepreneurship: in most countries covered, the share of patents related to climate change mitigation held by firms born after 2000 is higher than the share of patents held by these firms for all technologies.

Figure 1.7. Share of patents held by firms born after 2000



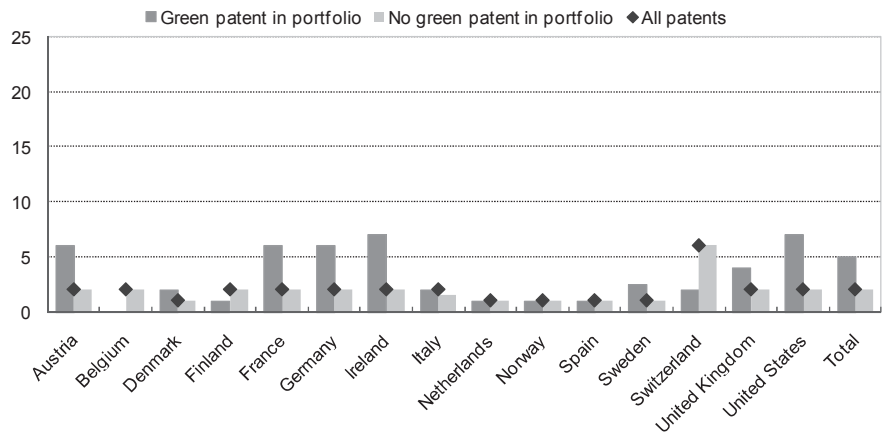
Note: Counts are based on patent applications filed under the PCT, by applicant's country and priority date. The selected countries are those with a high rate of successful matching and more than five companies having filed at least five patents for technologies relating to climate change mitigation.

Source: OECD, Patent Database, March 2010; Bureau Van Dijk Electronic Publishing, ORBIS Database, August 2008.

In addition, Figure 1.8 suggests that young green firms are more inventive than young non-green firms.

The case studies on selected technologies confirm that new firms and newcomers play a role in the development and deployment of eco-innovation. In the field of micro-CHP, Hexis AG is a Swiss company which has its main market in Germany and Austria. Hexis is now an independent start-up, but formerly belong to the Sulzer Group. The company develops and integrates all the components; it is now a leading firm in the 1 kWe (kilowatt electric) segment. Newcomers (*e.g.* battery manufacturers) play a critical role in the development of electric vehicles, and may lead innovation and market development in this area.

Figure 1.8. Median number of patents in the portfolio of firms created after 2000



Note: Counts are based on patent applications filed under the PCT, by applicant's country and priority date. The selected countries are those with a high rate of successful matching.

Source: OECD, Patent Database, March 2010; Bureau Van Dijk Electronic Publishing, ORBIS Database, August 2008.

The Global Forum on Environment focused on eco-innovation has been an opportunity to review instruments developed in Korea over the last decade (2001-10) to stimulate new business ventures in the field of green technologies. These include:

- Eco-Technopia 21 is an R&D fund which supports the development of core environmental technologies to put Korea on a par with the most advanced countries in the field. The fund merges public and private resources. Turnover totalled USD 1.6 billion as of June 2009.

- The Environmental Venture Fund. Performance of the fund was plagued by a number of factors, including uncertainty about the profit rate of environmental industry, and the lack of management capacity in the field.
- ETBI, the Environmental Technology Business Incubator. ETBI selects high-potential environmental ventures and provides comprehensive incubation services to support commercialisation.

Building on lessons learned, the Korea Environmental Industry & Technology Institute (KEITI) was established in 2009, to co-ordinate a comprehensive support system for environmental ventures. KEITI activities cover development of environmental technology, certification of environmental technologies and products, support to the promotion of Korea's environmental industry, including in foreign markets, and framework conditions (promoting green firms and green procurement).

The Korean Green Industry Complex cluster complements support to innovative firms. Its role is to enhance the global market share of Korea's environmental industry. It supports technology development through technical assistance and information sharing; it supports competitiveness; and it reinforces mutual co-operation through the Customised Technology Development Mechanism between large firms and SMEs.

Clustering and incubators for eco-innovation attract a good deal of attention in OECD countries, because they can stimulate the creation and development of new ventures, knowledge sharing and market opportunities. As an illustration, in the context of the strategy to develop carbon capture and storage for coal-fired power stations, the UK government says it will establish low-carbon economic areas (LCEAs) to create opportunities for firms in the carbon capture and storage supply chain and boost the industry in regions with existing assets. Concrete examples were reviewed at the Global Forum on Environment focused on eco-innovation, such as Manifattura Domani in Trento (Italy), which focuses on the construction sector and renewable energies.

Discussion at the Global Forum called for public support to create eco-clusters and for a worldwide alliance of science parks and eco-clusters. The way forward requires identifying and strengthening the best clusters. International benchmarking and evaluation are crucial.

The role of public-private partnerships

Co-ordination needs have fuelled the governance of eco-innovation policies. For instance, German authorities have set up a dedicated

organisation to steer and implement the NIP programme, which co-ordinates support for micro-CHP (see Box 1.8).

More generally, public private partnerships are seen as an option for facilitating co-ordination and leveraging resources (knowledge, finance, co-ordination) among a variety of actors. Evidence from the roadmaps and country profiles shows that such partnerships may take the form of knowledge networks (*e.g.* in the United Kingdom, a KTN on Energy Generation and Supply is planned, to operate as a "one-stop shop" for various low-carbon initiatives), technology platforms (experience with the Sustainable Chemistry Technology Platform in Europe was shared at the Global Forum on Environment focused on eco-innovation) or incubators for green start-ups, science parks specialised in green technologies, joint R&D, and venture capital funds.

Box 1.8. Governance structure for micro-CHP in Germany

The *Nationale Organisation Wasserstoff und Brennstoffzellen Technologie Gmbh* (NOW) was founded in 2008 as a private organisation. It acts as a consultancy wholly financed by the government. Its task is to co-ordinate and implement the German NIP programme by 2016. This includes evaluation and selection of projects, in particular for field-test activities; linking research and development with demonstration; international co-operation; communication and knowledge management. NOW gathers actors from the entire micro-CHP value chain.

Prior to its creation, most stakeholders called for a comprehensive and co-ordinated public strategy. NOW is the direct answer to these demands and plays a central role in the structuring of the institutional landscape.

The NOW organisation, although still quite recent, is expected to be valuable in supporting the pre-commercialisation phases and market entry of the fuel-cell-based micro-CHP technology. It plays a structuring role by co-financing projects, notably the Callux field-test projects. The public and central positioning of the NOW organisation is applauded by most interviewees, even though some would like to see a more aggressive structuring role. The organisation has created high expectations. Its capacity to influence micro-CHP policy remains to be seen.

Source: OECD case study on micro-CHP, see Chapter 3.

The case studies on selected technologies identified a number of such partnerships. Callux is one: this programme supports field tests for fuel-cell-based micro-CHP in Germany; the target is to test 800 fuel cell units in Germany by 2012; the programme is jointly financed by public (48%) and

private (52%) funds; beyond field-testing activities, the clustering and information exchange role of Callux is acknowledged by all stakeholders. Manufacturers claim that Callux has already had a significant impact, notably by setting technical requirements, performances, synergies and qualification.

Partnerships can have distinct structures (contracts or partnerships) and modes of operation (*e.g.* "coproduction" and consensus building between public and private actors, risk-sharing arrangements, decision making, criteria used to select projects). They can add value in different ways: *e.g.* synergies, cost reductions, transaction costs, mobilisation of private resources. They need to be co-ordinated with other policy instruments (*e.g.* public R&D, financing, creation of markets for eco-innovation). Two case studies shed some light on concrete examples.

The UK Carbon Trust covers five areas: insights (informing key decision makers in the United Kingdom), solutions (advisory services to businesses and the public sector), innovations (more on this below), enterprises (creation and development of low-carbon enterprises in markets facing important barriers), and investment (co-investor in early-stage low-carbon technologies). A technology accelerator is a particular instrument for supporting innovation. The National Audit Office (NAO, 2007) noted that the accelerator is particularly well designed to fill what could otherwise be a barrier to the development of commercially viable low-carbon technologies. The NAO also noted that the Carbon Trust's co-ordination of businesses and researchers for collaboration on the accelerator projects appeared to be unique in the UK policy landscape and that the focus on applied research and commercial development rather than on basic research and academic achievement meant that the Carbon Trust supported a different range of projects from other sources of grants (such as those supported by Research Councils).

The Carbon Trust also supports the development of low-carbon technologies and companies that are further from market entry. Its business incubator scheme helps companies with promising low-carbon technologies to become attractive to investors. The incubator activity is a publicly funded activity and is not part of the investment portfolio *per se*. It is part of the continuum of innovation support that the Carbon Trust provides, from R&D through applied and directed research.

As regards governance, the Carbon Trust claims that delivering multiple interventions through one organisation integrating a number of functions reduces the operational costs typically carried by many separate bodies. This seems to be the case as regards close collaboration between investment and

incubator teams which both benefit from expertise developed in the private sector.

Co-ordination with other bodies is improving: three of the main independent, publicly funded bodies – the Technology Strategy Board (TSB), the Energy Technologies Institute (ETI) and the Carbon Trust – created the Low Carbon Innovation Group (LCIG) in 2008, a strategic collaboration with a shared vision to reach the United Kingdom's low-carbon innovation goals. The Low Carbon Innovation Group meets regularly to review the strategic direction and content of their respective low-carbon technology programmes and initiatives. The group is to be expanded to include representation from the research councils, the Environmental Transformation Fund and, when relevant, regional development agencies and devolved administrations.

Sustainable Development Technology Canada (SDTC) operates one technological fund (plus one on next-generation biofuel). It bridges a gap in market finance at demonstration and development stages. SDTC interventions are designed to "de-risk" investment by partners (not other financiers) in technological eco-innovations.

SDTC differs from investment funds in a number of ways: it only provides grants and does not take equity or property rights in the projects it supports; it has a longer time horizon; selection criteria include sustainability; it covers a broad array of technologies, including competing ones.

The Carbon Trust and SDTC illustrate competing models. The Carbon Trust has been criticised for lacking a public dimension: it is fully financed by the public sector but has a high level of autonomy; some critics say it has lost its link to government. SDTC qualifies as a public-private partnership and operates as a not-for-profit foundation, established under federal legislation, and incorporated under the Canada Business Corporations Act. Its private side is not obvious: it relates to the way it operates, in a very flexible and open-ended way (no pre-defined technology area).

Both organisations play a pivotal role in feeding the knowledge gap within government to develop evidence-based policies; dissemination of experience and lessons learned is essential. At the same time, in the current context, they are faced with the issue of sustainability: the UK government can cut the budget of the Carbon Trust, and SDTC has no sustainable mechanism to replenish its fund.

New models for technology transfer

The transfer of environmental technologies, both between OECD members and between developed and developing countries, increasingly receives policy attention. This section explores selected issues related to opportunities and appropriate ways to stimulate and co-ordinate such transfers.

Spillovers and international co-operation on eco-innovation

An important theme is the increasing "mismatch" between policy with a domestic focus and economic activity with an international reach. Particularly challenging is the question of capturing national benefits from the spillovers of the ecosystems of innovative firms that span national borders. This is acute in the case of eco-innovation, as environmental goods and services are considered by OECD governments as a growth sector, with potentially significant employment opportunities.

The Global Forum on Environment focused on eco-innovation and the case studies provide instances in which spillover effects are acknowledged. In Canada, the possibility of spillover effects has been identified and discussed at federal level. The general view is that Canadian industry will also benefit from projects and innovations even though foreign suppliers may benefit first. For instance, the pulp and paper industry imports German equipment and machinery, but improved environmental performance will benefit the Canadian industry as well. In Germany, the Callux project, which supports field tests for micro-CHP, allows for testing fuel-cell-based micro-CHP plants based on foreign fuel cell technologies.

Different instruments exist to take account of spillover effects and mitigate their potential negative impacts on policies to support eco-innovation. Cost-sharing and reciprocity agreements, as well as joint development and public-private partnerships, can help. The potential national benefits must be communicated and demonstrated to public stakeholders.

Similarly, there is room for international co-operation in the field of public research. Joint investment in pre-competitive research, mapping of R&D needs, multilateral science and technology co-operation and pooled knowledge make it possible to share costs and effectively and efficiently stimulate eco-innovation at world scale. Such co-operation potentially facilitates outreach and access to funding and can contribute to technology transfer and capacity building. A number of examples are reported in the eight country profiles of eco-innovation policies; they take many forms and are supported by a variety of institutional arrangements, *e.g.* the

International Partnership for the Hydrogen Economy (IPHE), the Carbon Sequestration Leadership Forum (CSLF), the Generation IV International Forum (GIF), and the International Thermonuclear Experimental Reactor (ITER). Building on this experience, it might be useful to identify principles and best practices for further co-operation in this area.

Similarly, the case study on carbon capture and storage illustrates how international co-operation can contribute to the development of an international standard that will facilitate technology development and deployment.

Intellectual property rights

Intellectual property is often mentioned as a barrier to the diffusion of eco-innovation. On the one hand, technology vendors claim that more stringent protection in emerging economies can only stimulate innovation and its wider diffusion. On the other, technology takers remark that intellectual property rights (IPRs) increase the cost of technology and make access to eco-innovation more difficult. The debate is particularly vivid in the field of environmental technologies as eco-innovation has some public good characteristics: it is assumed that the diffusion of environmentally superior products benefits the wider community.

Recent research sheds some light on this hotly debated topic. A report by Maskus (OECD, 2009) addresses the question of whether particular changes in patent rules would effectively induce innovation and diffusion of environmentally sound technologies to address climate change. Quantitative and qualitative analysis finds that patents have not yet amounted to a significant barrier to access in developing countries. Johnson and Lybecker (2009) argue that a variety of technologies exist (including unprotected ones) and that protected technologies are not systematically more costly than unprotected ones. Econometric evidence on general licensing behaviour finds that multinational firms tend to increase the availability of new technologies when patent rights are strengthened, at least as regards transactions with partners in the middle-income and larger developing countries (OECD, 2009).

Box 1.9. Take-home messages from the study of policies to support carbon capture and storage

Carbon capture and storage (CCS) has a long history. It is a cluster of technologies, which are at the demonstration phase. It combines technologies developed in non-environmental fields which require adaptation to local conditions. The main clients are power utilities and large manufacturers. There are therefore only a few tens of potential clients in the world, in two market segments: developed countries (where CCS can be retrofitted to existing plants) and emerging economies. This is important when considering which policy instrument to implement to support the development and deployment of CCS.

Three technological trajectories compete. Governments face the choice of promoting all of these routes or selecting one. Among other factors, the deployment of CCS depends on the existence of downstream infrastructure (to transport and store captured carbon); Canada is considering building a collective carbon transport infrastructure.

The financial model depends on how reductions in carbon emissions are monetised (*e.g.* guaranteed CO_2 prices for CCS plants, feed-in tariffs for CCS-equipped power plants). Including CCS in emission trading schemes and in clean development mechanisms seems preferable to subsidising R&D.

Different industry contexts lead to different policy goals and interventions. In Canada, CCS is used by the oil and gas industry to enhance operating efficiency; this leads to the deployment of more mature technologies. In Germany, where energy producers predominantly use coal, more advanced technologies are being developed by other industries Rennings *et al.* (2009) argue that, should R&D on CCS be left to energy suppliers, radical technologies would not materialise. In France, the main incentive derives from prospects to export the technology (because Alstom is a global manufacturer of power plants); this led to R&D subsidies and to one demonstration site (Lacq).

A norm might be an appropriate way to plan the deployment of the technology, when information about the technological, environmental and economic benefits is available. In the meantime, a transitory standard is being considered at international level, forcing new fossil-fuel plants to be "CCS compatible".

One unintended consequence of the development and deployment of CCS is that it competes with investment in renewables. In Germany, feed-in tariffs become a problem because, when CCS is cost-effective, it may crowd out renewables. From an analytical perspective, this suggests a distinction between policy mix (designed and implemented consistently) and policy accumulation. The analysis of policy accumulation requires monitoring and raises the issue of governance and the capacity to adjust or phase out overlapping or inconsistent policies.

Source: OECD case study on carbon capture and storage, see Chapter 4.

The analysis suggests that there is some scope for adjustments of intellectual property regimes for environmental technologies. For instance, it may be beneficial to expedite applications for environmental technologies. The Patent Prosecution Highway in Japan illustrates this route: it ensures that applications for which patents have been granted in a first country will be eligible for accelerated examination through simple procedures in a second. Similarly, Japan has initiated the APEC Co-operation Initiative on Patent Acquisition Procedures, which sets out to enable applicants to obtain a higher-quality patent in the APEC region more quickly; the initiative was endorsed by APEC Ministers in September 2007. Another option is to encourage patent pools. The Eco-Patent Commons paves the way. This is an initiative to create a collection of patents on technology that directly or indirectly protects the environment. The patents are pledged by companies and other IPR holders and made available to anyone free of charge. The World Business Council for Sustainable Development (WBCSD) and IBM are initiating this effort in partnership with Nokia, Pitney Bowes and Sony. The pledged portfolio is available on a dedicated public website (*www.wbcsd.org*) which is hosted by the WBCSD. The actual impact of this initiative on the diffusion of eco-innovation and on environmental performance remains to be assessed.

Adjustments of intellectual property regimes require additional resources, *e.g.* in patent offices. They need to be accompanied by enforcement capacities in the recipient countries and by measures unrelated to IPRs. As mentioned, international research co-operation and domestic innovative capabilities play a role.

Technology transfers in developing countries

The deployment of eco-innovations in developing countries is a key means of addressing domestic and global environmental challenges efficiently. It is also an important driver of markets for eco-innovation and sustainable economic development. In the photovoltaics industry, research indicates that the main benefit of transferring technologies to emerging economies was not abatement in these countries but increased competition in global markets and thereby reduced abatement costs.[3]

Johnson and Lybecker (2009) identify a number of barriers developing countries face for accessing eco-innovation: lack of scientists and researchers, brain drain, small market size, lack of infrastructure (notably telecommunications infrastructure), quality of the business environment and governance conditions, bureaucratic climate and the formal/informal regulations regarding economic transactions, cash-strapped governments unable to make public investments in research and infrastructure. Most of

these barriers concern indigenous eco-innovation capabilities. These are essential for facilitating both the diffusion of existing eco-innovations in developing countries and sustainable economic development based on the adoption, adaptation and development of environmentally sound technologies that fit the specific conditions faced by these countries. This echoes OECD analyses which demonstrate that strong technological capacity in the recipient country is a key factor in encouraging transfers.

A paper for the Global Forum on Environment focused on eco-innovation (Ockwell, 2010) argues that the majority of existing policy mechanisms[4] fail to recognise the critical importance of developing indigenous eco-innovation capabilities. Building up eco-innovation capabilities in developing countries requires a shift away from the current focus on large project-based approaches, which emphasise the transfer of hardware aspects of clean technologies, towards approaches that emphasise flows of underlying knowledge (know-how and know-why) and tacit knowledge. This is not limited to higher education: low-skill jobs may be required to deploy and maintain some green innovations (which are not necessarily high technology). Policy also needs to respond better to the context-specific technological and cultural requirements which vary inter- and intra-nationally.

The paper argues that there is a need to address the shortfall of current international policy processes by putting in place institutional and funding structures that achieve maximum leverage from public investment, in terms both of maximising the impact on indigenous eco-innovation capabilities and of maximising the potential to attract sustained private-sector investment in eco-innovation as opposed to conventional innovation. Precedents exist, such as the Carbon Trust's proposed network of Low Carbon Technology Innovation and Diffusion Centres, and Fundación Chile (a not-for-profit organisation which facilitates access to relevant international innovations and seeks to increase indigenous innovation capabilities). These provide potentially viable models for a more focused, needs-based approach to increasing eco-innovation capabilities in developing countries than can be achieved by the centralised approach based on large projects that tends to characterise current international efforts.

Co-operation is this area can be South-South. The *Institut international d'ingénierie de l'eau et de l'environnement* (2iE) illustrates South-South green technology transfers. It is a public-private partnership serving eco-innovation; it contributes to building the capabilities needed to develop and transfer efficiently technologies that will yield results in the African context. 2iE combines research and training activities. Its research activities are specifically aimed at a "post-oil" world of solar energy, biofuels, eco-materials, and water and environmental management. 2iE's training

courses are based on this research. The approach is designed to promote innovative technologies in the main sectors of activity contributing to the sustainable economic development of Africa and draws on the work of five research laboratories specialised in ecosystem clean-up and health, hydrology and water resources, biomass energy and biofuels, solar energy and energy economics, and eco-materials.[5]

Notes

1. **Footnote by Turkey.** The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognizes the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of United Nations, Turkey shall preserve its position concerning the "Cyprus" issue.

   Footnote by all the European Union Member States of the OECD and the European Commission. The Republic of Cyprus is recognized by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

2. See for instance the EU country profiles developed by DG Environment, summarising the environmental situation of different member states, the *OECD Environmental Performance Reviews*, or the *OECD Environmental Outlook to 2030*.

3. See the presentation by Mathieu Glachant at COP15 (2009), "Beyond Patents. Competition, innovation and international technology flows in the photovoltaic industry", *www.cerna.ensmp.fr/images/stories/PV_Copenhagenfinal2.pdf*.

4. The mechanisms analysed are multilateral environmental agreements (including the Montreal Protocol and the Expert Group on Technology Transfer – EGTT; the Clean Development Mechanism – CDM; and the Global Environment Facility– GEF, under the auspices of the United Nations Framework Convention on Climate Change – UNFCCC); information sharing initiatives (including the Environmental Technology Verification Programme); and more targeted international collaborative initiatives (including the UK Carbon Trust's Low Carbon Technology Diffusion and Innovation Centres, and Fundación Chile).

5. A more detailed presentation was made at the Global Forum on Environment focused on eco-innovation.

Annex 1.A1

Methodology for assessing eco-innovation roadmaps under the European Union's Environmental Technology Action Plan

This chapter builds in large part on a study of eco-innovation roadmaps compiled under ETAP. The general aim of this study was to carry out a policy mapping exercise in order to assess the performance of ETAP countries as regards their eco-innovation potential. The questions guiding the enquiry were:

- Do countries with similar contextual features develop similar policy patterns?
- Are EU member states addressing the environmental priorities and needs of their countries?
- How do EU member states compare with non-EU OECD countries in terms of the balance of their policy instruments in the field of eco-innovation?

The main sources of information to address these questions were the national roadmaps and data gathered in a survey of national ETAP correspondents. Data from public sources have been collected in order to characterise the national context of each roadmap in terms of the country's innovation potential, the important environmental challenges it faces, and some key institutional framework conditions that typically affect innovation in general and eco-innovation in particular.

The first step in this study was to classify ETAP countries in a number of dimensions that are relevant for their eco-innovation potential using statistical cluster analysis. Classifications were developed for three fields. The first country classification concerned its level of development and its innovation potential. A second classification related to the principal environmental challenges faced and the third captured regulatory and market conditions favourable to innovation in general and to eco-innovation in particular. Overall about 30 indicators were used to classify countries.

The next step was to characterise the ETAP roadmaps using the information available from the ETAP roadmaps and from the survey conducted among ETAP correspondents. The data collected cover additional

information for the measures listed in each national ETAP roadmap in terms of the policy instruments they combine, the environmental policy priorities they address, the principal types of environmental technologies supported by each measure, the principal public entities in charge of each measure and whether the planning of the measures was initiated by the ETAP process. These data were used to characterise ETAP roadmaps on three dimensions: governance, the balance between supply-side and demand-side instruments and the steering role of ETAP roadmaps.

References

Acemoglu, D., Ph. Aghion, L. Bursztyn and D. Hemous (2010), The Environment and Directed Technological Change, *Harvard University Department of Economics Papers*, Cambridge, MA.

Bleischwitz, R., S. Giljum, M. Kuhndt, F. Schmidt-Bleek *et al.* (2009), *Eco-innovation – Putting the EU on the Path to a Resource and Energy Efficient Economy*, Wuppertal Institute for Climate, Environment and Energy, Wuppertal Spezial 38.

Braathen, N-A. (2007), "Instrument Mixes for Environmental Policy: How Many Stones Should be Used to Kill a Bird?", *International Review of Environmental and Resource Economics*, Vol. 1, No. 2, pp. 185-235.

Cames, M., K. Schumacher, J-P. Voss and K. Grashof (2005), "Institutional Framework and Innovation Policy", in M. Pehnt (ed.), *Micro Cogeneration: Towards Decentralized Energy Systems*, Springer Verlag.

Carbon Trust (2009), *Annual Report 2008/09*, CTC757.

Chappin, M.M.H., W.J.V. Vermeulen, M.T.H. Meeusa and M.P. Hekkert (2009), Enhancing our understanding of the role of environmental policy in environmental innovation: adoption explained by the accumulation of policy instruments and agent-based factors, *Environmental Science & Policy*, Vol. 12, Issue 7, pp. 934-947.

Diaz-Rainey, I. (2009), "Induced Diffusion: Definition, Review and Suggestions for Further Research", Robert Schuman Centre for Advanced Studies, European University Institute, Florence.

Doornbosch, R. and R. Steenblick (2007), "Biofuels: Is the Curse Worse than the Disease?", OECD Roundtable on Sustainable Development, 11-12 September, OECD, Paris.

Jaumotte, F. and N. Pain (2005), "Innovation in the Business Sector", *OECD Economics Department Working Papers*, No. 459, OECD, Paris.

Johnson, D.K.N. and K.M. Lybecker (2009), "Challenges to Technology Transfer: A Literature Review of the Constraints on Environmental Technology Dissemination", *Colorado College Working Paper 2009-07*, Colorado Springs, CO.

Johnstone, N. and I. Hascic (2008), "Preliminary Indicators of Eco-innovation in Selected Environmental Areas", internal working document, OECD, Paris.

Kletzan-Slamanig, D., A. Reinstaller, F. Unterlass and I. Stadler (2009), "Assessment of ETAP roadmaps with regard to their eco-innovation potential", Report commissioned by the OECD Environment Directorate, Austrian Institute of Economic Research (WIFO), Vienna, *http://ec.europa.eu/environment/etap/files/env-map_projektt2_finalreport_maindocument_final_030910.pdf*.Montalvo Corral, C. (2002), *Environmental Policy and Technological Innovation: Why Do Firms Adopt or Reject New Technologies?*, Edward Elgar Publishing, Cheltenham.

National Audit Office (2007), "The Carbon Trust, Accelerating the Move to a Low Carbon Economy", Report by the Comptroller and the Auditor General, HC 7 Session 2007-2008, 22 November.

Ockwell D. (2010), "Enhancing Developing Country Access to Eco-Innovation", *OECD Environment Working Paper No. 12.*

OECD (2008), "National Approaches for Promoting Eco-innovation. Policy Issues", internal working document.

OECD (2009), "Differentiated Intellectual Property Regimes for Environmental and Climate Technologies", internal working document, OECD, Paris.

OECD (2010a), *Eco-innovation in Industry. Enabling Green Growth*, OECD, Paris.

OECD (2010b), *Taxation, Innovation and the Environment*, OECD, Paris.

Reid, A. and M. Miedzinski (2008), "Sectoral Innovation Watch in Europe. Eco-Innovation. Final Report", *www.europe-innova.org.*

Rennings, K., P. Markewitz and S. Vögele (2009), "How Clean is Clean? Incremental versus Radical Technological Change in Coal-fired Power Plants", *ZEW Discussion Papers, n°9-021.*

Sutton J. (1998), *Technology and Market Structure*, The MIT Press, Cambridge, MA.

Part II

Case studies on selected eco-innovations

Chapter 2

Combined heat and power: Policies in Germany and Canada*

This chapter examines the role of public policies in the potential deployment of commercially efficient CHP solutions, with empirical observations from Canada and Germany. It considers the nature of the technological environment for CHP, market and demand characteristics, the specific challenges faced by this technology, and the various domestic policies and instruments implemented to support its wider adoption.

* This chapter is based in part on interviews with Alstom Power, Vattenfall, COGEN, Natural Resources Canada.

Introduction

Combined heat and power (CHP), also called cogeneration, is the joint production of heat and electricity in a single process for dual output streams. Interest in this technology stems from the significant increase in energy efficiency it allows. In conventional electricity generation, only 35% on average of the energy potential contained in the fuel is converted into electricity, while the remainder is dissipated and lost as waste heat. Even the most advanced technologies do not target a fuel-to-electricity conversion ratio higher than 55%. Cogeneration can increase efficiency to 75-80% and even 90% in the most modern systems, offering final energy savings of between 15% and 40%. The heat produced can be used in different forms (warm water, steam, hot air) and for various purposes (heating, cooling and refrigeration, and industrial processes such as drying or dehumidification).

CHP can hardly be considered an innovation, however, since the technologies involved are already proven, reliable and cost-effective. CHP's prototype, pilot and commercial demonstration phases have been successfully passed and its contribution to national power production already exceeds 30% in Denmark, Finland, the Netherlands and Russia. However, in the great majority of countries, CHP still plays a marginal role in electricity and heat generation. An analysis carried out by the IEA (2008a) estimates the large untapped economic CHP potential for a sample of 13 countries under a scenario replicating the policies and best practices of the most successful CHP countries. For example, in Germany, an accelerated CHP scenario would raise the share of CHP in electricity generation from 13% in 2005 to 18% in 2015 and 27% in 2030. The main public policy issue is therefore the wider and faster diffusion and adoption of CHP technologies.

This chapter discusses industrial and commercial CHP applications (large and medium power plants). Domestic markets (< 15 kWe) are therefore outside the scope of the study. They in fact involve quite distinct technologies, innovations (fuel cells, Stirling engines, micro-turbines), economic models and policy issues. A case study on micro-CHP is included in Chapter 3.

This chapter examines the role of public policies in the potential deployment of commercially efficient CHP solutions, with empirical observations from Canada and Germany. It considers the nature of the technological environment for CHP, market and demand characteristics, the specific challenges faced by this technology, and the various domestic policies and instruments implemented to support its wider adoption.

The technological and competitive environment

It is important to bear in mind that the notion of CHP (or cogeneration) does not refer to a single technical innovation, but in fact encompasses a wide range of equipment and technologies. CHP should be considered as an umbrella for a family of different technologies, which cannot be defined by a common physical or chemical process or by a main destination and category of users. It will however always be based upon an integrated energy system that combines the production of energy and heat.

CHP is in fact a technical concept with quite a long history. The formidable achievements of the theory of thermodynamics in the second half of the 19th century have challenged engineers to find solutions for combining electricity generation with thermal loads in buildings and factories and for moving closer to the thermodynamic efficiency frontier. One of the first examples of a modern CHP plant was Thomas Edison's power plant on Pearl Street in 1882, which was also the first commercial plant and produced both electricity and heat to warm neighbouring buildings, therefore achieving the impressive figure for that time of 50% overall efficiency. Indeed, at the turn of the century in the United States, CHP systems were the most common generators of electricity.

The aggregating rationale of CHP can be found in a shared expected technico-economic outcome: significantly more efficient use of energy. By capturing the heat output from production of electricity for heating or industrial applications, CHP plants can on average convert 75-80% of the fuel source into useful energy. The most modern CHP plants may even reach efficiencies of over 90% (IPCC, 2007). CHP plants also reduce network losses because transport is limited by the proximity of the end user. In comparison, the usual overall efficiency of a fossil fuel power plant only reaches 35-40%, owing to the high share of unavoidable heat conversion losses from thermal production.

The increased efficiency of integrated over separated generation of electricity and heat delivers several economic and environmental benefits: reduced emissions of CO_2 and pollutants, cost savings for the energy consumer, better usage of local resources (waste, biomass, geothermal). In addition, the flexible nature of CHP technology allows for greater use of renewables over time as they become technically more mature and cost-effective.

The above figures must however be considered with caution, because it may be misleading to add together electric and heating efficiencies. Experts explain that the energy quality of heat is lower than that of electricity, and decreases with the temperature at which it is available. Heat in the form of

hot water is for example of lower quality than steam, and the utility of steam depends on the temperature. This cautionary note on the real thermodynamic efficiency of CHP systems does not reduce their interest and potential role, but suggests that the case is not as straightforward as it may seem, when simply considering the numbers often claimed. This technology requires a comprehensive evaluation of its final cost and benefits. For example, alternatives to larger, more efficient heat production, such as better insulation of buildings, should also be considered and not simply dismissed on the grounds that they cannot match the efficiency of the technology.

A typical CHP plant consists of four basic elements: a prime mover (engine or drive system), an electricity generator, a heat recovery system and a control system. The many existing CHP system configurations can be distinguished on the basis of three main variables: the size of the facility (*i.e.* the volume of power generated), the type of prime mover, and the fuel used as an input.

The size of the facility is first determined by heat and/or cooling needs and corresponding local demands, as the heat cannot be easily transported very far, or only at high cost. Usually, this means that more electricity than needed locally is generated. The surplus has to be supplied to another customer or sold to the electricity grid. CHP can then be viewed primarily as a source of heat, with electricity as a by-product. The next section discusses the three main markets for large and medium CHP systems: industry, district heating, and commercial or public buildings. Depending on the required power capacity, the type of prime mover used draws on different technologies.

The prime mover drives the electricity generator and creates usable heat that can be recovered. In terms of equipment, various technologies can be applied to cogenerate electricity and heat. Four mature and reliable technologies are currently in widespread use: steam turbines, gas turbines, combined cycle, diesel and Otto engines. New innovative schemes not considered here have also recently emerged, such as micro-turbines, fuel cells and Stirling engines. In all cases, fuel combustion creates mechanical energy directly or first produces steam which is subsequently converted to mechanical energy. The mechanical energy is used to spin a generator which produces electricity.

Gas turbine systems generate electricity by burning fuel (natural gas or biogas) to run a power generator and then use a heat recovery unit to capture the hot exhaust gases from the combustion stream. This heat is converted into useful thermal energy, usually by adding water to produce steam or hot water. This solution is suited for large industrial or commercial CHP units requiring large amounts of electricity and heat. In a CHP system with a

steam boiler, electricity is generated as a by-product of generation of steam for heat (contrary to the previous case). This steam turbine-based CHP configuration has been used in industrial processes for quite some time, as solid fuels (coal and now biomass) or waste products are readily available on site to fuel the boiler unit.

CHP can be based on a wide variety of fuels, sometimes with a combination of several different sources. These can be divided into fossil-fuel-based commercial fuels (coal, diesel, natural gas, oil), biomass, and waste (refinery gases, landfill gas, agricultural waste, forest residues). Theoretically, almost any fuel is suitable for CHP, although for new systems, natural gas currently predominates. Some CHP technologies may use multiple fuel types, providing valuable flexibility at a time of growing fuel insecurity and price volatility. Table 2.1 summarises the main features of the four CHP technological families, with their respective advantages and weaknesses.

Table 2.1. Comparison of the different CHP systems

Equipment	Principle	Typical range (MWe)	Efficiency[1] Power-to-heat ratio	Main advantages and disadvantages
Steam turbines	Fossil fuels are burnt in a boiler producing steam which drives a turbine to run an electricity generator and exhaust is captured for heat	0.5-300	80% 0.15-0.75	High overall efficiency Fuel input flexibility Costly high pressure boiler needed High maintenance costs
Gas turbine	The fuel burnt in a combustion chamber expands in a turbine to generate electricity; exhaust gases are captured by a heat recovery system to produce steam	0.5-300	70-85% 0.45-0.75	High grade heat supply Compact, reliable, simple, clean Quick start/stop Limited investment
Combined cycle	High-temperature exhaust gases from the turbine are recovered in a steam generator to produce high-pressure steam and run a turbine generating electricity as well as heat	10-300	70-90% 0.75-1.8	High power efficiency High quality steam Complex system (two prime movers combined)
Diesel and Otto engines	Similar to gas turbine with oil, gasoline, diesel as fuel and lower temperatures.	0.001-10	60-75% 0.5-1.8	High electrical efficiency Lower temperature of thermal energy Compatible with biofuel

1. Efficiency here refers to total system efficiency, *i.e.* total power and thermal energy output divided by fuel used to produce electricity and heat.

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

This technological landscape may seem at first sight quite varied, with a number of parallel alternative trajectories in competition. However, many components are shared by the different configurations: *e.g.* turbine, heat recovery system and alternator. The range of accessible power capacity for each system also induces a clear differentiation between the technical options, mirroring the segmentation of final users and applications. Overlaps do exist but, for a given need determined by the heat-to-power ratio of demand, the power capacity necessary and the type of customers, only one or two CHP systems will be considered. Therefore, internal technological competition, while not absent, is reduced and does not constitute a decisive parameter as regards the prospects and economic potential of CHP.

Market, utility and demand characteristics for CHP

There has long been a strong case for large-scale industrial facilities requiring significant amounts of heat in their operations to adopt local CHP equipment. Today the benefits are significantly increased by climate and environmental considerations. Industrial CHP is a very cost-effective carbon abatement technology. Given the long-term rising trend in the price of energy and the opportunity cost of waste, the efficiency and cost savings delivered by utilising waste heat are now an increasingly attractive option for a wide range of businesses. The economic utility and multiple benefits of a CHP installation are first reviewed before analysing the different markets for and applications of this technology.

Experts participating in world conferences have often emphasised the role of CHP in solving climate issues. Recently, Working Group 3 of the Intergovernmental Panel on Climate Change's fourth assessment report (IPCC AR4 WG3) mentions CHP systems in Chapters 4, 6 and 7, and stresses the role they should play in climate change mitigation policies.

The main economic benefits associated with CHP are energy efficiency, emissions reduction, reduction of energy and dependency on imports, higher electric grid security, and reduced need for power transmission and distribution networks.

Energy efficiency is discussed in the previous section. The environmental benefits result first and foremost from savings in energy input due to more efficient production of power and the associated reduction of CO_2 emissions. In a centralised power supply, often located far from built-up areas, waste heat is necessarily released into the atmosphere, losing about two-thirds of the primary energy. The efficiency gains from CHP vary depending upon the technologies and fuel/energy source(s) employed and the heat and power generation systems displaced. But there are several other

gains for the environment and climate change mitigation. Because they are located close to users, CHP plants also reduce transport losses (about 1% of the primary energy input for electricity and 2% for heat, as opposed to 4-8% for electricity transport in coal-fired power plants). In addition to carbon dioxide, CHP also significantly reduces emissions of other pollutants such as dust (by 99%), SO_2 (by 98%), and NO_2 (by 29%).

From a policy perspective, a strategic decision to invest in CHP will not be limited to cost and climate considerations. Energy security is also an important argument. Massive use of CHP can simultaneously improve the cost efficiency of energy production, lower energy imports, and reduce domestic emissions of greenhouse gases.

Another overall advantage of an increased base of CHP plants is reduction of consumption peaks, with a policy of peak shaving, so that they produce their maximum electricity output during times of high overall power loads and cut back at times of low loads. Of course, this requires R&D and engineering efforts to ensure smooth integration of thousands of centralised plants into the overall supply system, to develop and roll out efficient information and communications systems to manage in real time the supply and demand for electricity in a much more complex power system.

CHP technologies finally allow for potential adoption of renewable energy, and in particular biomass. However, this requires new research and development as not every CHP system is directly suitable for every biofuel. In many cases (diesel, gas engines, gas turbines), the biomass has to be first converted into liquid or gaseous fuel. Only steam and Stirling engines allow for direct use of solid fuels (such as energy crops, wood, organic waste or residual forestry products).

The market for CHP is very large and should be segmented according to the power required. In electrical output terms, CHP plant sizes range from 1 kWe (kilowatt electric) to over 500 MWe (megawatt electric). For larger plants (greater than 1 MWe), equipment is generally site-specific, while smaller-scale applications can use pre-packaged units. The proportions of heat and power needed (also known as the heat-to-power ratio) vary from site to site. As a result, the CHP system must be selected to match demand as closely as possible. Since CHP plants are usually sized first to meet heat demand, excess electricity can be sold to the grid or supplied directly to another customer via a distribution system. Any additional electricity needs at the site are supplied by the grid; supplementary heat is typically supplied by stand-by boilers or boost heaters.

The great majority of CHP applications can be grouped into three categories: industrial (*e.g.* oil refineries, paper mills, bakeries, breweries,

data centres), commercial/institutional (hospitals, universities, prisons, office buildings, hotels, high schools), and district heating systems (municipalities, apartment buildings). CHP has a long history in the industrial sector, which has large concurrent heat and power demands, and in the district heating sector, especially in countries with cold weather, with stable and predictable year-round demand for heating buildings. However, advances in technology have made available smaller CHP systems, with lower costs, reduced emissions and greater customisation. As a result, CHP systems are increasingly used for smaller applications in the commercial and institutional sectors, and are being incorporated more often into district heating and cooling (DHC) systems.

Table 2.2. Main markets for CHP systems

Market	Industry	Commercial and institutional	District heating and cooling
Customers, usages	Chemistry, pulp and paper, metallurgy, breweries, glass furnaces, oil refineries	Hospitals, hotels, office buildings, small manufacturing facilities, agriculture	Office buildings, airports, individual houses, university campuses
System size	1 MWe-500 MWe	1 kWe-10 MWe	Any
Prime mover	Steam turbine, gas turbine, combined cycle	Stirling engines, fuel cells, microturbines	Steam turbine, gas turbine, waste incineration, combined cycle gas turbine (CCGT)
Main players	Power utilities	End users and utilities	Local community
Specific features	Medium compatibility with renewables and waste Liquid, solid or gas fuels fuel + industrial process waste gases Process-specific needs for heat and electricity load	Low compatibility with renewables and waste Liquid or gas fuels User-specific needs for heat and electricity load	High compatibility with renewables and waste Any fuel Daily and seasonal fluctuating needs for heat and electricity load

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

The resulting demand is therefore very large: for example, households consume 30% of final energy in Germany, of which almost 90% is used for heating and hot water generation. However, overall demand for CHP applications is broken into distinct segments according to the power required. The orders of magnitude are the following: hundreds of MW for district heating, 10-50 MW for industrial facilities such as a printing plant, 200- 300 kW for a public swimming pool or fitness centre, 100 kW for an average office building.

Table 2.2 illustrates these different applications and the associated markets for CHP, with their specific and somewhat contradictory requirements. A key insight from this very diverse landscape is that public policy for CHP will have to deal with different final users, locations, plant sizes and economic interests. A single instrument is therefore unlikely to respond to these distinct needs and investment priorities. Rather, a large set of dedicated instruments is likely to be required, raising issues of design, implementation and sound articulation in an overall policy framework. To assess precisely the potential scope and relevance of available policy tools, the specific obstacles faced by CHP technologies for broader adoption and roll-out must first be examined and discussed.

Main challenges faced by CHP technologies

Contrary to other examples of eco-innovation, the main challenge faced by CHP for broader diffusion and adoption is not the lack of proven economic value for the consumer (electric car), the choice of the most efficient technology among parallel alternative trajectories (CO_2 capture), or the need to demonstrate on a real scale the technical and economic feasibility of the concept (carbon capture and storage). A large portfolio of proven, mature and differentiated technologies is available. The system design has been validated for quite some time in many industrial and commercial plants. Therefore, economic issues mainly determine investment in and expansion of CHP. Large upfront capital expenditures are required for CHP investment, paybacks are between five and eight years, during which future revenues are uncertain. Without incentives and public support, it is likely that potential users will prefer to wait for clear, long-term regulation; this limits the potential for the scale economies and technical improvements made possible by a growing market. This is not to say that future R&D efforts are not necessary and useful, but that their outcome will be to further improve the system's overall efficiency, which is likely a factor of secondary order in CHP profitability. In contrast, spark spread, *i.e.* the gap between fuel and electricity prices, remains the primary determinant of CHP investment decisions. Policy also plays an important role, in two major ways: definition of subsidies, incentives and market framework; and removal of existing barriers to CHP development.

An IEA review in 2008 identified a series of barriers commonly faced by CHP:

- economic uncertainty about future prices of CHP electricity exported to the grid;

- electricity interconnection (access to the grid, transparent back-up charges);
- the difficulty of including CHP in existing emissions regulatory schemes (such as permits trading) owing to its mixed power and heat output.

The multiple origins of these different obstacles are well identified:

- lack of information (potentially enlarged uses for CHP, awareness of the retrofitting of CHP system in existing plants without more modifications, poor image of the technology);
- conflict of interest between users of communal and industrial CHP and the strategies of large electricity companies (*e.g.* the Big 4 in Germany: E.ON, RWE, EnBW and Vattenfall);
- conflict of interest between CHP producers and electricity grid operators;
- rising and unstable gas and oil prices.

This section first examines the financial determinants of CHP investment and the resulting obstacles, then the technical challenges ahead, and finally the most worrying regulatory uncertainty according to the players involved, the treatment of CHP plants in emissions trading systems.

Cost and financial uncertainty

The total investment in a CHP project depends upon the size of the plant and its technological design (fuel, prime mover) but is often quite high. Average capital costs for medium and large CHP projects usually amount to USD 500-1 000/KW electricity. The profitability of CHP schemes relies crucially on the relative difference between the input price (fuel or other sources) and the sales price of electricity, called the spark spread, which is highly dependent on the efficiency of conversion.

Spark spreads are however also directly and unpredictably affected by the macroeconomic environment. From 2008, most economies went into recession, with a sudden and dramatic fall in domestic demand. This resulted in a significant drop in energy prices (*e.g.* the export power price in Germany halved from EUR 73/MWh to EUR 37/MWh between Q4 2008 and Q4 2009). However, gas prices did not follow the same pattern. Consequently, CHP spark spreads have been severely reduced during the crisis. In Germany, 40 MWe and 15 MWe gas turbine systems (CHP systems for industry and power plants) had spark spreads between EUR 10/MWh and EUR 15/MWh in 2009, whereas it was over EUR 30

during the three previous years. Such sudden changes in the economic variables determining CHP profitability increase uncertainty and discourage new investment.

Rather paradoxically, the superior efficiency of CHP is also a major obstacle to its general adoption, as it fundamentally derives from the plant's close location to built-up areas in order to utilise the heat generated. It therefore requires a decentralised power system. The high costs of investment cannot benefit from the economies of scale enjoyed by very large centralised power plants as capacity is determined and limited by local demand. The optimal size of a CHP plant is finally a trade-off between meeting as much demand as possible and achieving the highest level of utilisation possible (more than 4 000 full-load hours). The lower running costs allowed by fuel savings can only be recouped over time, as the upfront investment required is quite high. Without government support, standard economic conditions would result in paybacks for a CHP 5-40 MWe gas turbine plant of 10-20 years. Bonus tariffs (as detailed in below) could help reduce this delay to less than five years.

This factor also explains why large national utilities have so far shown little interest in CHP. For example, the "Big 4" in Germany explain in interviews that they are more interested in high performance fossil power plants (IGCC, ultra supercritical plant) and carbon capture and storage (CCS). However, they are aware that the German government is increasingly concerned by the capacity gap, as old power plants close progressively while the commissioning of new ones stalls owing to the lack of financing and regulatory uncertainty regarding future carbon costs and abatement requirements. About 60 GW (gigawatts) of power capacity operational in 2000 will need to be replaced by 2020 and about 90 GW by 2030; this is 75% of total domestic electricity capacity. Another plausible explanation is that utilities prefer to invest in large coal and gas plants without heat recovery because the architectures and models are incompatible. For industrial and commercial applications, the small size (as compared to large energy facilities) of CHP plants makes major banks and other lending institutions reluctant to finance investment.

CHP technical challenges

CHP research and development focuses primarily on improved performance, greater reliability, modular and smaller units, and lower emissions (*e.g.* through the use of renewable inputs such as biomass). This translates into certain fields of technological development for large and medium-size CHP facilities: biomass gasification to source CHP plants; greater turbine efficiency; combination with CCS and intelligent grids for

efficient connection; and management of the CHP installed electricity power base.

The first three aim at improving energy and environmental efficiency on the CHP site. The fourth has a different focus. Taking into account concerns raised by the compatibility costs of CHP interconnection to the centralised electricity grid, various solutions are explored to allow a higher level of decentralisation in the power system, without weakening its reliability and robustness. This requires fully integrated network management and real-time access to detailed information on local fragmented supply of and demand for electricity. If this objective is considered and introduced in R&D programmes, CHP could then benefit from the massive ongoing R&D efforts worldwide on smart grids.

Although not a technical issue, existing information about CHP technologies should be mentioned as a significant obstacle. It affects first the image of the technology and its attractiveness for investors, the media and policy makers. Since CHP technology has been on the market and widely used for decades, it is often considered archaic, especially compared to new and more spectacular technologies such as solar thin films or offshore wind power plants. Also many CHP plants are still going to use fossil fuels; this is not seen as an attractive, radical and sustainable solution. The effective use of biomass or waste is not widespread and well publicised. Second, the lack of specific and widely available information on CHP complicates the permission approval process. Multiple permissions, from many different bodies including government agencies and utilities, are required to launch a new CHP installation. The process is often complex, costly, time-consuming and uncertain, and may delay the project for more than a year.

In the battle for a positive image, which directly affects investors' interest and the way the permissions process is handled, it is interesting to consider the different reasons why non-governmental organisations (NGOs) such as Greenpeace or the Worldwide Fund for Nature (WWF) publicly support cogeneration. First, since the use of fossil fuel is presumably going to continue for a while, it is important for its use to be as efficient as possible to reduce CO_2 emissions, and CHP offers this. Second, it offers an efficient and renewable alternative to nuclear power, which is now presented by many as the "silver bullet" to cut greenhouse gases, with no available superior alternatives. CHP however can directly meet substantial needs for energy in the form of heat and cold without the electricity stage imposed by nuclear plants. In addition, biomass cogeneration plants produce lower emissions than nuclear power plants. Third, CHP investment is seen as a significant, preliminary and facilitating step towards a decentralised and renewable energy system.

Regulatory uncertainty: Inclusion of CHP into emissions trading systems

The potential for CHP to bring about significant reductions in emissions is increasingly recognised. The 2008 IEA study estimates for example that a scenario of accelerated CHP deployment would lead to a 10% reduction in emissions beyond that achieved by the low-carbon alternative policy scenario (baseline). The question is then: Do the emissions trading schemes now in place (Europe) or emerging worldwide also offer the relevant incentives for the development of high-efficiency CHP systems, giving these technologies a fair role in the portfolio of carbon mitigation solutions? Or is there a risk that these programmes would penalise and hold back CHP adoption? In practice, and despite an apparent compatible objective, emissions trading systems (ETS) such as the EU's raise several complex problems for CHP investment.

First, while CHP reduces overall emissions (suppressing the offsite emissions of conventional plants), onsite emissions will inevitably rise compared with separate electricity and heat generation. This raises a major obstacle in an ETS based on the source of emissions and not the final user (as in the EU ETS), and for which the site is directly accountable for the emissions it generates. A CHP project will have to hold and pay for additional CO_2 allowances.

A second problem deals with the sector classification of CHP. An ETS scheme works with a sector economic classification to set differentiated targets for the allocation of emissions volumes. As CHP plants produce both electricity and heat, this creates confusion about the appropriate filing. The viability of a CHP project will be significantly affected by the emissions stringency imposed on the sector it belongs to and the level of the allocation caps.

Finally, a competition bias affecting CHP might be introduced depending on the inclusion or not of the alternatives in the emissions trading system. ETS for example works with the size of facilities. All electricity generation is affected but only 10-20% of the heat market. This could result in a competitive bias detrimental to CHP and district heating. These plants are often above the threshold for inclusion (20 MW thermal input in the EU ETS) and are then subject to emissions allocations, while individual conventional smaller boilers avoid inclusion. In many industrial sites, building a CHP installation would mean qualification for the EU ETS, which is likely to discourage the associated investment.

To maintain incentives for CHP solutions within the scope of an ETS, several options should be considered, mainly dealing with the design of the

allocation of allowances. Three basic methods are usually considered: grandfathering (the historic emissions of the site are used as a proxy for the allowances needed); benchmarking (comparison with the emissions of a typical generating plant); and auctioning (existing sites and new facilities are required to purchase allowances).

Historic emissions profiles (grandfathering) have been used in Phases I and II of the existing ETS scheme in Europe. However, this methodology penalises emitters that have made energy efficiency efforts in the past, such as CHP plants, as further emissions reductions are likely be far costlier than those of a site that has not invested in efficiency. To remedy this, reducing the compliance factor for CHP sites is one available option for recognising this "early action". But there is still a problem for new plants that will get a lower allocation, as this does not give the right incentives to replace or update old sites.

In a benchmarking approach, permits are allocated on the basis of a comparison with the emissions of a reference plant (often using the best available technology). Its application to CHP, which produces electricity and heat, is called "double benchmarking". Allocation for the power output is based on the emissions of a conventional fossil-fuel-fired plant and allocation for the heat fraction of its output on emissions of a steam plant or a conventional boiler. This twin allocation based on distinct benchmarking for heat and power removes possible distortions due to increased onsite emissions of a CHP plant, rewards the integrated system in terms of carbon savings as compared to separate generation, and is quite flexible and easy to implement. The overall approach relies however on a very sensitive assumption about the load factor of power plants (*i.e.* annual hours of operation). If the assumed level is lower than the normal operating hours of a CHP plant, then the site will be significantly short of allowances and its viability reduced.

Finally, in an auctioning scheme, such as the one proposed by the European Commission for ETS Phase III after 2013, the main challenge for CHP plants is the increase in onsite emissions and the need to buy more allowances, even if the technology ultimately means a reduction in global emissions. Policy makers can adopt a number of solutions to overcome this potential and inefficient penalty: free allocation of permits equivalent to carbon savings from CHP, to its electrical output or to its heat output. In each case, the plan will have to purchase permits but will receive a free allocation, the volume of which corrects the distortion and internalises offsite carbon emissions reductions.

Other instruments can also be considered, such as setting a separate, more favourable (*i.e.* closer to one) compliance factor for CHP plants than

for non-CHP plants. This would measure the speed at which annual reductions are required in a cap-and-trade scheme and ensures effective downward pressure on emissions. Also, the definition of a specific CHP sector in the ETS segmentation could be considered. It would facilitate, in a bounded scope, the introduction of pro-CHP measures, such as a higher compliance factor, specific allocation methodology such as double benchmarking, or a specific bonus.

Domestic public policies for CHP

Review of the available policy instruments

In the long list of available policy instruments to support eco-innovation, four types of measures emerge as particularly relevant and effective in the case of CHP: feed-in tariffs, utility supply obligations, stimulation of local heat and cooling demand, interconnection measures. They aim at addressing the various economic, financial and regulatory challenges discussed above. Table 2.3 summarises the main features, objectives and problems for each instrument presented below.

Feed-in tariffs for electricity produced in CHP facilities both reduce uncertainty for investors (with long-term contracts and guaranteed prices) and improve the plant's economic efficiency. This is a rather flexible instrument that can be easily differentiated over time or according to the fuel source (*e.g.* to promote the use of biomass as in Germany). As the incentives are fixed for long time horizons, typically 20 years, it basically provides a guaranteed revenue stream, which can be borrowed against easily. Unlike renewable energy certificates, which have annually fluctuating values through a trading mechanism, feed-in tariff incentives never change and do not require administration or any additional cost. As the cost increase is passed on to the consumer, it avoids conflicts of interest between the different players along the value chain. In doing so, it also corrects existing market biases, by bringing parity to the many incentives, tax breaks and environmental damage done by traditional energy sources which are never reflected in their market prices.

Utility supply obligations oblige electricity suppliers to source a mandatory percentage of their electricity from CHP plants (either directly or on the gross market). This directly stimulates the demand for CHP electricity. The target level can be adapted annually according to policy targets. Such a system (usually implemented with CHP certificates allocated by the regulator) allows small CHP producers to enter the market successfully and to overcome barriers due to their lack of expertise in

electricity trading and the preference of electricity suppliers to source from a small number of large power plants.

A parallel policy option consists in stimulating final demand for the heat output of CHP facilities (for heating or cooling applications). In this case, a local approach is necessary, with a key role for local governments or municipalities in planning and promoting district heating and cooling networks, setting standards for public and private buildings, and sometimes investing directly in the distribution infrastructure.

Finally, interconnection measures aim at facilitating the participation of CHP plants in the domestic electricity system and their access to the network grid. They could include for example: net metering, priority dispatch or exemption from licensing. The objective is to give CHP plants the ability to export any surplus of electricity to the grid (or to import if necessary), with safe, reliable and economical interconnection rules.

Table 2.3. Comparison of policy instruments to stimulate CHP investment and diffusion

Instrument	Objective	Enabler	Problems faced
Feed-in tariffs	Reduce uncertainty, improve economic efficiency	Energy investors	Investment bias
Utility supply obligations	Create and stimulate demand for CHP electricity	Electricity suppliers	System implementation and monitoring costs
CHP and DHC local planning	Create and stimulate demand for CHP heat	Municipalities, local governments	Institutional rigidities
Interconnection measures	Allow CHP plants to export electricity surplus in a viable and profitable way	Network electricity grid operator	Supervision and monitoring costs

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

CHP policy in Germany

Germany is a particularly interesting case for examining public policies for CHP as the German government in 2007 gave CHP a special role in shaping its 2020 energy and climate policy. It announced an ambitious target of doubling the use of CHP by 2020, with a parallel expansion in industry, district heating and small units (this appeared as the first element in the list of measures announced in the integrated energy and climate programme). An annual budget of EUR 750 million was earmarked to fund the different incentives and subsidies. In less than two years, a substantial legislative and regulatory package was adopted and implemented to build a comprehensive and coherent framework for reaching that objective.

The interesting point is the variety of instruments used. While this sparked criticism that one instrument should have been used and priority given to efficient CO_2 trading, it marks recognition of the specific issues for public policy arising from the coexistence of different incentive instruments. For example, to avoid competition between feed-in tariffs under the Renewable Energy Act and the CHP Law, it was decided to treat both equally. Otherwise, as feeds from wind power plants may fluctuate a lot and surge brutally, this could provoke sudden disruptions in the operations of CHP industrial plants and make economic and financial previsions impossible. Another key element of German CHP policy is the early priority given to the use of biogas, with a real and very supportive vision, which put the country in a leading position on this world market today.

This strong CHP policy is rooted in two key features of the German energy landscape, which shape specific initial conditions. First is the massive proportion of fossil fuels in primary energy sources. The bulk of electricity in Germany is still generated in power plants fired by fossil fuels (coal and natural gas) and nuclear plants. There are still a number of coal-fired condensing power plants that are less than 35% efficient. On average, the efficiency of the hard-coal power plants is 42%. While renewables are a top priority, the very low starting points reduce their potential contribution at the time horizon set for collective actions against climate change (2020, 2030). This explains the domestic interest in technical solutions for climate mitigation that are compatible with fossil-fired power plants, such as carbon capture and storage and combined heat and power.

The second element is that, while CHP is already well established in Germany, with a reported capacity of 23 GWe (Table 2.4), *i.e.* 16.5% of total domestic capacity, there remains a huge untapped potential for CHP deployment that could be easily and quickly realised and bring a very significant short-term contribution to domestic reduction of CO_2 emissions. IEA research (2008a) estimates that the simple application of best practices and policies implemented elsewhere could raise the share of CHP in German electricity generation to 18% in 2015 and 27% in 2030.

In 2008-09, Germany implemented an extended, comprehensive and attractive policy framework to support CHP development. It combines different pieces of legislation and regulation to address the challenges described above. The main element is the CHP Law which came into effect in January 2009 with a planned annual budget of EUR 750 million. The ecotax exemption applies to a CHP plant with a load factor higher than 70%. The domestic application of the EU ETS gives special treatment to CHP plants compared to traditional power plants, by taking into account the full emissions savings for both heat and power outputs to allocate emissions allowances (double benchmarking) and by offering them a less stringent

compliance factor (required emissions to be achieved from the baseline). Finally, the Renewable Energy Law sets very favourable feed-in tariffs for biomass CHP. A common element of these support mechanisms is their secured time-horizon validity (guaranteed until 2020 except for ETS), which is crucial for reducing investment uncertainty.

Table 2.4. CHP installed base in Germany in 2008

	Industry	Power sector	Small	Total
Capacity (GWe)	10	10.8	2.4	23.2
Generation (TWh)	38	32	13.5	83.5
Dominant fuel used	Natural gas/oil (41%), biomass (34%)	Coal, lignite (81%)	Biomass (73%)	
Growth	+	+	+++	++

Source: BMU (2009), "Renewable Energy Sources in Figures", *www.bmu.de/english/renewable_energy/downloads/doc/5996.php*, quoted in M. Brown (2010), "CHP Policy & Markets – German Update", Delta Energy & Environment, Edinburgh, March.

The central incentive mechanism of German CHP policy is feed-in tariffs. As early as 2002, a first CHP Law (*Kraft-Wärme-Kopplunggsgesetz*) introduced a premium payment for electricity from CHP plants being modernised or under 2 MW. This was a key signal, indicating a clear political commitment for using CHP as a priority tool to achieve domestic CO_2 emissions targets. This is stressed by the estimated budget between 2002 and 2010, which amounts to EUR 4.5 billion. The main instrument implemented by the law is the bonus payment for electricity sold to network operators in addition to the normal price defined as the average base-load price of the European Energy Exchange over the previous quarter. The only new plants eligible for support are those smaller than 2 MW with a pre-set price bonus of 2.25 ct/kWh in 2006. Plants put into service before 1990 and between 1990 and 2002 would benefit from 0.97 ct/kWh and 1.23 ct/kWh, respectively, in that same year. Finally, modernised plants in the interim period running from April 2002 to December 2005 would receive a 1.69 ct/kWh bonus payment. In addition, CHP plants are compensated for the network costs avoided as most of the generated electricity is used on-site, within a range of 0.4-1.5 ct/kWh, depending on their location.

As a result, CHP accounted in 2005 for 21 GW of installed capacity, *i.e.* 13% of total electricity generation. Contrary to conventional fossil fuel power plants, this installed capacity is quite fragmented as it is produced by 3 000 units (28% belong to auto producers and 72% to public utilities). However, CHP growth and diffusion was not enough to reach the targets set

by the initial law. Several studies and reports explored the possible explanations for this mixed result and helped identify the remaining obstacles and weaknesses of the existing legislative framework: the 2 MW threshold, interconnection problems, uncertainty regarding future ETS. The market for industrial CHP is not very active, except in the chemical and mining industries, owing to uncertainty regarding its long-term viability and little support from the existing law. District heating CHP is instead widely applied in Germany. Municipal authorities have been supplying power and heat to businesses and residents for more than a century with *Stadtwerke* utilities. The role of large utilities is still limited. E.ON and Vattenfall developed CHP assets by connecting their power plants to district heating networks. RWE and EnBW focused on industrial CHP applications.

To reach the even more ambitious target defined at the political level in 2007, a new CHP Law was designed and approved in June 2008 as a part of the German global climate and energy policy, amending the initial 2002 Law. The Federal Ministry of Economics and Technology built its argument on several studies, which demonstrated that CHP could allow CO_2 emissions savings of up to 54 million tonnes a year, or 13% of the reduction necessary to achieve the government's target of 40% by 2020 compared to 1990 levels. The main elements of the new legislation are: an increased CHP bonus, an additional technology bonus for innovative CHP technologies, the removal of capacity limits for new plants, interconnection obligations, the use of benchmarks under the European emissions trading system, a DHC building-friendly code, a natural gas and oil tax exemption for CHP, high feed-in tariffs for biomass CHP.

Basically, the core mechanism remains the bonus tariff for the price of electricity. To stimulate the investment in new CHP installations by the end of 2016, a revised incentive scheme was introduced, starting in January 2009. A bonus is paid on electricity fed into the public grid or used directly: 1.5 ct/kWh for plants over 2 MW, 2.1 ct/kWh for power size between 50 kW and 2 MW, and 5.11 ct/kWh for under 50 kW. The first two tariffs are limited to six years (four for industry) or 30 000 hours and the last to ten years. A cap to subsidies is also set at EUR 600 million a year for CHP plants and EUR 150 million for district heating systems.

The 2009 law also incorporates the guidelines of the 2004 EU CHP Directive by introducing a guarantee of origin for CHP electricity, as well as a definition of high-efficiency CHP. The obligation for public grid networks to connect CHP plants and buy their electricity surplus is complemented by a dispatch priority, equivalent to that for renewables. The price bonus, without capacity limits, is extended to new CHP plants put into service between 2007 and 2016. The associated suppression of the existing 2 MW cap indicates a will to promote CHP directly in the power sector, and not

only in peripheral applications such as industrial facilities or district heating and cooling. Finally, electricity for own consumption becomes eligible for the tariff bonus.

The first noteworthy characteristic of this domestic CHP policy is that it combines all the instruments available to support the diffusion of this technology. The objective is to offer solutions for every obstacle identified and create massive incentives for CHP investment. As the accumulation of various instruments can confuse potential applicants and have contradictory impacts when combined in practice, a particular effort was made to define clearly the primary scope of application for each instrument (fuel input, plant size, final user) and to resolve in advance possible discrepancies in the overall framework.

The second interesting and original policy orientation is that the use of biomass (broadly defined) in CHP plants is strongly supported and encouraged. A specific section of the 2009 EEG Law (Renewable Energy Sources Act) was devoted to CHP to complement the mechanisms in the CHP Law. Three types of incentives can eventually be added together for a very significant price bonus: a fuel bonus for renewable resources, a bonus for power generation using CHP, and finally an innovation/technology bonus (if a new CHP technology is introduced). Table 2.5 describes the possible bonus combinations according to the size of the plant. The maximum subsidisation is 26.7 ct/kWh (a 20% increase from the previous regulatory framework) for plants up to 150 kW and 16 ct/kWh for medium plants between 0.5 MW and 5 MW (most commercial and industrial applications), including the additional 2 ct/kWh innovation bonus (not mentioned in the table). The assumption of German policy makers is that bio-CHP is likely to play a major role in the transition to an environmentally durable power system for three reasons: cost, foreseeable production and internal process efficiency. With solid biomass, the cost of electricity in a 20 MW CHP plant is expected to decline by 6-9 ct/kWh by 2030 (economies of scale, technological improvement). Also, contrary to wind and solar renewable energy sources that must cope with large fluctuations, biogas CHP can supply power in line with demand. It thus offers a crucial buffer for the demand peaks which most renewable systems cannot cope with owing to their intrinsic nature. Finally, the heat produced in the CHP process can be used to improve fuel inputs (distillation of alcohol, drying wood pellets). These economic prospects and the associated opportunities justify more intense public support for this specific CHP technology.

While it is too early to assess the impact of the new legislative and regulatory framework introduced in 2009, observable trends from previous policies are encouraging, since incentives for CHP investment have increased significantly. First, Germany has become a world leader and a

major market for biogas CHP, as capacity has grown from 180 MW in 2000 to over 1 GW in only six years. Second, between 2005 and 2008, the CHP installed base increased by 10.5%. The corresponding annual rate of growth during these three years (3.5%) is exactly in line with the political objective set in 2009 to reach a 25% share of CHP electricity by 2020.

Table 2.5. Guaranteed electricity price bonus for biogas in Germany

2009 CHP and renewables laws

Capacity	Basic rate for biomass	Bonus for agricultural wastes and energy crops	Bonus for CHP	Maximum price
0-150 KWe	11.67	11/9	3	25.67
150-500 KWe	9.18	9	3	21.18
500- 5 000 KWe	8.25	4	3	15.25
5 000-20 000 KWe	7.79	0	3	10.79

Source: IEA (2008b), *CHP/DHC Country Scorecards: Germany*, IEA, Paris, p. 8.

Finally, Germany has a pioneering experiment which links CHP technologies and another eco-innovation, carbon capture and storage (CCS). CCS can be plugged onto a modern, highly efficient power plant with cogeneration of heat and power to increase the fuel utilisation rate by up to 61% while cutting CO_2 emissions by 25%/kWh compared to old coal-fired plants. A full-scale project of this kind is currently conducted by Vattenfall in the new Moorburg power plant near Hamburg to be completed in 2012, and aims at satisfying half the electricity and heat requirements of the city.

CHP policy in Canada

CHP has been slow to penetrate the Canadian market. This may be surprising as countries with cold climates such as northern European countries have recorded high levels of CHP penetration. However, the two main reasons for the low penetration of CHP are historically low energy prices (Canada is a large oil and gas producer) and utilities policies related to the provision of back-up power and the sale of surplus electricity. CHP was long restricted to specific industrial applications, such as the pulp and paper and chemical sectors, which have large on-site demand for both electricity and heat. The level of installed CHP capacity only started to rise in the 1970s (as a response to the dramatic increase in energy prices) and rose more significantly after 1990. More recently, the nature of CHP investment has changed: 90% of new systems use natural gas and more than half are small, less than 10 MW. A 2002 study by Natural Resources Canada

estimated, using different scenarios reflecting price, cost and policy parameters, that cogeneration could provide as much as 30% of the country's electricity needs. It underlined that existing regulatory barriers and, in particular, access to the electricity grid for the sale of excess electricity by CHP plants and the lack of interconnection standards, impeded greater development of CHP in Canada. It was essential to remove such obstacles to allow further investment in CHP installations.

Unlike eco-innovations such as carbon capture and storage or electric cars, public policy for CHP in Canada was until recently less active and supportive than in European countries, which undertook many domestic initiatives after 2000 and paved the way to a directive from the European Commission in 2004 on this topic. If CHP benefits from public support in Canada, this is due to decisions by provincial governments (especially Alberta and Ontario, the two provinces with the largest CO_2 emissions, the highest levels of technology investment, and the greater expected opportunities in terms of business activity and jobs) and in the framework of broader, more general legislation on renewable energy. The following therefore focuses on Ontario, whose recent renewable energy initiative gives a key role to feed-in tariffs, a decisive instrument for CHP investment.

However, CHP was not the main focus of the Green Energy Act (GEA) tabled as Bill 150 at the Legislative Assembly of Ontario on 23 February 2009, and entered into force on 14 May 2009. Regulations and other tools needed to fully implement the legislation were introduced through the month of September 2009. A system of advanced renewable energy tariffs is the primary procurement mechanism for renewable and clean distributed energy to stimulate the growth of a sustainable energy sector. Tariffs per kilowatt-hour of generation are based on key components of the German and French models: differentiation on the basis of technology, resource intensity, project scale and location; minimum profitability index between 0.1 and 0.3 for green energy projects; cost orientation with reasonable return for prices; no cap on project size. Fixed under 15-20 years contracts with utilities, feed-in tariffs for renewable power systems are the following: 13.5 ct/kWh for on-shore wind, 19.0 ct/kWh for off-shore wind; 44.3-80.2 ct/kWh for solar; 12.2-13.1 ct/kWh for hydro; and 13.5- 9.0 ct/kWh for biogas and biomass.

This core mechanism is completed by a series of enabling instruments, including:

- obligation for utilities to connect and to grant priority grid access to green energy projects;
- creation of a Green Energy Debt Finance Program (to raise the financial capital required through green bonds for example) and a

Community Power Corporation (to ensure equal opportunity for participation of local communities in the power sector);

- use of smart grid technologies, including energy storage, to facilitate the evolution of the energy system from highly centralised to more distributed;
- mandated commitment to a minimum 2.5% annual (compounded) reduction in energy resource needs from 2011 to 2027;
- streamlined regulatory and approval processes to enable development of green energy projects across the province, by reducing uncertainty and transaction costs for all involved.

The impact of the new legislation was immediate and impressive. In less than a year, the Ontario Power Authority received about 930 applications for feed-in tariffs, representing about 8 000 MW of renewable energy potential. In March and April 2010, the province successively announced the award of 510 contracts for mid-scale projects (10 kW-500 kW) with a generating capacity of 112 MW, and 184 contracts for large projects over 500 kW with a total capacity of 2 421 MW. CHP is only a small and peripheral field in this massive increase in investment in renewables projects but it could clearly benefit from the overall shift towards a more decentralised power system with lower CO_2 emissions. In addition, the preferential bonus for biomass offers a strong incentive to CHP plants using it as a fuel.

In summary, the framework implemented in Canada looks very much like the German one. The main differences lie in the additional financial programme to facilitate investment, and the lack of specific measures for CHP plants. Another more fundamental difference deals with the distribution of political responsibilities between the federal government and regional institutions (*Länder* or provinces). In Germany, the federal government plays a central role by setting collective domestic targets for emissions reduction through the diffusion of CHP for electricity generation. The associated instruments provisioned by the law are then implemented on this basis in each region. This provides a common ground for investors, consumers and companies. In Canada, the Constitution gives provinces full jurisdiction over energy supply as well as ownership and control of energy resources such as oil, gas and hydro on their soil. Concerns about climate change, the multiple dimensions of energy security (which now include environmental, economic and social issues along with the historical strategic priority), the increasing international dimension of the energy business (large global companies and investors) have dramatically changed the landscape. While the fragmentation of policy and regulations was not a problem for exploration for and exploitation of natural resources, it now

increases costs and risks for investors in energy power plants, duplicates efforts for innovative solutions such as renewables, and prevents a coherent national approach to energy security and social inequalities issues. Ongoing initiatives led by provinces surely play a major role in putting the energy and climate issues at the top of the political agenda, and in experimenting with different frameworks and instruments. But a national energy strategy at the federal level will soon be necessary to improve the efficiency of these efforts and to avoid the rise of artificial biases and new inequalities which could be detrimental to business as well as citizens.

Conclusion

While mature, reliable and cost-effective, CHP technologies are not deployed as widely today as they could be in their three main markets for large and medium operations: industry, district heating, commercial and public buildings. Yet in most countries CHP could make a rapid and effective contribution to emissions reduction as well as energy savings and reduced dependency on imports. The main reason why this large untapped potential is not exploited is that the economic model for CHP investment crucially depends on the resale of excess electricity on the national grid.

Uncertainty regarding access conditions to the grid, future export electricity prices, as well as the way in which emissions trading schemes will apply to CHP plants are the main obstacles to a larger and profitable CHP roll-out. Four types of instruments are likely to play a role in a public CHP policy: feed-in tariffs, utility supply obligations, stimulation of local heat and cooling demand, interconnection measures.

Germany chose to give CHP a central role in its national energy and climate policy and set an ambitious target to double the share of CHP in electricity generation by 2020. An impressive legislative and regulatory framework was implemented in 2009 to support that goal. While giving a central role to attractive feed-in tariffs, this CHP policy also combines every instrument available to deal with the obstacles identified and proposes the highest possible incentives. Another distinctive feature is the special priority and public support for CHP plants fuelled by biomass, also called biogas CHP. First results seem positive and Germany is on the way to achieving its targets for CHP diffusion, giving it a leading world role in that technology, especially biogas CHP.

In Canada, CHP did not benefit from the same dedicated support. Support measures are included in the recent but much broader legislation and regulations regarding renewable energy. In the absence of an integrated national energy strategy, the fragmentation of policy responses across

provinces does not help to reduce the uncertainty faced by investors considering new CHP projects.

References

Brown, M. (2010), "CHP Policy & Markets – German Update", Delta Energy & Environment, Edinburgh, March BMU (2009), "Renewable Energy Sources in Figures", *www.bmu.de/english/renewable_energy/downloads/doc/5996.php*.

IEA (International Energy Agency) (2008a), "Combined Heat and Power: Evaluating the benefits of greater global investment", Report prepared by Tom Kerr, IEA, Paris.

IEA (2008b), *CHP/DHC Country Scorecards: Germany*, IEA, Paris.

IPCC (International Panel on Climate Change) (2007), *Fourth Assessment Report*, Geneva.

Chapter 3

Micro combined heat and power generation: Policies in Germany

This case study focuses on micro combined heat and power fuel cells (micro-CHP fuel cells). It is mainly based on field investigations (literature review, interviews) in Germany, which has interesting initiatives to foster the development of these technologies. The results of similar investigations in France, where development is less advanced, are also presented to add contrast to the German case and draw lessons from the differences in the two countries' system configurations and strategies of public and private stakeholders.

Micro-CHP fuel cell technologies, markets and industry

CHP systems and applications

Cogeneration (also called combined heat and power, CHP) is the use of a heat engine or a power station to generate simultaneously electricity and useful heat. It is one of the most common forms of energy recycling. Micro-cogeneration (micro-CHP) is a small-scale distributed energy resource (DER). The technological core of micro-cogeneration is an energy conversion unit that allows the simultaneous production of electricity and heat in very small units.

This unit is sized for the needs of households and is installed on the customer's side of the energy meter. The EC Cogeneration Directive 2008/4/EC defines micro-cogeneration as "a cogeneration unit with a maximum capacity below 50 kWe". However, in practice, it is generally accepted that micro-cogeneration systems provide less than 15kWe [kilowatts electric] (the power range needed for most home and small businesses applications).

Micro-CHP systems heat the building as a central heating system and at the same time generate electricity. Some of this is directly used for building consumption; the remainder is exported to the grid. If bigger CHP units (more than 50 kWe) are more dedicated to electricity production, the first objective of a micro-CHP unit, in the current state of the art of building energy management systems, is to produce heat.

According a French PREBAT study (Husaunndee and Catarina, 2007), the key benefits of CHP technology for end users are: reduced primary energy consumption; lower energy bill; easy to install and use (could be a replacement solution for classic boilers); and reduced cost of electrification in rural areas owing to the decentralised energy system. Micro-CHP can also be of great benefit to the grid as it reduces grid losses (up to 7%). Depending on the option and the energy source, the environmental benefit can be considerable as well.

Micro-CHP systems have five major technological aspects: the energy converter itself; fuel supply; energy management; grid access; and communication technology.

Table 3.1. Characteristics of micro-cogeneration technologies

Conversion technology	Electrical efficiency	Thermal efficiency	Noise level	Pollutant emissions	Fuel flexibility	Market availability
Reciprocating engine (ICE)	20-25%	>85%	Medium	Rather high, depending on catalyst/engine technology and maintenance	Medium	Commercially available
Stirling engine (ECE)	10-24% (depending on the burner)	>85%	Low	Very low to medium (depending on the Stirling concept)	High	Near to market
Steam expansion engine (ECE)	n.a.	n.a	Low	Not yet measured, in principle similar to Stirling	High	R&D
Fuel cells	28-35%	80-85%	Low	Zero (H_2) to almost zero (hydrocarbons)	Medium	R&D and demonstration

Source: Pehnt, M. *et al.* (2006), *Micro Cogeneration: towards decentralized energy systems*, Springer.

Competing technologies

The main competing technologies for micro-CHP applications (Table 3.1) are:

- internal combustion engines (ICE), which are already on the market; they burn (piston or turbine) the fuel and produce heat and mechanical energy for the electricity directly;
- external combustion engines (ECE), basically Stirling engines, organic Rankine cycle engines or steam engines; they burn the fuel or the heat source in a dedicated burner then produce through a steam or a Stirling process the mechanical energy to produce electricity and heat;
- fuel cells (FCs) which convert the chemical energy of a fuel (hydrogen, natural gas, methanol, gasoline, etc.) and an oxidant (air or oxygen) into electricity and heat.

Some new competing conversion technologies are still at the stage of basic research. For instance, thermo-photovoltaic engines burn the fuel in the burner to produce the heat, which is then converted in semiconductors to obtain electricity. Other technologies are based on thermoelectric devices which directly convert electromagnetic radiation into electricity or wind power.

These different options have various performance characteristics and are at various stages of development. Fuel cells clearly have the better prospects in terms of performance, especially with regard to electrical efficiency. This attribute is especially important for CHP applications since it determines the business models of these decentralised units: the greater the electrical efficiency, the higher the revenues stemming from selling electricity to the network to partly or totally offset the higher upfront costs. Moreover, since buildings are becoming increasingly energy-efficient, thermal needs will diminish in the coming years; when thermal efficiency is high, the CHP system does not need to operate long to heat the building. Hence, the amount of electricity produced will be limited. Electrical efficiency and a low heat-to-power ratio will be the keys to the success of the different CHP technologies.

The different stages of technology development and (expected) market availability show that some of these technologies may not compete directly in the future: Stirling engines, which are currently seen as the "next CHP technology" are perceived by some interviewees as an opportunity for fuel cells as they may help to raise awareness of micro-CHP applications and legitimise advanced micro-CHP technologies.

State of the art of micro-CHP market deployment

A major market study led by Micro-Map in 2002 (FaberMaunsell *et al*., 2002) presented very optimistic prospects for micro-CHP by showing that between 6 and 11.5 million micro-CHP systems could be installed and operated commercially in EU countries by 2020 (mainly in Germany, the Netherlands and the United Kingdom). According to the study, Stirling engines would be the most promising technology.

Although sales forecasts were very optimistic in the mid-2000s, based on the idea that micro-CHP units would replace traditional condensing boilers, the expected exponential growth of the micro-CHP market did not materialise. On the contrary, market growth has slowed and some key industry players such as utilities have already stepped back. This trend is of course accentuated by the current economic crisis.

In 2004, total installed capacity was 24 MW, which increased to 31 MW in 2005 (29% increase). The delay in market development already severely affected some developers, such as Microgen, which closed its business in 2007, and Solo Stirling which also ceased operations in 2007.

Growth started to slow in 2005 (increase of only 22%). Japan represented about three-quarters of sales and Germany one-fifth. ICE micro-

CHP systems still account for the bulk of the installed capacity and new sales.

Fuel cell technologies

Fuel cell technologies hold much promise: they can offer cleaner, more efficient and more politically secure energy that the paradigm that has dominated the world economy for over a century. The market potential of both the H2 (hydrogen fuel cell) infrastructure and fuel cell systems is enormous as they can serve a wide variety of applications, from stationary, transport to consumer electronics.

However, how and when this promise, largely unfulfilled today, will materialise is still uncertain. Although research on fuel cells has been active for several decades, there is great uncertainty regarding the real potential of these technologies, which still face major technological and economic challenges.

Technological options

Several types of fuel cell technologies coexist. They all have their strengths and weaknesses, as well as specific operating conditions, which make them suitable for particular groups of applications: phosphoric acid fuel cell (PAFC); molten carbonate fuel cells (MCFC); proton exchange membrane fuel cell (PEMFC); and solid oxide fuel cells (SOFC). PEMFC and SOFC currently raise the highest expectations and therefore attract the bulk of financing and attention. PEMFC is especially well known since it has been widely applied in demonstrations of fuel cell vehicles. One of its greatest advantages relative to its predecessors lies in its versatility: it can power anything in the 1-300 kW power range, it operates under temperatures suitable for many consumer applications (around 80°C), and is expected to benefit from substantial cost reductions through mass production and material substitution. Particularly, in a context of growing environmental concerns, the potential application of this green technology to mobile applications, from electric bicycles to consumer cars and buses, has led to growing interest in various industries and governments. Even within automobile applications alone, PEMFC could be used as an auxiliary (for the increasingly energy-consuming on-board electronic equipment) or principal power source.

A fuel cell system that includes a "fuel reformer" can use the hydrogen from any hydrocarbon fuel. High temperature fuel cells such as SOFC do not need a fuel reformer and can use fossil fuels such as natural gas or coal gas directly. Since the fuel cell relies on chemistry and not combustion,

emissions from this type of system are smaller than those from the cleanest fuel combustion processes.

Applications of fuel cells

Fuel cell applications have three commonly defined segments: portable, stationary and transport. The main stationary applications, CHP among them, are:[1]

Distributed power	Greenhouses
Off-grid power	Peaking applications for grid
Back-up generator power	Residential in individual homes and subdivisions
Cogeneration of power/heat	Emergency standby: hospitals, fire stations and airports
Cellular telephone towers	Remote industrial operations: mines, portable mills
Data centres	Military use

Electric or hybrid vehicles, depending on the configurations, represent the most demanding application in terms of required performance. However, they are also the most significant in terms of potential market size and potential reduction in CO_2 emissions (although this depends on the mode of production of hydrogen). Based on its promise and high media coverage, large-scale tests have also been undertaken in all industrialised countries and for all types of applications, including fuel cell vehicles and CHP at different scales.

Rapid history and current state of development of fuel cell market development

Fuel cells R&D activities were undertaken as early as the end of the 1950s in the United States for space applications and since the first oil shock in Europe and in Japan under energy security and environmental pressures. Since then fuel cells have gone through several cycles of impressive investment followed by rapid "crowding out" in favour of competing technologies (such as batteries). Several promising technological options have been explored (AFC, PAFC, SOFC and MCFC) and some have been successfully applied in military and space applications or even brought to the pre-commercial stage as large central power units. However, they appeared in the early years poorly suited to, or far too expensive for, consumer applications.[2]

Their most recent – and most significant – revival dates to the mid-1990s. It occurred with the development of PEMFC technology. For more than ten years, there have been high expectations in terms of economic activity, environmental benefits and energy security for a wide range of applications, from laptops to individual vehicles. The bulk of public and private investment was directed to research on fuel cells for transport applications.

More recently, in the last two years or so, the fuel cell area has gone through a new downturn, with a significant decrease in leading actors' interest and investments. This severe downturn is evident in firms' announcements and strategic moves as well as in the public budget dedicated to fuel cell research. Most car companies have clearly expressed their intention to focus on battery-powered electric and, especially, hybrid vehicles, leaving fuel cells as a long-term option. Moreover, the stationary fuel cell industry has also recorded several announcements of companies reducing or stopping their R&D programme. Finally, public fuel cell research expenditures have also decreased in most countries.

According to the interviews, fuel cell technology, and the hydrogen economy in general, benefited around 2005 from a high degree of excitement among energy suppliers. However, no commercial products came to the market and the subsequent disillusion is still perceptible among energy actors. Hence, the decrease is mainly based on disappointment regarding progress, especially on the market side. The long-awaited wide diffusion of fuel cell electric vehicles, which would, as mentioned, strongly affect the world volume of fuel cell activities, has been regularly postponed. Even more worrying, delays are increasing in forecasts: from 2010 in 2000[3] to 2020 in 2005; most experts now do not foresee mass production for transport applications before 2030[4] or 2050. The portable segment, although the technology is claimed to be ready, has also been regularly postponed. It is now planned for 2010-12 according to some recent market research.

As of now, despite significant progress in laboratories and on test benches, market deployment remains anecdotal for all mobile, stationary and transport applications. On the user side, cost and durability issues are claimed to prevent market uptake. On the producer side, many stakeholders claim that progress on these two crucial parameters can only be achieved through experiment in real conditions and in pre-commercial use.

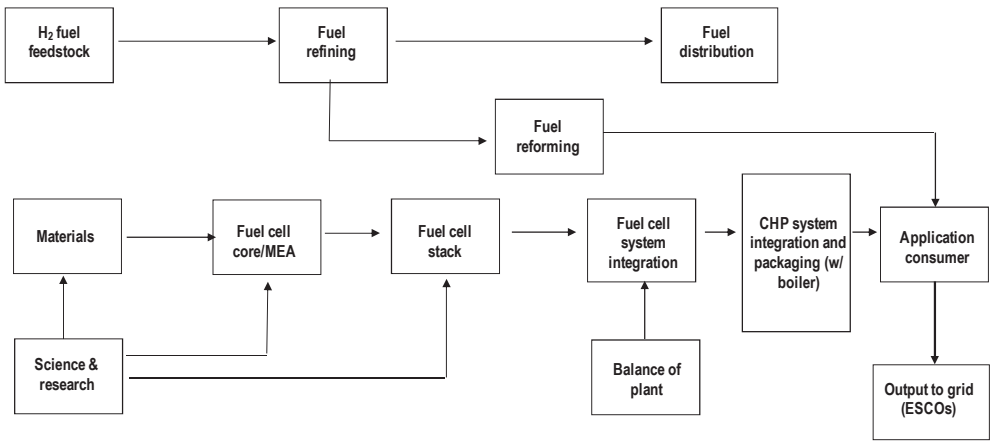
Interestingly, disappointment with progress in fuel cell vehicle technology could represent an opportunity for other fuel cell applications. The US Department of Energy (DOE) declared its intention to realign funding priorities in order to focus on fuel cell technologies for near-term applications. Hence, it was decided to broaden the scope of research to a

more diverse set of fuel cell applications including combined heat and power (CHP), auxiliary power units (APUs) and portable applications. In France, the *Agence Nationale de la Recherche* decided to focus its new fuel cell research programme H-PAC on stationary applications, in contrast to the former programme PAN-H (2005-08) which emphasised transport applications. The newly established strategy is to demonstrate the technology on portable and stationary applications prior to transport applications, starting with fleet vehicles.[5]

The micro-CHP fuel cell value chain

Micro-CHP fuel cells are part of a complex overall system that goes from the energy source to hydrogen production to its conversion to heat and power in the CHP fuel cell. The fuel cell itself includes a variety of components (Figure 3.1).

Figure 3.1. The micro-CHP system components



Source: Adapted from Hendry, C., J. Brown and P. Harborn (2006), "Framework conditions for FC in residential CHP in four countries", Cass Business School, Oxford, September.

This complex system is supplied by a long and diverse value chain, which includes actors from various communities and industries (technology supply, system development, manufacturing and packaging, product distribution, end use). This diversity creates a strong challenge for co-ordinating the development of the technology and its application.

The main elements of the FC-based micro-CHP value chain are the following:

- Material producers and component manufacturers, mainly in the United States, Japan and Canada (but also in Europe, *e.g.* Switzerland and Nordic countries). They are mostly financed through supply-side instruments and some units sold for demonstration.
- Fuel cell developers and fuel cell system integrators; the relationships between fuel cell stack developers, fuel cell system integrators and total micro-CHP system integrators vary greatly: in some instances, an actor can develop both the system and integrate it in a complete FC-based micro-CHP system, including the boiler. In others, different companies take charge of individual elements of the value chain. For instance, micro-CHP technology developers such as ENATEC license the technology to boiler manufacturers.
- Equipment (boiler) manufacturers. Their commitment is also important. A number of boiler manufacturers are developing their own micro-CHP products or are working with technology developers to develop a micro-CHP product (Baxi,[6] De Dietrich, Vaillant, Whisper Tech and Microgen, etc.). Also, independent micro-CHP product developers will need the manufacturing capability of boiler manufacturers to help them commercialise their products.
- Energy suppliers, utilities and equipment distributors. According to the literature and interviews, these are key actors in the value chain, not only because of their concrete links with the market as downstream actors, but also because they may control the energy source (natural gas for instance), the energy output (the electricity generated and sent back to the grid) and the main alternatives (production of electricity from other sources, including the current centralised production).
- End users (buildings – commercial or residential, industries and services, etc.).

In general terms, the value chain for FC-based technology lacks some elements in all countries but Japan and the United States. This calls for international partnerships. More specifically, gas suppliers' interest in micro-CHP in Europe is still patchy. E.ON (the leading gas supplier in the United Kingdom), is the only one that currently offers a micro-CHP unit to households. In the Netherlands, gas suppliers (*e.g.* GasUnie) are

encouraging the development of the Dutch micro-CHP market by sponsoring field tests. In Germany, a similar strategy is being implemented.

The following section considers the scientific, technological, institutional and economic challenges to be tackled in order to support the development of micro-CHP technologies.

Remaining barriers to market deployment of micro-CHP fuel cells

Scientific and technological challenges

Fuel cell components still present scientific challenges such as internal or external conversion of hydrogen or natural gas. Some are being tested in the field. Current research works on the durability (longevity) of the fuel cell and system cost reductions. There have been slight improvements in recent years:

- Durability has improved but remains a major scientific bottleneck. Lifetime requirements are evaluated at between 10 to 15 years (*i.e.* 5 000 hours of functioning a year). However, according to interviews, only lengthy field-testing can certify performance in real operating conditions.
- Cost is the most difficult challenge. According to interviews, cost of an FC-based micro-CHP unit is still ten times too high for market entry. Cost is linked to production volume. Very slight improvements have been made in terms of cost reduction but components and integration of the fuel cell remain too expensive for competitive market entry.

These bottlenecks translate into different scientific and technological challenges according to the type of technology:

- the remaining challenges for PEMFC relate to membranes issues, catalysis and fuel cell degradation issues;
- the main challenge for SOFC relates to length time of the stack. Researchers are currently working on high-temperatures ceramic materials.

In parallel to research activities, stakeholders are addressing the refinement of FC-based micro-CHP specifications. Early-market specifications have three aspects: performance, lifetime and costs. Past and ongoing demonstrations also show that maintenance is a major challenge for FC-based solutions. Field tests, as in Japan years ago, are frequently shown

by experts to be mandatory. Moreover field tests could have a direct effect on cost reduction and production volume challenges.

Regulatory and institutional barriers

The current regulatory framework in most countries is poorly suited for micro-CHP fuel cells and could represent a major barrier in the future. Security concerns are still high among the population and regulators. According to interviews, communication and education should be strengthened in the coming years to increase understanding of stationary fuel cells and decrease concerns regarding security and safety.

Other potential barriers include:

- Norms and standards. Some industrials fear excessive technical requirements concerning, for example, conditions for connecting the micro-CHP to the public grid (grid stabilisation norms) or specific security devices (such as inverters) imposed by electricity utility companies.
- Uncertainty about environmental benefits. A debate about carbon externalities of micro-CHP has already been raised by environmental associations and other experts. The multiplicity of sources of information, the poor comparability of study results and their sometimes controversial nature and questionable neutrality create fuzziness and hinder the political process.

Economic barriers

Product cost is obviously the major barrier for market entry. According to interviews, the cost of FC-based solutions is still ten times too high, despite very significant progress (costs was said to be 100 times too high 10 years ago). Further cost reduction depends on scientific and technological progress (see above) but also on market deployment, which would create economies of scale and scope.

Lack of specialised competencies can also be an important barrier since boiler maintenance staff would have to be trained to fix a non-functioning FC-based micro-CHP unit. This problem could be tackled by energy service companies (ESCOs), distributors and public bodies.

Other economic barriers include:

- Gas fuel volatility: a concern regarding micro-CHP technology is that gas fuel prices have historically been very volatile. This makes it difficult to forecast the system's operating cost. Moreover, competition with other technologies, such as classical micro-CHP or

other renewable energy systems, could be a major barrier for FC-based micro-CHP. A combination of different sources of energy (*e.g.* FC-based micro-CHP coupled with photovoltaic) is also an interesting option, but it does not seem to be explored at this stage.

- Wrong price signal for electricity. The price of electricity in most countries does not reflect all of the negative externalities of electricity production. Also, in countries such as France where the bulk of electricity is produced using nuclear power, there is a debate regarding the full cost of electricity generation (which would include all radioactive material recycling costs, as well as the cost of dismantling and reconstructing the plants). The difference in price between the inputs (gas for instance) and marketable outputs (electricity[7]) reduces the expected profitability of micro-CHP fuel cells and therefore hinders their market diffusion.

The dynamics of the micro-CHP fuel cell innovation system

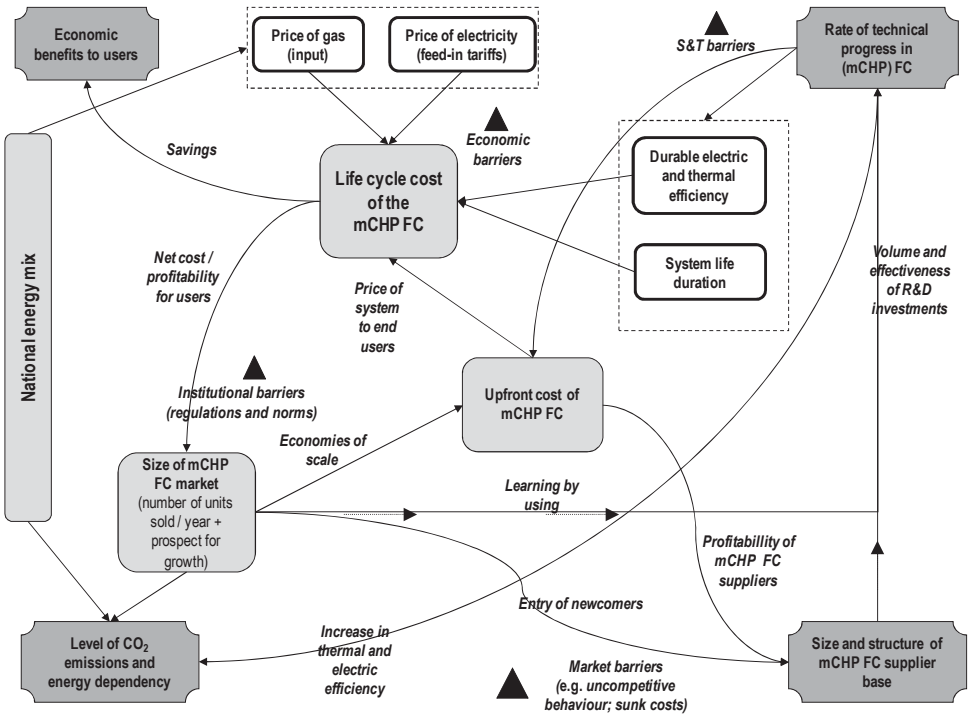
The presentation of the micro-CHP fuel cell technology and system of actors, in general and in Germany, has demonstrated the extent to which market deployment of this technology depends on numerous and deeply intertwined factors.

Figure 3.2 aims to reveal this complex system of drivers, in which scientific technological, industrial, institutional and economic components are interdependent: starting from the supply side, the pace of technical progress determines the performance, durability and stability of the fuel cell, as well as the system's upfront cost (and, hence, its price to the end user). It also allows an increase in the system's energy efficiency, which permits greater environmental benefits and reduced energy dependency.

The life-cycle cost of the micro-CHP fuel cell not only depends on the durability of the equipment and its upfront cost but also to a great extent on the difference between the cost of input (gas for instance) and the output price (electricity). The greater the difference the more profitable, and therefore attractive, the system is for end users. Greater attractiveness will support market expansion which, in turn, leads to economies of scale and learning by using that will feed further cost reduction and technology improvements.

In the absence of market barriers, deployment of the technology will attract newcomers to the sector, who will compete with incumbents. This should result in an increase in R&D investment volume and effectiveness and accelerate the rate of technical progress, feeding further cost reductions and increased durability.

Figure 3.2. Synthesis of the main drivers of micro-CHP deployment



Source: Technopolis Group.

This system consists of many self-reinforcing loops and cumulative processes (notably the long-awaited economies of scale and learning effects) which, once the virtuous circle is created, can result in rapid market deployment. All together this should result in a significant increase in the economic benefits to users (decreased energy bill), environmental gains (reduction of CO_2 emissions, reduced energy dependency), higher level of technical progress in fuel cells (which will benefit other applications) and a more profitable and growing industry.

However, the downside of the system is the difficulty to initiate the virtuous circle of market uptake and technical progress. As of now, in most countries, this process has hardly started. The main barriers highlighted in the figure are still high.

Policy instruments to support micro-CHP fuel cells

It is widely accepted that the initiation of the virtuous circle requires policy intervention. Public authorities can act on several levels:

- support to R&D, for instance through specific subsidies and tax credits (as has been the case in all industrialised countries in the last 20 years, although not targeted specifically to small-scale stationary applications, and increasingly in emerging countries such as China which invests heavily in fuel cells);
- support to early demonstration through specific subsidies (such as Canada's early adopter programme);
- removal of legal and institutional barriers (*e.g.* review and adaptation of current regulations that affect the storage and use of hydrogen in buildings);
- negotiation with electricity utility companies in order to "smooth" their approach to decentralised energy production and remove unjustified norms and conditions to grid connection;
- subsidies for the purchase and use of micro-CHP fuel cell systems (in Korea from 2010 to 2012, the government plans to cover 30% to 80% of the cost – around EUR 30 000 – of buying and installing micro-CHP fuel cells in homes; the percentage subsidised would drop to 50% from 2013 to 2016, and to 30% up to 2020);
- support for market uptake and technical progress through pre-commercial procurement of high-performance systems beyond the state of the art;
- taxation of fossil fuels, to account for the environmental damage caused by conventional modes of electricity production and raise the price of electricity.

A wide range of instruments have been implemented in different national contexts. The most widely used are presented in Table 3.2.

Table 3.2. Policy instruments to support micro-CHP

Type of instrument	Objectives and means	Example
Research programmes	Supporting progress in material, component and system performance	NIP (Germany) SECA (United States) ANR (France)
Demonstration programmes	Revealing and testing the performance of systems based on newly developed technologies in real operating conditions	GECOPAC (1 SOFC unit) demonstration project supported by Ademe (France)
Field-test/ lighthouse demonstration projects	Test simultaneously and in parallel numerous systems in order to test reliability, consumer acceptance, and initiation of economies of scale and the learning curve	Callux project (Germany)
Feed-in tariffs	Guarantee throughout a certain period a bonus added to the market electricity price or a superior guaranteed price for each kWh fed in the grid	CHP 2002 and 2008 Law (Germany) Renewable energy Law (*Erneuerbare*-Energien-*Gesetz, EEG*)
Regulations	Guarantee CHP technologies favourable (access to grid, interconnection standards) or constraining conditions (technical requirements to access to the grid)	*Real Decreto 436/2004* (Spain) Energy Policy Act which urges states to implement interconnection standards (United States)
Upfront investment or financial support	Subsidy provided to end users or investors to offset partially or totally the high cost of new innovative solutions	Impulse programme (Germany)
Utility supply obligations	Impose utility to purchase obligation on electricity suppliers, based on a system of certificates	Belgium – Wallonia (with certificates based on CO_2 emissions)
Planning, governance and co-ordination	Co-ordinate public and private investments and strategic plans Reduce uncertainty, create consensus	FCCJ Fuel cell roadmap (Japan) European platform fuel cell strategic research agenda (EU)

Source: Technopolis Group.

The deployment of micro-CHP fuel cells in Germany

This section investigates the deployment of micro-CHP fuel cells in Germany. It aims to assess the extent to which, and how, different public policies have influenced the trajectory of this technology. Public intervention is addressed following an analysis of the overall context of eco-innovation and new energy technologies in Germany.

Wherever possible and relevant, information on other countries or other sectors in Germany is provided as an element of comparison. For the sake of comparison, an overview of micro-CHP fuel cells in France is presented in a separate section.

The diffusion of new energy innovations

The overall strategy for eco-innovation

The main German eco-innovation-related policy is the High-Tech Strategy, which identified 17 priorities for preferential funding. The High-Tech Strategy aims to foster lead markets, industry, science and sound framework conditions for innovation. The strategy defines five lead markets. One concerns climate change and deals notably with energy technologies, including fuel cells. For example, the strategy launched a batch of initiatives under the National Hydrogen and Fuel Cells Technology Innovation Programme (NIP).

As part of its national sustainability strategy and the High-Tech Strategy, the federal government has created a plan which includes climate and resource protection targets:

- Climate protection and adaptation to climate change. As the German contribution to an international climate protection agreement after 2012, the federal government has offered to lower greenhouse gas emissions to 40% below 1990 levels by 2020. This offer is made on the condition that the European Union lowers its emissions to 30% below 1990 levels within the same period.
- Economical and efficient use of resources. Energy productivity in Germany is to be doubled by 2020 (compared to 1990). A further target is to double raw materials efficiency by the same year (compared to 1994).
- Sustainable and future-proof energy supply. The proportion of renewable energies is to be increased to 10% of total primary energy consumption and at least 30% of electricity consumption by 2010. By 2050, renewable energies are to cover approximately half of primary energy consumption.

The federal government launched a comprehensive package of energy and climate policy measures in December 2007, the Integrated Energy and Climate Programme (IEKP). The package contains 29 measures, especially for increased energy efficiency and more renewable energy. It combines legal changes and investments in research and development. Measures include the amendment of the Combined Heat and Power Act, amendments to the Energy Conservation Act and the Energy Conservation Ordinance (EnEV), and amendments to the Renewable Energy Sources Act (EEG) and the Renewable Energies Heat Act (EEWärmG). Also included are measures for the facilitation of biogas feed-in, a law governing the expansion of the

extra-high voltage grid, and the transition from the current motor vehicle tax to a tax system based on pollutant and CO_2 emissions.

Launched in 2005, the High-Tech Strategy for Climate Protection brought different measures and stakeholders in the area of climate protection together in a single, interdisciplinary approach. As part of the High-Tech Strategy, it brought together partners from science, industry and policy to lay down the foundations for state-of-the-art, resource-efficient technologies:

- expanding the knowledge base as a prerequisite for climate protection and adaptation (*e.g.* through reliable climate prognoses and improved short-range weather forecasts, especially for extreme weather events);
- research, development and demonstration projects that help improve the technological outlook for climate protection and strengthen Germany's position in this important future international market;
- making knowledge about climate change and its impact more accessible to decision makers in industry and politics (*e.g.* through the establishment of the Climate Service Center);
- taking on global responsibility via international dialogue and collaboration.

In view of the current global challenges, research activities, particularly in the fields of climate and resource protection, climate adaptation and the environment, should have a strong international orientation. For this reason, research activities should be internationally co-ordinated.

The German renewable energy industries

Although fuel cells are not a renewable energy technology *per se*, they are a fair indicator of the status of environmental technologies.

The German renewable energies sector (RES) is one of the biggest in the world, notably in the fields of photovoltaics and wind energy. According to the German Foreign Trade and Inward Investment Agency (*www.gtai.com*), the national RES industry generated EUR 30 billion in revenues in 2008, over EUR 9 billion in exports, over EUR 13 billion in domestic investment and over EUR 15 billion in government R&D investment. The German RES industry occupies around 280 000 people, and nearly 800 000 work in the larger German environment technology sector.

Germany is far above any other European country in terms of R&D expenditures on renewable energy and even more in terms of patents. Based

on these crude indicators, Germany seems not only particularly active but also very effective in transforming investments into technological comparative advantage in the renewable sector.

CHP technology in Germany

Germany is the European country with the largest number of classical micro-CHP units. Reciprocating engines are commercially available and produced in large numbers. Senertec-Baxi-Group's Dachs model and Vaillant's Ecopower model are the most widely diffused. Around 2005-06, 1 938 classic CHP units were owned, of which 836 by auto producers and 1 102 by utilities. The former Baxi-Group and Vaillant are both in the world's top five largest boiler manufacturers.

Germany has therefore considerable experience in CHP technology, owing in part to the supportive environment established by the government. In 2005, CHP, qualified as "highly efficient", accounted for 21 GW of installed capacity and amounted to 12.6% of total electricity generation. The feed-in tariff provided incentives that encouraged the pioneer CHP market.

Fuel cells in Germany

Germany's traditional strength in car manufacturing and its strong cultural interest in environmental technologies, combined with a world-class scientific community and strong engineering skills, have resulted in its undisputed position as European leader in hydrogen and fuel cell development. France follows with a much more unbalanced and incomplete value chain (excellent research, comparatively weaker industrial base).

The German fuel cell arena is also distinguished by many demonstration projects, especially in the period 2000-06, such as the two hydrogen-refuelling stations at Munich Airport to support three buses and a fleet of hydrogen-powered BMWs (direct hydrogen, not fuel-cell powered). Another noticeable initiative is the Clean Energy Partnership initiative in Berlin, which involves the installation of a refuelling station for up to 30 fuel cell cars. It is estimated that about three-quarters of all fuel cells demonstrated in Europe during this period were operated in Germany, mostly for transport applications (Fuel Cells 2000, 2007). A similar figure is provided by IEA (2004), according to which "more than 70 percent of today's European fuel cell demonstration units are in Germany". In total, the country's fuel cell industry employed an estimated 3 000 people.

This leading position is clearly demonstrated by German research performance in the European Commission's Sixth Framework Programme (FP6). In the fuel cell sub-area of the Energy thematic, Germany is far ahead

of other European countries, both in terms of number of projects and volume of funds received from the Commission (three times more than the United Kingdom, in second place). It is also remarkable that the funds are evenly split between industry and research organisations (each with about a 40% EC contribution). By contrast, the major share of the FP6 funds allocated to French participants goes to research organisations (77%, against an industry share of 17%).

Micro-CHP fuel cells market and industry in Germany

Recent history of micro-CHP fuel cells in Germany

Two major periods can be distinguished in the history of FC-based micro-CHP technology in Germany. The first, from 1999 to 2006, emphasised basic R&D, notably in large universities throughout the country (*e.g.* Jülich IEF-PBZ) or public research organisations (*e.g.* the Fraunhofer institute in Dresden). At that time work on FC-based micro-CHP mainly concerned integration of the fuel cell in the micro-CHP system. Driven by mobile automotive fuel cell applications, developers of materials and components saw new opportunities in home energy markets and especially micro-CHP technology. Industrial companies worked on their own programmes or in co-operative partnership with public research organisations and universities to cluster and integrate the knowledge. Since the beginning, fuel cell developers have co-operated with major boiler manufacturers to ensure a broader market in the energy market. In 2002, based on the Plug Power fuel cell stack, Vaillant was able to show the first prototype of FC-based micro-CHP. During this period, the entire fuel cell sector benefited from very positive expectations built on the "hydrogen economy" dogma: most companies believed they could deliver products around 2010.

The second period, from 2005, is the time of "disillusion" with research progress. R&D actors made further improvements to the systems but actors faced market entry problems. First, despite progress, serious scientific barriers (in particular related to persisting challenges of durability and costs) appeared along the technological trajectory. Basic research therefore continues. However, in parallel, refinement challenges arose, leading the whole value chain to understand the need to field-test the prototypes, instead of focusing only on R&D. Indeed, technical aspects (durability, electrical performance or cost of components) were still not good enough for market entry in 2010. As a result, in 2008, a large-scale residential fuel cell field-testing project, Callux, was set up in the newly implemented initiative NOW GmbH. Almost the whole value chain – system developers and integrators, utilities, suppliers and public research organisations – contributes to this

unprecedented field-testing project. Prototypes of small-scale fuel cells are now being tested throughout the country and supported by utilities, energy suppliers, manufacturers and R&D teams. The goal is to have a product close to market entry around 2015.

Current state of micro-CHP fuel cell technologies in Germany

The FC-based micro-CHP technology in Germany is now in a field-test phase to refine performance. FC-based micro-CHP is not yet commercially available.

Germany is now at a crossroad concerning the choice of the best adapted type and size of technology for market entry. The co-ordinated research and field-test activities should support critical choices that condition the future of micro-CHP fuel cells in Germany:

- The correct sizing and specifications of the FC-based micro-CHP units is a key issue. The goal of the German current field-testing phase is to refine specifications and produce a FC-based micro-CHP unit close to market entry requirements.
- The selection of the best fuel cell option for small-scale residential applications. Currently, both PEM and SOFC technologies are being tested in Germany for micro-CHP applications. It recently appeared that the PEM technology faces more scientific bottlenecks (membranes and electro-catalysis issues) than the SOFC technology (lifetime issues). According to interviews, the PEM technology might be better suited for bigger units (more than 5 kWe) than for 1 kWe home-scale micro-CHP. According to the literature review and interviews, scientific and market perspectives seem greater for SOFC solutions around modules of 1 kWe (Harrison, 2008). Five or six competing technologies are investigated in current field tests, all of which have specific pros and cons. Nevertheless, three developments dominate the demonstration activities:
  - 1 kWe/1.7 kWth (kilowatts thermal low temperature PEMFC system from Baxi Innotech;
  - 1 kWe/3 kWth SOFC system from Hexis;
  - 1 k We/approx 20 kWth SOFC system from Vaillant.

A third option was proposed by Vaillant in December 2009: the 5 kWe/7 kWth high-temperature PEMFC system.

Germany is also testing the feasibility of networked micro-CHP systems (Virtual Power Plant – VPP) under the control of a monitoring station (partially funded by the EU).

Safety standards, connection to grid standards and regulations are being discussed and tested. For example, energy suppliers initiated in 2009 two working groups to discuss technical specificities for CHP operations: the FNN working group (grid stabilisation) and the TAB working group (grid access technical specificities).

The German micro-CHP fuel cell value chain

According to the literature and interviews, the German FC-based micro-CHP value chain is one of the most comprehensive in Europe, and it is efficient enough to permit the development of the technology trajectory. Moreover, this value chain is now becoming more integrated thanks to recent institutional changes, especially the creation and set-up of the NOW organisation and the NIP programme. Even it if it is still not comparable to the compact Japanese value chain model, Germany tends to shorten its value chain by associating key actors from downstream stages early in the process of developing the technology.

The German fuel cell industry includes companies from a wide variety of technology-based sectors. It comprises material science for technological breakthroughs, basic engineering for balance of plant, and downstream heating engineering and utility companies to support market entry. When a key value chain actor is missing in a given network, German manufacturers establish international partnerships with Japanese, Canadian or US companies. For example the German equipment manufacturer Vaillant developed its FC-based micro-CHP unit in partnership with the US stack developer Plug Power. In the same pragmatic way, Vaillant is now developing its SOFC micro-CHP with the German IKTS Fraunhofer Institute.

The role of German energy suppliers and operators is vital, notably in long-term contracting with consumers. Companies such as E.ON Ruhr Gas, EWE, EnBW, MVV Energie or Verbdunnetz Gas AG are essential to make the link between field tests and market entry. As noted, their commitment to product development is a key factor: they have been involved in R&D partnerships (with major key players) over the last ten years. Large energy suppliers (such as EnBW) are also active in the German demonstration programme (each energy supplier is responsible for its segment).

Major boiler manufacturers and systems integrators have ambitious strategies in the micro-CHP fuel cell business. Interviews confirmed their

desire to take advantage of this potential market. Three major heating energy manufacturing companies involved with FC-based micro-CHP technology have been key players for almost a decade. These manufacturers now have several years of experience with the operation of well over 100 appliances:

- Vaillant is one of the historical developers of FC-based micro-CHP technology in Germany. It is an international company with a focus on heating and air-conditioning technologies. In 2007 the group achieved sales of about EUR 2.4 billion with 12 400 employees. Vaillant micro-CHP activities were mainly based on the ICE-based Ecopower unit but the company is now developing FC-based solutions. Vaillant has been developing the PEM technology since 1999 and is a leader in this segment. It has also worked on the SOFC technology since 2006. The company defines itself as a system integrator but is deepening its development effort (for the SOFC technology). More than 60 PEM fuel-cell heating products are being tested in Europe (including 31 connected as a VPP). The fuel cell component comes from the US Plug Power but Vaillant is also working with Webasto for the SOFC. Vaillant is leading further development of the high-temperature PEM fuel cell with BASF and the IKTS Fraunhofer Institute for the SOFC unit. According to interviews, Vaillant began development of high-temperature PEMFC in November 2009.

- BAXI-Innotech: The fuel cell division of Baxi (ex-Fuel Cell Europe) developed the Senertec ICE-based micro-CHP unit. Baxi is currently working on an FC-based mini-CHP called Gamma 1.0 in partnership with Ballard for the fuel cell stack; Baxi has been taken over by De Dietrich (Netherlands).

- Hexis AG is a Swiss company with its main market in Germany and Austria. Hexis is now an independent start-up, but formerly belonged to the Sulzer Group. The company develops and integrates all components. Following a decrease in activity after leaving the Sulzer Group, the company has recovered and is now a reference in the 1 kWe segment. HEXIS developed the "Galileo 1000N" fuel-cell heating system, producing a 1 kWe and 2.5 kW thermal output. The Galileo fuel cell is now being tested in co-operation with EWE, E.ON Energie, EnBW and GVM in Germany in the Callux programme. Commercial use is expected in 2011-12, provided that the five-year stack durability is proven.

Major manufacturers such as Buderus or Viesman are awaiting further developments before becoming involved in R&D activities. Viesman used to

be a major player for fuel cell activities but now is waiting for field-test results.

German fuel cell research is often described as excellent in terms of achievements and services (*e.g.* Jülich, OWI, DLR IKTS, Fraunhofer, etc.). Partnerships between public research organisations and the private sector seem effective, despite some research segmentation which could lead to a disjointed picture of FC-related research in Germany. German private research organisations are also deeply involved with R&D activities (*e.g.* Eifer, IFEU, IZES).

Public strategy and modes of intervention

The literature on energy innovations and FC-based micro-CHP technology emphasises the key role of the public sector. The innovation path of FC-based micro-CHP is essentially influenced by institutional structures in the field of implementation (Pehnt *et al*., 2004, 2006). This section describes the main supply-side and demand-side public policies to foster the FC-based micro-CHP industry and market. The mixing and timing of German public policy instruments are also analysed.

Fuel cell research and demonstration budget

According to the German Federal Ministry of Economics and Technology, fuel cell activities were funded at around EUR 200 million between 1974 and 2003. In the mid-2000s, Germany had the highest public funding level in Europe, evaluated at EUR 72 million for both the government and the *Länder* in 2005 (European Commission, 2006) (France was second with EUR 60 million).

In 2006, the budget was estimated at EUR 80 million (EUR 60 million from ministries and EUR 20 million from states). Since 2007, the federal innovation programme for hydrogen and fuel cell technology alone (*i.e.* not including state funding and other sources of government funding) provides an overall budget of over EUR 50 million a year out of a total of EUR 200 million for R&D and EUR 500 million for demonstration and market preparation from 2007 to 2016 in the areas of fuel cell, hydrogen production, storage, and infrastructure (German National Innovation Program NIP). The total budget for fuel cells from 2007 is about EUR 115 million (Hesse, 2007).

Some elements of comparison regarding the R&D budget in the United States, Japan and European Commission are provided in Box 3.1.

Box 3.1. Fuel-cell R&D budget of the United States, Japan and the European Commission

The budget of the Department of Energy (DOE) (including USD 167 million EERE [Office of Energy Efficiency and Renewable Energy] basic energy science departmental funding and the federal contribution to the freedom car) was USD 235 million in 2005. This amount does not include other departmental funding (missing of course is Department of Defense funding, as well as non-federal public funding which may be significant in New York City, California and Massachusetts).

The 2010 DOE dedicated fuel cell budget was significantly diminished. The White House decided to put an end to funding for hydrogen fuel cell vehicle research (it proposed a reduction of about 60%, a cut of USD 100 million) while keeping research into stationary and military fuel cells. Congress fought back and the budget was saved to some extent. Nonetheless, the 2010 fuel cell research budget decrease is significant. However, the DOE research budget for hybrid electric vehicles was increased (by USD 39 million) as was that for biofuels.

Source: US Department of Energy, various sources.

In Japan in 2005, the METI budget (through the NEDO agency) to fuel cells and H2 was USD 260 million.

The EC contribution to fuel cell and H2 research and technological development has risen dramatically in the last 15 years: from EUR 8 million in FP2, the budget has more than doubled for every new Framework Programme. For FP5 and FP6 it reached EUR 145 million and EUR 300 million, respectively. These amounts represent about EUR 30 million and EUR 60 million a year in FP5 and FP6, respectively. German participants received about EUR 30 million in FP6, hence nearly EUR 6 million a year.

Source: European Commission (2006), "The state and prospects of European energy research: comparison of Commission, member and non member states R&D portfolios", European Commission, EUR 2239.

The supply-side instruments

A significant volume of basic R&D deals with topics relevant to fuel cell process and system analysis, analytics, production engineering, electrochemistry, modelling and simulation, catalysis and reaction engineering, and process and system engineering.

Basic research on fuel cells was carried out between 2001 and 2005 under the ZIP Programme (Programme of Investments for the Future) which aimed at accelerating the development and deployment of key hydrogen

technologies, including fuel cells. Under this programme, the public authorities allocated EUR 120 million to develop and integrate fuel cell components, and adapt them to application requirements. The ZIP Programme facilitated further expansion of fuel cell development especially for micro-CHP applications.

Today basic research on fuel cells is mostly funded under the 5th Federal Government Energy Research Programme, which is co-ordinated by the Jülich Research Center.[8] More downstream activities, R&D, demonstration and field testing are funded under the NIP programme.

The 5th federal government energy research programme

The major goals of the 5th Federal Government Energy Research Programme are consistent with the German National Strategy for Sustainable Development and the National Climate Protection Programme:

- maintenance of a well-balanced energy mix;
- improved energy efficiency;
- an increased share of renewable energies;
- improved flexibility of the future energy supply by securing and expanding technological options;
- other political objectives such as economic growth, increased employment, environment and climate protection.

The 5th Federal Government Energy Research Programme aims to rationalise the use of energy by promoting CHP, clean coal technologies, storage, energy-efficient buildings and fuel cell technologies. On behalf of several federal ministries, Project Management Jülich supervises substantial parts of energy research funding, including the funding programmes for renewable energies, rational energy use and power plant technologies. According to the Federal Ministry of Economics and Technology, the programme was financed for EUR 96 million in 2008. Fuel cell activities account for 24% (around EUR 22 million).

The German strategic objectives for supply-side instruments are co-ordinated under the 5th Federal Government Energy Research Programme.

The NIP programme and the NOW co-ordination organisation

Since 2005, the major instrument for developing the FC-based micro-CHP technology has been the NIP programme (National Hydrogen and Fuel Cell Technology Innovation Programme), which mainly aims to develop

applied research and field testing. NIP was set up just after the ZIP programme to prepare the market for hydrogen and fuel cell technology in the fields of transport, buildings, industrial applications and special markets. It is an alliance of several federal ministries: BMVBS, BMWi and BMBF and the BMU (environment). For political reasons, the NIP programme began two years later than initially planned.

Designed as a ten-year programme (2007-16), the NIP provides focused support to applied fuel cell R&D projects, field-testing activities and market preparation. The industry welcomed this initiative at a time when the situation was fragmented (different norms, technology types, partnerships, etc.). Developers and energy suppliers understood the need for a large co-ordinated programme (see Box 3.2).

Box 3.2.The NOW co-ordination organisation for the NIP programme

The NOW co-ordination organisation (*Nationale Organisation Wasserstoff und Brennstoffzellen Technologie GmbH*) was founded in 2008 as a private organisation. It acts like a consultancy wholly financed by the government. Its task is to co-ordinate and implement the German NIP programme to 2016. This includes evaluations and selection of projects, in particular for field test activities, linking research and development with demonstration, international co-operation, communication and knowledge management. Prior to its creation, most stakeholders called for a comprehensive and co-ordinated public strategy. The NOW organisation is the direct answer to these needs.

The public and central positioning of NOW is viewed positively by most interviewees, although some would like to see a more aggressive structuring role. However the "influence" of NOW on the political sphere may not meet private-sector expectations. While quite recent, NOW is expected to be of great help for supporting the pre-commercialisation phase and market entry of the FC-based micro-CHP technology, for instance, through the intervention of the Brennstoffzelle (IBZ) Initiative. The role of the IBZ is to organise, support and promote the NIP programme for stationary home-energy supply. IBZ is a privately promoted organisation of heating manufacturers and energy suppliers. IBZ is notably dedicated to the pre-commercialisation and post-field-test phase. The IBZ initiative is becoming less important. By encompassing the actors of the whole value chain, NOW presently has a central role in the structuring of the institutional landscape. It also has a structuring role by co-financing all of the projects, notably the Callux field-test projects.

The public budget amounts to around EUR 500 million for ten years and is expected to get an additional EUR 500 million from the private sector (see Callux budget). The work programme has two major goals:

- continue and expand targeted R&D, ranging from basic research to demonstration projects (notably by drawing an agenda);
- establish and expand demonstration and lighthouse projects for the purpose of commercialisation (65% of the overall budget).

There were lengthy discussions on the priorities of the German NIP programme during the inception phase. Public research organisations wanted to continue basic research, while the private sector wanted to launch the demonstration phase. Indeed, almost all the boiler manufacturers in 2005 had developed a micro-CHP fuel cell prototype. After fierce discussions between the different actors, it was agreed that the industry would provide half of the funding for NIP.

According to the interviews, the interaction between basic research and technical development works well in Germany, especially in the fuel cell sector. Moreover, capacity building of basic research actors was a key driver for further research developments. Today, basic research activities are decreasing and research organisations seem oriented to more focused and applied research.

The Callux field test programme

The Callux programme is the major field test programme in support of the FC-based micro-CHP programme. Part of the NIP programme, Callux is managed by NOW. The goal is to test 800 fuel cell units in Germany by 2012. Around 180 fuel cell micro-CHP plants are already being tested in 2010. This programme has gained high visibility in recent years. It aims to:

- demonstrate technical maturity;
- support further improvements to ensure commercialisation;
- develop the supply chain (by winning binding orders for large number of actors);
- refine product specification on the market;
- support training of market partners;
- validate requirements against end users and the market;
- promote the fuel cell pattern.

The NIP finances 48% (EUR 41 million) of Callux projects and the private sector 52% (EUR 45 million). In a first period Callux focused on four German regions (Oldenburg, Essen, Leipzig and Mannheim). Beyond the field-testing activities, Callux has a clear clustering and information exchange role and aims to bring the product closer to the market.

According to all interviews, the Callux programme appeared at the right time with the right structure. Callux was able to bring together the major FC-based micro-CHP key players: EnBW, E.ON, EWE, MVV, VGG, Baxi, Hexis, Vaillant and ZSW. FC-based micro-CHP actors understand the innovation scheme as a perpetual loop. Manufacturers and energy suppliers understand that after the demonstration phase, they need to return to applied research to improve performance. According to the manufacturers, Callux already has had a significant impact, notably on setting technical requirements, performance, synergies and qualification.

In clear contrast with other countries, the Callux project allows for testing FC-based micro-CHP plants based on foreign fuel cell technologies.

Demand-side instruments

Due to the early stage of the FC-based micro-CHP technology, demand-side instruments currently have little ability to pull the technology closer to the market. The FC-based micro-CHP benefits from specific treatment under the following incentives schemes:

- the 2002 CHP law and its feed-in tariff;
- the Impulse programme managed by Federal Office of Economics and Export Control (BAFA);
- the renewables heat law compensation measure for CHP devices;
- the German building code targets.

The 2002 and 2008 CHP Law

The 2002 CHP Law provides the core of Germany CHP policy. The goal is to achieve a reduction of 23 Mt (metric tonnes) of CO_2 emissions by the end of 2010 (compared to 1998) by modernising existing CHP installations and promoting the operation and commercialisation of new CHP plants.

The CHP law's total budget until 2010 is almost EUR 4.5 billion with EUR 358 million earmarked for fuel cells. It supports CHP plants through a guaranteed bonus tariff for cogenerated electricity.

A new CHP Law approved in July 2008 amends the 2002 law. It aims to save 54 Mt of CO_2 a year, provided the economic potential of these technologies is achieved. The new CHP Law continues to support CHP through tariffs on the electricity price.

Under the CHP Law, network operators are obliged to connect CHP plants to their system and to buy their electricity at a "normal" price, unless agreed otherwise in a bilateral contact with the CHP plant operator. The normal price is defined as the average base-load electricity price of the European Energy Exchange (EEX in Leipzig) over the previous quarter. CHP plants also receive from the government a bonus on the electricity they supply to public electricity networks. The fuel cell bonus is 5.11 ct/kWh (for ten years after becoming operational). The bonus is valid for installations starting operations between April 2002 and December 2016.

Despite the specific treatment, in the end the fuel cell bonus is the same as the classic CHP bonus (5.11 ct/kWh) under the CHP Law. According to the interviews, fuel cell feed-in tariffs would eventually have an effect, but this is not measurable during the field test phases. Different opinions exist about the supportive effect of this kind of instrument, especially for FC-based units. According to Cames *et al.* (2005) as fuel cells are still in the stage of product development and field testing, this bonus will not be sufficient to lift FC-based micro-CHP technology over the break-even point and facilitate market introduction. Moreover, the bonus does not take into account the real value of micro-CHP electricity. On the contrary, some boiler developers claimed that the current difference between feed-in tariffs (output) and the price of natural gas (input) is sufficient to cover the high acquisition costs over the expected lifetime of the system. However, feed-in tariffs make micro-CHP fuel cells only profitable when life-cycle costs are considered, which is still not very common among end users.

Moreover, CHP is compensated for the network costs for electricity that are avoided. This bonus is additional to the fuel cell feed-in tariff.

In addition to the CHP Law, CHP units using biogas can benefit from the Renewable Energy Law (*Erneuerbare*-Energien-*Gesetz EEG*), which came into force in 2004. The feed-in tariffs enforced by this law can add up to 27.67 ct/kWh to the price of electricity. The level of compensation is guaranteed for 20 years. This incentive is recognised for its contribution to the development of medium- to large-scale biogas CHP units: the installed capacity reached 1 200 MW in 2007, from less than 200 MW in 2000.

The Impulse programme

The Impulse programme (BMU Mini-Kwk Anlagen) is another incentive programme managed by the BAFA with financial incentives of up to EUR 1 650/kWe for micro-CHP units, including fuel cells (Box 3.3). From 0 to 4 kWe units, the incentive is fixed at EUR 1 650. The amount of the incentives decreases with the volume of production. According to interviews, this incentive could have a strong effect on customer decisions and significantly reduce the energy bill.

Box 3.3. Features of the Impulse programme

Basic requirements:

- plant producing up to 50 kWe
- in line with EU CHPP directive, Clean Air Act
- functioning plant
- integrated electricity meter.

The basic support funds all new micro-CHP plants that meet the performance and price ranges:

Power range	Per kWe – cumulative
From 0 to 4 kWe	EUR 1 650
From 4 to 4 kWe	EUR 775
From 6 to 12 kWe	EUR 250
Etc.	Etc.

For example, for a 10 kW plant the subsidy will be EUR 8 850 (1 650*4 + 2*775 + 4*250)

The bonus promotion is granted for plants with very low emissions (including fuel cells), which meet the requirements of half of the value of the current Clean Air Act for NOx and CO_2. A plant providing from 0 to 12 kW will receive additional funding of EUR 100 per kW.

An additional factor – called VbH – takes into account the number of working hours of the plant.

Source: BMU Min-KWK Factsheet.

Other demand-side instruments

Other demand-side instruments include:

- The owners of CHP plants are exempted from the ecotax for mineral oil if their load factor is over 70%. Since the power sector is exempted from the ecotax, this advantage only covers the boiler fuel avoided. However, the amount of tax avoided on gas or heating oil for boilers can be quite substantial, up to EUR 2 million a year for a large CHP plant. In practice, it seems difficult to activate this tax exemption owing to administrative obstacles (Meixner and Stein, 2002, quoted by Cames *et al*., 2005).

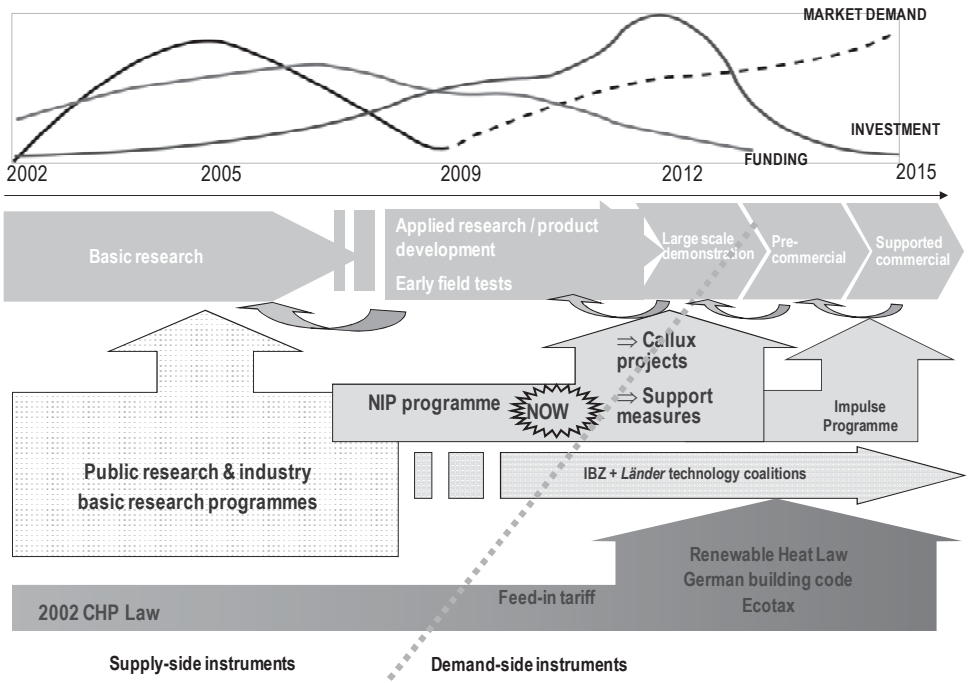
- The Renewable Heat Law requires owners of new buildings to ensure that part of the building's heat demand is supplied by renewable energies. To ensure coherence with energy efficiency policies, buildings that are supplied by CHP systems are exempted from this obligation.

- The German building code consistently targets reduction of primary energy use (instead of final energy use). Heat supply options are rated by primary energy factors which reflect the fossil-fuel content. The default value used for CHP is 0.7, compared to the value of 1.3 for natural-gas-fired boilers and 3.0 for electricity. The code has been criticised because it includes a built-in trade-off between efficient heating systems and building insulation, rather than promoting both at the same time and thereby reaching higher efficiency gains (Cames et al., 2005).

According to Pehnt *et al*. (2006), the institutional setting for micro-CHP in Germany is ambivalent, with an intricate mix of advantageous and disadvantageous measures for micro-CHP.

On the one hand, many regulations in place provide direct incentives to micro-CHP or contain favourable conditions for distributed generation, efficient energy use or for CHP in general, which have indirect positive effects for micro-CHP. On the other hand, some of these formal regulations are ineffective because they are not properly enforced, or because they are overshadowed by more fragmented and informal institutional settings, which may be felt as an encroachment by micro-CHP investors, operators and users.

Figure 3.3. German supply-side and demand-side instruments



Note: Funding and investment curves are based on a presentation by NOW; Market demand is a rough appreciation of the market perspective based on literature review.

Source: Technopolis Group.

The fragmentation of the demand-side instruments and policies was underlined during interviews. Although this is not yet a problem, it could become one in the future. For example, although the 2002 CHP Law is a positive instrument, as it forces operators to connect CHP units to the grid, existing utilities may have an interest in hindering the development of distributed energy. They can do so through under-compensation of the avoided use of the grid or even directly by denying grid access through excessive technical requirements for grid access. Both literature review and interviews emphasise the lack of reliable enforcement of network access regulations. Dr. Pehnt proposes the creation of an independent regulatory authority.

According to interviews, because it is not yet the right time, the lack of focus on demand-side instruments for FC-based micro-CHP is not yet a problem for market entry. While the context for demand-side instruments

has improved considerably during the last decade it may call for strong improvements in the near future. Demand-side instruments seem slightly too early to have an effect on market demand.

A synthesis of the German supply-side and demand-side instruments that apply to micro-CHP fuel cells is presented in Figure 3.3.

The future of micro-CHP fuel cells in Germany

Prospects for the future

Opinions about the future of the FC-based micro-CHP technology in Germany are very diverse. A fair degree of disillusion was found when meeting actors. Further to several wrong projections in the past regarding fuel cell technologies, no actor is ready to give a precise market entry date. However, there is a clear consensus that the field-test phase and its transition to a new phase of early market entry will be crucial with regard to the technology's potential success. Should manufacturers and R&D actors succeed in solving the scientific bottlenecks and challenges by 2015, no major barriers should interfere with market entry since there are instruments, although imperfect, in place to support demand. According to interviews, most of these challenges could be solved during the current field-test phase. Nevertheless legal and regulatory barriers could slow down the technology trajectory.

Recommendations for improving public support

Different recommendations were collected in the literature review and during interviews. They are reported below:

- A political agenda would be well received by value chain actors. In order for market entry to happen around 2015, a decision should be taken now to take advantage of recent political changes. One of the key decisions to be taken concerns a credible engagement towards a decentralised energy system.
- The portfolio of policy instruments relevant to FC-based micro-CHP technology seems sensible in the German national context and well balanced. Supply-side instruments have been rationalised and now seem efficiently clustered. Demand-side instruments are already in place, but they could be simplified and streamlined to tackle upcoming issues. NOW could gain competencies to address these demand-side challenges, especially by offering a common structure to help customers with incentives or exemption procedures.

- Past examples of other technologies (*e.g.* RES) have demonstrated the importance of technological coalitions for preparing the pre-commercialisation and early market entry phases. Such technological coalitions do not exist at the national level in Germany for advocating micro-CHP fuel cells. The Japanese example is often quoted as best practice in this regard. A co-ordinated plan for the revision of regulatory and institutional barriers has been designed and implemented. The Fuel Cell Commercialization Conference of Japan (FCCJ) "coalition", in particular, has been very active in this initiative.
- Despite the good reputation of fuel cells in Germany, a massive campaign to educate, train and communicate the advantages of FC-based micro-CHP could be addressed to distributors, retailers and customers in order to prepare market entry.
- Supply-side activities have been significantly reformed during the last years to be more coherent, better co-ordinated and simplified. Demand-side support could now be reviewed and streamlined, notably for regulations and institutional issues. A dedicated agency might facilitate enhanced co-ordination of demand-side instruments.

The main drivers affecting micro-CHP fuel cell deployment

It is well known and well documented that it is necessary to co-ordinate the implementation of demand-side and supply-side instruments if the market and the technology are to evolve together. However, it is still not known how to fine-tune the mix of policy instruments, what would be an effective timetable to progressively ramp up market sales and industry production, and what attributes these instruments should have (*e.g.* level of ambition, scope of application).

The aim of the study of the deployment of micro-CHP fuel cells in Germany – the country in which micro-CHP fuel cells are closest to market entry – and its comparison with other countries, has been to explore these questions further. This section looks at the lessons learned; the findings are placed in a framework that conceptualises the policy needed to support the deployment of a learning curve on which the technology and the market develop together.

Main lessons learned from micro-CHP fuel cells in Germany

Germany has built upon its position of leader in environmental technologies to make significant steps forward in the micro-CHP fuel cell area. This technology has benefited from ambitious public initiatives, both

in terms of volume of financing and structure of governance. Micro-CHP fuel cells are not only supported by ambitious environmental policies, but also by a voluntary industrial policy to develop the whole value chain and install production capacity in the country. This relates to a strong specificity of German policy making, that is, the integration of environmental policy, innovation policy and other important policy area "as the way to promote eco-innovation and to open up leading markets for environmental technologies" (OECD, 2009).

Germany has also put in place very early in the technology trajectory instruments to develop not only the technology but also the market, such as reliable and rather generous feed-in tariffs and purchase subsidies. These demand-side policy tools have driven the involvement of important companies and research organisations in this technology. Germany now has a world-class scientific community in this area and, even more important, an industry base that covers the whole value chain.

These concrete achievements have taken place in the last ten years. Basically, two related shifts in German public and private strategies concerning fuel cells deserve to be highlighted:

- A shift from a "single-stage strategy", focused on R&D, toward a "multi-stage" strategy, which intends to combine, in a coherent manner, the development of the market and the refinement of the technology. The situation has never been clear-cut in Germany, which has a tradition of accompanying the market take-off of emerging technologies. Even during the first phase, a certain degree of effort was put into supporting the demand side. For instance, in 2002, Germany passed a law specifically to encourage the development of CHP: the Law on the Conservation, Modernisation and Development of CHP. It provided CHP operators with the statutory right to connect to a distribution grid and receive the market price, plus an additional bonus payment, plus an "avoided grid use" allowance.[9] However, as mentioned, the bulk of funding was targeted towards research. Only in recent years have large field testing campaigns been initiated.

- Increasing attention to demonstration went along with another, related shift: the focus of effort during the first phases was on longer-term transport applications. The emphasis is now more on nearer-term applications, such as FC-based CHP applications. From support to basic and applied research dedicated to long-term options, the priority is now also demonstration of early applications. Both R&D activities and initial field trials are being carried out.

Today Germany is perceived as one of the most attractive countries for micro-CHP investment. As a result, even foreign companies make their most ambitious strategic move in Germany. For instance, the Australian CFCL (micro-CHP fuel cell developer) has set up a EUR 12.4 million pilot factory for stack assembly. The factory's capacity should be 10 000 fuel cell stacks, with a plan to expand to 160 000 stacks on the same site. The *Land* has contributed about EUR 6 million to this investment.

Towards a learning curve policy strategy to develop eco-technologies

Germany has already been successful at "unblocking" eco-innovations such as photovoltaics. This has required a co-ordinated set of supply-side and demand-side policy initiatives. For micro-CHP fuel cells, as claimed earlier, Germany has already made significant steps on both sides.

Two key elements for spurring the trajectory are:

- A mix of policy tools to address the different challenges a technology faces in its different phases (diachronic axis) as well as in different components of the system of actors (synchronic axis).
- An overall structure of governance, or at least a forum of co-ordination and dialogue, in order to ensure a certain coherence in the overall system. This is of foremost importance in areas such as micro-CHP fuel cells where the value chain is long and complex. This should be related to the benefit of policy integration discussed earlier: the different areas of policy (environment, research, innovation, industry) should be integrated as much as possible to support eco-innovations.

A functional framework is proposed, based on these two basic principles of sound policy making for eco-innovation. Two strands of innovation have been distinguished: stationary and transport fuel cells. Their technical requirements and markets are different, while still allowing some knowledge spillovers, legitimacy effects and even economies of scale (on some specific components and materials) between the two "sub-trajectories".

These two strands are distinguished according to mileposts which correspond to different generations of technologies applied to different types of applications with increasing performance demands. The most demanding application in terms of performance is the fuel-cell powered electric vehicle.

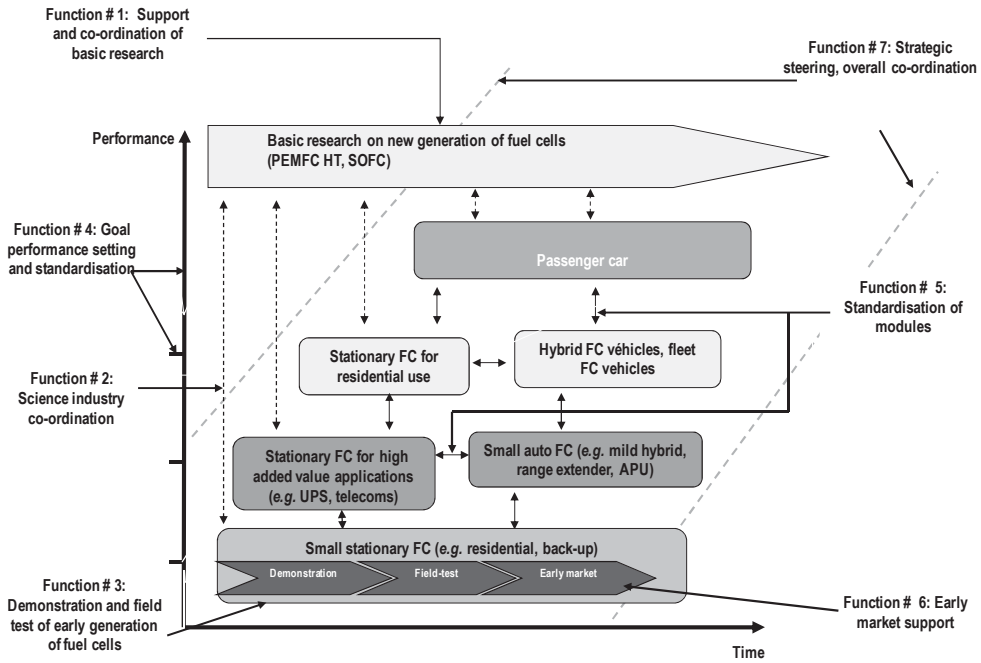
In accordance with the literature in innovation economics, research activities take place all along the trajectory, albeit with somewhat different roles: more exploratory at the start of each generation, more oriented to

problem solving later in the process. The German fuel cell case has shown that new "calls for science" occur at different stages of the trajectory as new bottlenecks are revealed (especially with regard to fuel cell durability, which can only be investigated in real operating conditions).

Based on this simple vision of the fuel cell learning curve, seven policy functions can be identified (Figure 3.4):

- Function 1: Support to and co-ordination of basic research. This function is well implemented in all advanced countries. The main difference lies in the degree of co-ordination of the different research institutions and projects and, more generally, in the level of integration of the research community.
- Function 2: Science-industry co-ordination. It is widely accepted that science-industry research must be encouraged through specific instruments, mostly the financing of co-operative projects.
- Function 3: Demonstration of early generations of fuel cells. This function is essential, as the German case study shows, in order to learn from tests in real conditions, raise awareness of the technology and support company development programmes. This function is now well addressed in Germany through the Callux programme, managed by the NOW organisation.
- Function 4: Performance setting and standardisation. In order to reduce uncertainty during the early years of a technological trajectory, it is important to harmonise and create consensus regarding the technical requirements of different groups of applications, at different milestones (such as those for residential applications set by the Fuel Cell Platform). The NIP programme has also been instrumental in this regard.
- Function 5: Standardisation of modules. In order to maximise economies of scale and various types of synergies, some research programmes aim to develop standardised multi-application fuel cell modules. This is the case of SECA (the largest SOFC programme in the United States).

Figure 3.4. Functional policy framework to support the unfolding of the fuel cell trajectory



Source: Technopolis Group.

- Function 6: Early market support. This type of intervention is different from demonstration and field tests, although learning effects are still expected at this stage of technology implementation. Different types of instruments exist to provide such support: pre-commercial procurement, bonuses, subsidies on price, sales incentives. In Germany attractive feed-in tariffs, with specific bonuses for fuel cell-based CHP, as well as sales incentives, have been put in place but it is too early to measure their impact as there is as yet no commercially available product.

- Function 7: Strategic steering. This function allows for co-ordination of the different stakeholders as well as, in some instances, the strategic orientation of their collective activities. The fuel cell technology brings together different industries (*e.g.* energy, materials, environment) which have no common governance structure (industry associations, councils, the well-known *shingikai*

in Japan and other forms of coalitions). This function in such emergent technological areas is therefore crucial. One of the best examples of such an institution is the FCCJ in Japan or the Hydrogen and Fuel Cell Technology (HFP) platform in Europe. Their role is to bring together all stakeholders in order to advise public authorities on R&D policy and regulations, draft roadmaps and research agendas, set commonly agreed performance goals, liaise with standardisation bodies, and raise awareness. Germany has not yet created such institutions. Several interviewees have called for such institutions to add coherence to the complex landscape of public initiatives to support fuel cells for micro-CHP and other applications.

Back to Germany…

Such a policy framework can be instrumental for investigating the current state of public support in different countries for different types of eco-innovation and exploring and benchmarking the different types of policy tools for each of these functions.

A rapid overview of policy support for fuel cells in the leading countries shows that no country currently implements a policy infrastructure that would cover all the aforementioned functions. The emphasis is still very much on the more upstream functions relating to basic and applied research and development (functions 1 and 2). However, as previously mentioned, the disillusion that followed the heavy investments made in research for fuel cell vehicles from 2000 to 2006 has paved the way for a stronger focus on downstream functions. The momentum starts with the demonstration of first generations of fuel cell technologies, especially those suited for stationary applications, including CHP applications. The next step is support for early market introduction. This step is more complicated as the choice and fine-tuning of the attributes of the different demand instruments are still debated.

As of today, the policy infrastructure is as follows:

- Function 1: Support to and co-ordination of basic research. Like all advanced countries, Germany still makes an important effort in basic research, as exemplified by the 5th Federal Government Energy Research Programme.
- Function 2: Science-industry co-ordination is especially developed in the NIP programme which funds both applied research and demonstration. Half of the funding is earmarked for industry.

- Function 3: Demonstration of early generations of fuel cells. No other country has put in place such an ambitious programme of field testing of micro-CHP fuel cells.
- Function 4: Performance setting and standardisation. Indicative performance targets are set at European level by the European HFP platform in its Research Agenda and its Deployment Strategy. The different programmes do not appear to set performance criteria that would be valid beyond each project frontier.
- Function 5: Standardisation of modules. No information was collected on this matter.
- Function 6: Early market support. Germany has set up incentives under the CHP Law (feed-in tariffs). More recently it has put in place the Impulse programme to subsidise consumer adoption of small CHP plants. It is still too early to assess the effectiveness of such measures. However, as mentioned, these instruments are still fragmented and poorly co-ordinated.
- Function 7: Strategic steering. Overall governance is still the main weakness of this comprehensive policy infrastructure. There is no organisation in which the different stakeholders can get together and reflect upon relevant collective actions and policy interventions.

Notes

1. *www.fuelcelleurope.org/index.php?m=7&sm=45*.
2. Fuel cells developed for the NASA space programme (Gemini 1 kW, Apollo 1.5 kW) in the 1960s and 1970s cost up to USD 600 000/kW and were impractical for terrestrial power applications. Their performance was highly debated, and some experts claimed they were responsible for the problems during the Apollo 13 mission.
3. See for instance a market forecast by Research and Markets in 2000 which claims that "Fuel cells will replace all alternative fuels by 2005. Fleet vehicle markets will evolve first. Vehicle fuel cell markets at $40.5 million in 2005 represent the beginning of commercial introduction of cars that use fuel cell systems. Markets are expected to reach $8.5 billion by 2011." See also the 2002 Canadian study undertaken by PricewaterhouseCoopers which claimed that global demand for fuel cells should be nearly CAD 46 billion in 2011 (PricewaterhouseCoopers, "Fuel Cells: The Opportunity for Canada", Fuel Cells Canada).
4. Or 25 million vehicles by 2030 according to a study from the US National Research Council in July 2008.
5. ANR H-PAC 2010 call for project proposal.
6. Baxi was bought by De Dietrich in October 2009.
7. Heat is of course used directly by users for their own convenience.
8. Jülich carries out research and manages research programmes under the authority of federal ministries. Fuel-cell R&D by Jülich over the last two decades is widely recognised as excellent and efficient. According to interviews, Jülich plays a key role in advancing the state of the art in FC-based micro-CHP. In addition, Project Management Jülich (PTJ) undertakes management of support programmes and research priorities for various contractors, for example the Federal Ministry of Education and Research (BMBF), the Federal Ministry of Economics and Labour (BMWA), the Federal Ministry for the Environment (BMU) and numerous federal state ministries and agencies.
9. The feed-in tariffs implemented under the CHP Law are described in greater detail below, in the section on demand-side instruments.

Annex 3.A1

List of interviews

Name	Organisation	Position
Antoine Loïc	ADEME	In charge of fuel cells and batteries
Dauensteiner Alexander	Vaillant GmbH	Head of Product Management Innovation
Edel Markus	EnBW	Energie Baden-Württemberg AG Projektleiter Brennstoffzellen
Esdaile-Bouquet Thomas	COGEN Europe	Public Affairs Manager
Freyd Claude	De Dietrich Thermique	Director of R&D
Gautier Ludmila	EIFER	Head of project
Golbach Adi	B.KWK e.V.	Managing Director
Hacque-Cosson Françoise	CEA Saclay	Deputy to the Director of New Technology for Energies
Junker Michel	Alphea Hydrogen Platform	Director
Klinder Kai	NOW GmbH	CFO Programme Management Stationary Fuel Cells
Lima Alexandre	VEOLIA Energy Research Centre	Fuel Cell expert
Mermilliod Nicole	CEA Grenoble	Strategic foresight and evaluation

Name	Organisation	Position
Monjau Roland	Berlin University of Technology	Research Assistant at Department of Energy Systems
Pehnt Martin	IFEU	Scientific Director, Head of Department "Energy"
Steinberger-Wilckens Robert	Planet Energie & Jülich GmbH	Senior Consultant & Head of Unit
Volker Nerlich	Hexis AG	Director Business Development
Wichmann Daniel	Oel-Waerme-Institut GmbH (OWI)	Abteilungsleiter Energiesysteme

Annex 3.A2

The added value of micro-CHP fuel cells

FC-based micro-CHP technology offers several benefits:

- Fuelled with hydrogen, fuel cells produce zero toxic emissions and no carbon dioxide at point of use. Moreover, hydrogen from renewable sources (biomass or "surplus" energy from intermittent sources) produces negligible emissions of greenhouse gas.
- Even if the hydrogen is sourced initially from fossil fuels, emissions are negligible, given the fuel cell's higher efficiency. However, potential emission gains are a highly debated issue among experts; emissions levels depend on the mode of production of the hydrogen and each country's policy mix.
- Because they are extremely clean and quiet, fuel cells can be used wherever power is needed, including in sensitive urban locations.
- Moreover, micro-CHP fuel cells contribute to the smooth process of transformation of the power generation portfolio.
- Micro-CHP fuel cells could complement renewable energies.
- They can have positive effects on the security of supply for electricity grids.
- The European fuel cells platform lists additional economic benefits:
- Job creation and development of small and medium enterprises (SMEs) for supply, installation, financing, operation and maintenance of CHP fuel cell systems;
- Cost savings to users.

In terms of system performance, as for all CHP systems, there are two major indicators for micro-CHP fuel cells: electrical efficiency and thermal efficiency. Usually, it is accepted that FC-based micro-CHP units may reach seasonal electric efficiencies of the order of 28% to 33% (and in the long

term 36%) and thermal efficiency of around 80%. (Energy conversion efficiency is the ratio between the useful output of an energy conversion machine and the input, in energy terms.) Despite the better performance of SOFC, the thermal performance of FC-based micro-CHP is the weak point of such systems compared to others.

Furthermore, the performance of micro-CHP depends not only on individual energy conversion devices but also on their integration into a larger system, as a "virtual power plant" (VPP). A VPP is a cluster of distributed generation installations (such as micro-CHP, wind-turbines, etc.) which are collectively run by a central control entity. Communication interfaces are necessary to be able to network the various VPP. The co-ordinated operating mode should offer an extra benefit in delivering peak load electricity or load-following power at short notice.

The performance goals for micro-CHP fuel cells are provided in Table 3A2.1, which shows that different levels of performance are required at different milestones of the technology trajectory. Increases in performance and decreases in costs are expected as the learning curve and economies of scale come into play.

Table 3.A2.1. Performance requirements for micro-CHP fuel cells for different stages of development

	Early field tests	Demonstration	Lighthouse and deployment
For stationary applications 1-10 kW (residential)			
Time frame	2006-08	2007-10	2009-12
Electrical efficiency @ BOL including DC/AC conversation	30%	32%	34%
Total efficiency BOL @ best point	>70%	75%	80%
System cost (EUR /kW)	20 000	10 000	4 000
Stack durability 90% BOL performance (h)	3 000	5 000	>10 000
Number of temperature start-ups from 15°C (l/a)	20	35	50

Source: Strategic Research Agenda, HFP Platform 2006.

Annex 3.A3

Leading countries in FC-based micro-CHP

Japan

Japan is the leading country in FC-based solutions and the world's biggest market in micro-CHP. Internal combustion engine (ICE) micro-CHP solutions are already on the market and many industrial actors and intermediaries are working to make FC-based solutions available on the mass market. Japan is the most interesting market and energy landscape for micro-CHP solutions:

- 60% of the country's electricity is produced from fossil energy;
- there is insufficient electricity production capacity (recurring consumption peaks);
- high energy dependency;
- the OECD area's highest electricity costs;
- gas market clustered around local or regional utilities (Osaka Gas, Tokyo gas, etc.) and open to competition since 1995.

Therefore, public authorities and energy utilities are encouraging micro-CHP technologies and industries. The Japanese private sector is a very active supporter of technology development: many energy utilities (12 throughout the country), and three large gas firms are active in fuel cell research for transport and micro-CHP.

The Japanese government has been very active in supporting micro-CHP systems. A subsidy of EUR 1 500 is given to end users and represents about 30% of the upfront costs of the system.[1] As a consequence, 22 000 classic micro-CHP systems had been sold by 2006. The Japanese government expected 200 000 products to be sold by 2010.

The Cass Business School, in addition to public support, also stressed several characteristics that are favourable to the wider deployment of micro-CHP in Japan (Hendry *et al*., 2006):

- a shorter industrial value chain (more integrated than those of the United States or Europe, as interview confirmed);
- greater effort for technology development/demonstration projects to adapt CHP to Japanese requirements;
- gas suppliers (*e.g.* Osaka Gas, Tokyo Gas) are more often implicated in FC-based micro-CHP R&D than in other countries;
- the presence of technological coalitions dedicated to the pre-commercialisation phase facilitates the spread of the technology;
- commercialisation of FC-based micro-CHP units is done through a leasing system, which motivates customers.

Japan has the clearest technological focus on FC-based micro-CHP (Brown *et al*., 2007), as evidenced by the highest number of working FC-based micro-CHP units: around 400 in 2006, mainly based on PEM technology. These fuel cells were built by Ebara Ballard, Matsushita, Toshiba and Sanyo. According to the literature (Slowe, 2006) and interviews, Japan is likely to continue to be the leading micro-CHP market in the world, at least in the near future.

North America

North America industry actors have been involved in micro-CHP for many years. US and Canadian research efforts in fuel cell technology are active (PlugPower and Nuvera for the United States and Ballard for Canada). Significant obstacles in the United States work against micro-CHP developments (cost, climate differences, differences in energy use). However, there are important FC-based micro-CHP programmes being developed in the states of California, Connecticut and New York. The US Energy Policy Act of 2005 included a first tax incentive for fuel cell power plants at the federal level. The US incentive has been drawn under a feed-in tariff scheme (with specific requirements, *e.g.* producing at least 0.5 kWe). The consumer who owns an FC-based micro-CHP plant can claim a credit of 1.5 ct/kWh over a five-year period. Other financial incentives exist in half of the US states. Other incentives relate to exemption from air quality permit requirements, portfolio standards for fuel cells, or metering deduction concerning grid access.

The Canadian government is tackling the issue more systematically. However, the source of funding mostly depends on corporations (47% of national R&D expenditure for fuel cell activities); public funding represents 16% of R&D expenditures (PricewaterhouseCoopers, 2008). Demonstration projects are being implemented notably in British Columbia, mostly funded by the Canadian government. Fuel cell transport activities dominate the sector.

France

CHP is underdeveloped in France when compared to neighbours such as Germany or Spain. Although France has endorsed the European objective to double the share of electricity produced by CHP (2004 Directive), it has hardly taken action. On the contrary, the number of new CHP installations decreases every year. CHP is very controversial in France: in 2006-07 two official reports to the government recommended against actively supporting these technologies because of their limited benefit. These conclusions have been debated since the argumentation is perceived as partial by several CHP advocates.

The recent large-scale collective reflection on environmental issues in France (*Grenelle de l'Environnement*) only addressed larger CHP solutions using biogas. A call for proposals was launched and 32 projects (out of 106) were selected, representing 25 MW; they will benefit from feed-in tariffs of EUR 145/MWh. Another call for proposals is expected in 2010 to support the installation of 800 MW (a CHP system >12MW).

Research activities

Research activities are primarily financed by the national research agency (ANR). The H-PAC programme has planned to dedicate EUR 7 million to a project for CHP fuel cell applications during the period 2009-11 (*e.g.* the projects CONDOR, Oxygène and CIEL, in all of which EDF or GDF-Suez have a key role,[2] and the European Commission project REALSOFC). It is worthwhile noticing that ANR has recently changed its strategy with regard to fuel cells. Although the focus was on transport applications in the past, it has now been decided only to support fuel cell research for stationary applications. The national energy agency ADEME also supports selected applied research projects such as GECOPAC.

However, the worldwide slump in fuel-cell activity has also affected France. One of the main research actors, the Atomic Energy Authority (CEA), which committed a very significant amount to research on fuel cells in the last ten years, has stepped back from SOFC research.[3] The CEA not

only suffered from the decrease in public financing for these technologies, but also from the lack of an industrial supplier base with which to co-operate.

The evolution of the number of fuel cell patents awarded by the French intellectual property (IP) organisation INPI is very telling: patent numbers were divided by two between 2005 (year of the peak) and 2009 (INPI, 2010).

Demonstration

Currently, no small-scale CHP fuel cells are being tested in France. From 2002 to 2005, Gaz de France tested five proton exchange membrane fuel cells, with support from ADEME. In 2004-05 EDF tested four others. Currently, only a few large-scale units are tested by gas and/or electric utility companies. These activities are limited and focus on R&D almost exclusively.

Potential support for demonstration of fuel cells could take place under the *Fonds démonstrateur* operated by ADEME. However, no fuel cell project is currently planned since the community is not yet prepared to endorse such a high-level effort.

Supplier base and system integrators

One of France's main weaknesses with regard to micro-CHP fuel cells is the absence of a supplier base to develop and demonstrate these products. No French company currently develops the key components of micro-CHP fuel or integrates fuel cell systems. The only integrator that has invested in these technologies in France is the Dutch company De Dietrich (boiler manufacturer, in collaboration with the Australian CFCL and EDF). However, it is clear for this company that the technology developed will be commercialised elsewhere, especially in Germany. A potentially important supplier is Saint Gobain, which intends to supply ceramics for SOFCs. The French start-ups that develop fuel cells do not target the micro-CHP applications: Axane develops and commercialises back-up systems; Hélion develops fuel cells and electrolysis devices for coupling with intermittent renewable energy systems;[4] Paxitech concentrates on test benches. Dalkia/Véolia only develops fuel cells for large CHP applications. All other companies involved (EDF, GDF-Suez) merely test systems in order to keep up with recent developments, assess the state of the art of fuel cells, and maintain sufficient absorptive capacity in-house.

The absence of a solid supply chain has consequences: public authorities have no incentive to propose generous schemes that would largely benefit

foreign companies; there is no powerful lobby (contrary to the photovoltaics industry for instance) that would pave the way to political decisions; demonstration and field testing are not possible; co-operation between research institutes and industry cannot be set up.

Barriers to the development of micro-CHP fuel cells in France

Since the French energy mix is dominated by cheap electricity which does not release CO_2, the added value of the micro-CHP fuel cells is very small, as was claimed in all interviews. Basically, the window of opportunity for this technology in France is very narrow: it is of interest only to compete with conventional (fossil-fuel-fired) plants which are used to respond to peaks of demand which cannot be supplied by the nuclear baseline production. In this case, fuel cells have the advantage of low CO_2 emissions and higher efficiency (the efficiency of nuclear plants is about 37%, much lower than the 55% or more of fuel cells).[5] However, this issue is still debated between GDF (which intends to develop distributed power production, using natural gas) and EDF (which views distributed energy production with caution).

Regulatory barriers are also important since no regulatory framework specifically concerns fuel cells and H2 in France. Fuel cells are therefore grouped with other types of devices so that it is difficult to test and later commercialise them.

Public support to demand for micro-CHP fuel cells in France

Public support for market development of micro-CHP fuel cells is very limited. Feed-in tariffs in France (between 6 ct/kWh and 9.15ct/kWh) which apply to small CHP systems are much lower than in Germany. According to potential investors, the difference between this price and the price of gas (about 5 ct/kWh) is not sufficient to offset the high acquisition cost over the lifetime of the system.[6] CHP systems can also benefit from some tax credits.

Conclusions

Prospects for micro-CHP applications based on fuel cells or other technologies are weak. The only potentially positive trend for micro-CHP is the increasing demand for electricity (an increase in consumption of 1.5% a year) which might call for an additional clean option for demand peaks. In 2009, although France is an important net exporter of electricity (15% of total production) to Germany, Italy, Spain and the United Kingdom, it also imported electricity during demand peaks.

The French fuel cell community is trying to gather strength within HYPAC, the national fuel cell and H2 platform. Working groups have been set up, for instance on regulations. The platform also aims to produce a roadmap for fuel cells and H2.

Other European countries

The United Kingdom is the second European source of greenhouse gases (GHG). Its primary source of energy is thermal power stations, and UK electricity production generates a high rate of CO_2 owing to the country's energy mix. Public bodies are making strong efforts to reduce GHG pollution. The UK government recognises the interest of cogeneration technology and has engaged to obtain a cogenerated capacity of 10 000 MWe before 2010. Energy utilities play a large role in the United Kingdom by helping to develop micro-CHP solutions (such as the Whispergen Stirling unit sold by Powergen from E.ON UK) (Slowe, 2006). The UK energy landscape and household structure work in favour of classic micro-CHP solutions. This might be due to the lack of government focus and a clear institutional structure for FC-based micro-CHP.

The Netherlands is often described as a perfect country for FC-based micro-CHP technologies owing to its high dependency on gas for electricity and heat. The context and market potential are quite high but the Netherlands is not developing micro-CHP solutions. Energy utilities are playing a significant role in developing micro-CHP technologies; GasUnie and Eneco are following closely field tests of FC-based micro-CHP by the German company Vaillant.

Denmark is well involved in FC-based micro-CHP technology. The Danish fuel cell industry is characterised by co-operation between R&D organisations, the emerging supply chain (*e.g.* Topsoe), and customers for a wide range of early market applications, including micro-CHP. Denmark has a full domestic supply chain for high and low temperature PEM and SOFC, and the public and private sectors are working together under the Danish Fuel Cell Partnership to translate R&D into commercial products.

Notes

1. For instance, EcoWill, Honda's internal combustion engine micro-CHP unit, costs around EUR 5 000.
2. Some of these projects were selected and financed under PAN-H, the predecessor H-PAC.
3. Most SOFC competencies have been reallocated to low and high temperature electrolysis for large-scale production of hydrogen (which would allow electricity storage during off-peak hours and coupling with renewable energy).
4. Hélion has recently shown some interest in fuel cells for micro-CHP applications (the COREPAC project in 2006), but it has stopped this activity for the time being.
5. Based on the marginal allocation approach (micro-CHP during peak demand), the CO_2 content of electric heating consumption rises to 600 g CO_2/kWh according to a 2007 study led by French transport system operator RTE in collaboration with the French national energy agency.
6. This tariff is to be compared with the one that prevailed in 2009 for phhotovoltaics (58 ct/kWh). This tariff, the world's highest, was so high that the government had to reduce it in 2010, to avoid a major increase in the price of electricity. The average price of electricity is currently about 5 ct/kWh.

References

Al-Nasrawi, B. (EIFER) (2008), "Micro Cogénération Essais *in situ*", presented at the 2ème journée sur la cogénération en France, h*ttp://energie.cnrs.fr/2008/DOCS/cogeneration/B.AL_NASRAWI/Boris_AL-NASRAWI.pdf.*

Brown J., C., Hendry and P. Harborn (2007), An emerging market in fuel cells? Residential CHP in four countries, *Energy Policy*, Vol. 35, Elsevier, pp. 2173-2186.

Cames, M., K. Schumacher, J-P. Voss and K. Grashof (2005), "Institutional framework and innovation policy", in M. Pehnt, *et al.* (2006), *Micro Cogeneration: towards decentralized energy systems*, Springer.

European Commission (2006), "The state and prospects of European energy research: comparison of Commission, member and non member states R&D portfolios", European Commission, EUR 2239.

FaberMaunsell *et al*. (2002), "Micro-map*,* Mini and Micro CHP – Market Assessment and Development Plan", *www.microchap.info/MICROMAP%20publishable%20Report.*

Fuel Cell 2000 (2007), *International Hydrogen and Fuel Cell Policy and Funding*, Fact Sheet.

Harrison, J. (2008), "Microgeneration & micro CHP", update of an article originally published in *Modern Power Systems*, presented at Claverton Energy Conference, November.

Hendry, C., J. Brown and P. Harborn (2006), "Framework conditions for FC in residential CHP in four countries", Cass Business School, Oxford, September.

Hesse, H-P. (2007), German Hydrogen & Fuel Cell Technology Update, IPHE Implementation & Liaison Committee, January, Oxford.

HFP Platform (2006), Strategic Research Agenda, *http://ec.europa.eu/research/fch/index_en.cfm?pg=documents*.

Horwitz, J. (2008), Fuel Cell Intelligence Consulting Services, 2008 Fuel Cell Seminar, Phoenix, AZ, October 27-30.

Husaunndee, A. and C. Orlando (2007), "Comparaison internationale Bâtiment et énergie", Chapter 10, *Micro-cogénération*, CSTB.

IEA (2004), "Comparative Review of National Programs on Hydrogen and Fuel Cells R&D", Hydrogen Co-ordination Group, IEA, Paris.

INPI (2010), "L'éco-innovation: tendances et enjeux économiques : Etude prospective de la direction des brevets de l'INPI", *www.inpi.fr/fr/presse/espace-presse/communiques-de-presse/detail-communique/article/eco-innovation-tendances-et-enjeux-economiques2483.html?tx_ttnews[backPid]=1984&cHash=023bd6fba2*.

OECD (2009), *Eco-Innovation in Industry, Enabling Green Growth*, OECD, Paris.

Pehnt, M. *et al.* (2004), "Micro-CHP – a sustainable innovation?", Discussion Paper N°4, TIPS Works, SOF.

Pehnt, M. *et al.* (2006), *Micro Cogeneration: towards decentralized energy systems*, Springer.

PricewaterhouseCoopers (2008), *Canadian Hydrogen and Fuel Cell Sector Profile 2008*, Canadian Hydrogen and FC Association, Canada.

Slowe, J. (2006), "Micro-CHP: Global Industry Status and Commercial Prospects", 23rd World Gas Conference, Amsterdam.

Chapter 4

Carbon capture and storage: Policies in Germany and Canada

This case study examines the role of public policies in the potential deployment of commercially efficient CCS solutions, with empirical observations from Canada, France and Germany. It considers the technological environment and the proposed eco-innovation, market and demand characteristics, specific challenges, and domestic policies to support CCS. It underlines the crucial role of initial (economic, industrial, regulatory) conditions in shaping the objectives, the nature and the timing of public policies for CCS innovation.

Introduction

It has long been assumed that the reductions in carbon dioxide (CO_2) emissions necessary to combat climate change will be achieved through a combination of increasing the efficiency of energy use and switching to non-fossil sources of energy, such as renewables or nuclear. During the last decade, a new innovative option has emerged: the use of fossil fuels with minimal emissions of CO_2, accomplished by capturing the carbon content of fossil fuels and storing the resulting concentrated CO_2 away from the atmosphere. Carbon capture and storage (CCS) technology is a method whereby CO_2 from fossil-fired power plants is captured, compressed to liquid form, and permanently stored deep underground in a location connected with a pipeline. This idea marks a radical break with traditional thinking about the responses of the energy sector to climate problems. While CO_2 capture and storage is currently not deployed on a commercial scale, this technology is widely considered crucial for achieving the ambitious targets of reduced greenhouse gas emissions required to limit the rise in temperature to under 2°C.

This case study examines the role of public policies in the potential deployment of commercially efficient CCS solutions, with empirical observations from Canada, France and Germany. It considers the nature of the technological environment and of the proposed eco-innovation, market and demand characteristics, the specific challenges faced by this eco-innovation, and the domestic policies implemented to support CCS. In conclusion, the crucial role of initial (economic, industrial, regulatory) conditions in shaping the objectives, the nature and the timing of public policies for CCS innovation is underlined.

The technological and competitive environment

Industrial separation of CO_2 is not a new technology, as it was first tested in the 1920s in the chemicals sector. But the concept of capture and storage of carbon and its application to the power sector is much more recent and was presented for the first time in the mid-1980s by Norwegian researchers at the SINTEF institute.

CCS illustrates the role of the technological environment in innovation deployment and public policy design, as it displays several alternative, semi-independent technological routes to reaching the objective of CO_2 capture. Three technological pathways are currently considered for carbon capture (*i.e.* separating CO_2 from other exhaust gases) for retrofit as well as new power plants. In a fossil plant, the flue gas is typically made of CO_2,

nitrogen, oxygen and water vapour with various pollutants. Depending on the type of fuel used and the power plant process, the CO_2 ratio of the flue gas varies between 3% and 15% in volume. However, a quasi-pure captured CO_2 flow is required for further compression, transport and geological storage. This can be achieved either by separating CO_2 from the flue gas (post-combustion), producing a higher concentration of flue gas (oxyfuel combustion), or removing carbon before combustion (pre-combustion). Table 4.1 illustrates this technological variety in the power sector; it presents different technologies available for carbon capture, transport and storage.

Table 4.1. Technologies for carbon capture, transport and storage in the power sector

Stage of CCS	Available technologies		
Capture	Post-combustion	Oxycombustion	Pre-combustion
Transport	Onshore pipeline	Offshore pipeline	Ship
Storage	Onshore	Offshore	

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

In post-combustion capture, CO_2 is captured after combustion of the fossil fuel. To remove low-concentrated CO_2 from the exhaust gas streams, chemical or physical solvents are used to dissolve CO_2, which is later released for compression. The original and most developed system is amine separation, a process derived from techniques used for a long time in the natural gas industry to separate CO_2 from valuable components in the initial gas stream. The flue gas from the plant enters an absorbing chamber containing the solvent. While the other gases are released, the mix of solvent and dissolved CO_2 is removed from the chamber to a desorber that separates the captured highly concentrated CO_2 from the lean solvent. Heat and pressure are needed to trigger the release of CO_2 from the solvent, which requires high levels of additional energy for CO_2 capture. In most cases, the solvent used is monoethanolamine (MEA). It allows for a simple and proven CO_2 separation, but regenerating the pure solvent afterwards substantially increases energy use. MEA also degrades and must be complemented regularly. It is quite corrosive and requires special and costly materials. Therefore, research is very active around the world to find the best solvent, either with an improved MEA or different solvents: different types of amines, amino acid salts, ammonia, sodium carbonate solutions, etc.

The second method of capture, called oxycombustion (or oxyfiring, oxyfuel, oxycoal), consists in the combustion of the fossil fuel in an oxygen-rich environment. This technology has been used in various high-

temperature industrial processes since the 1940s. The principle is that burning fuel in pure oxygen produces a highly concentrated CO_2 flue gas mixed with steam, which makes its capture less expensive. But it creates at the same time very high temperatures which are incompatible with the usual steel boilers. The flue gas with CO_2 has first to be recycled into the boiler and then cooled after removal of the pollutants. The CO_2 can then be extracted and compressed.

A third approach, called pre-combustion, consists in producing hydrogen by gasification of coal, biomass or petroleum products and burning it with no CO_2 emissions. In this case, the CO_2 is separated from a hydrocarbon fuel before the fuel is burned, hence the name. Gasification produces hydrogen and carbon monoxide; the latter is converted into CO_2, removed and compressed. This process derives from a widely used industrial technology: "reforming" of natural gas, where methane reacts with steam to produce hydrogen and CO. A similar process is also used by over 100 gasifiers currently operating around the world to produce synthetic fuels and/or chemical products out of petroleum products. The CO_2 by-product of this gasification process has been used traditionally for commercial purposes, such as beverage carbonation, urea production or enhanced oil recovery. With this process, it is possible to implement CO_2 capture easily in industrial sites. The idea has been used in the power sector with the concept called integrated gasification combined cycle (IGCC), which is used by four coal plants and about 20 facilities in oil refineries, and which offers a demonstration field for CCS implementation.

A number of other methods may offer additional alternatives but are today at a much earlier stage of development (R&D or prototype stages): membrane separation (post-combustion with a semi-permeable barrier to separate the flue components), chemical looping combustion (metal oxide particles reacting with the fuel to produce solid metal particles and a mixture of CO_2 and water vapour, condensed afterwards to leave pure CO_2), cryogenic separation and distillation (using the different temperatures of gas to liquid conversion between the different components and the CO_2in an exhaust stream).

Table 4.2 compares the key characteristics of the three existing capture technologies, their respective advantages and challenges. It illustrates how R&D priorities and targets differ and require distinct efforts. Therefore, even if components such as the compressing equipment are common and R&D in that field would benefit each capture technology, the extent of scope economies in R&D is limited. The CCS technological context is thus characterised by the coexistence of separate trajectories. This raises specific economic, regulatory and organisational issues for companies as well as public policies. Should R&D efforts and budgets be concentrated on one

technological trajectory or should a diversity of solutions be encouraged by supporting all the alternative routes in parallel?

Table 4.2. Three alternative CO_2 capture technologies

Capture method	Post-combustion	Pre-combustion	Oxyfuel
Original application	Natural gas production	Gasification processes (ammonia plants, refineries)	Industrial high temperature processes
Capture principle	Flue gas scrubbing with a chemical solvent	Carbon removal from the fuel before combustion	Fuel combustion in pure oxygen
Main technical, industrial and economic challenges	Efficiency (low CO_2 concentration) Identification of the best solvent (efficiency, stability, life duration, corrosion) Need for considerable compression of CO_2 at atmospheric pressure Scaling issues	Cost issues System complexity and integration (IGCC complementary still in a development stage) Need to develop new combustion turbine to burn hydrogen, different from the current fuel steam turbine	High cost of oxygen production New design for boilers and burners Removal of impurities from the CO_2 steam
Key advantages	Proven technology Easier adaptation to manufacturing facilities Retrofit	CO_2 produced at high pressure Flexible output mix of electricity, hydrogen or chemicals	Early-stage technology Efficiency
Firms involved in producing and experimenting CCS	Alcatel Alstom, RWE, EON, TransAlta, Mitsubishi	Vattenfall, RWE, Shell, Mitsubishi, GE, Siemens	Vattenfall, Total, Doosan, Hitachi

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

Each solution has strong advocates in the scientific and business communities. But it is unclear today which one will ultimately prove most cost-effective, and even whether one will dominate or they will coexist for different specialised applications. In 2009, there are about 25 capture projects operational or under construction (United States, Europe, Australia, Japan, East Asia, India). Ten use food-grade CO_2/carbonation, five use post-combustion, four use oxyfiring and two use pre-combustion. If one considers also the projects announced, there are some 50 planned or operational projects around the world (Scottish Centre for Carbon Storage, 2009). In April 2010, the Global Carbon Capture and Storage Institute provided an update of eighty large-scale integrated projects for carbon capture and storage around the world (up from 67 in 2009). Over half of the projects are for power generation, with gas processing facilities representing the next most common type of facility. Pre-combustion technologies will be

used with post-combustion methods (including gas processing) as the capture type, with a handful of projects employing multiple capture technologies. Transport of CO_2 by pipeline is the dominant means of transport. Plans for the vast majority of captured CO_2 is evenly split between beneficial re-use by industry and geological storage, mainly in deep salt water formations (Global CCS Institute, 2010).

Technological issues are less critical in the two stages of CCS following CO_2 capture: transport and storage. Both have been operated commercially on a large scale for decades, albeit for purposes different from reduction of CO_2 emissions. The feasibility of CO_2 transport through pipelines or by ships, as well as the injection and storage in depleted and active oil and gas fields or deep saline aquifers, has been largely demonstrated. While there are still many uncertainties, such as transport infrastructure regulation, storage permits allocation, public acceptance, or a comprehensive review of storage sites, locations and volumes, their nature is not primarily technical. They are discussed in a later section.

The review of the technological environment would however not be complete, if other available CO_2 mitigation techniques were not considered. CCS is actually in competition with every solution that could potentially contribute to the common goal of reduction of CO_2 emissions, such as energy efficiency, renewables and nuclear. It is necessary to consider two dimensions: the need for CCS in the technological mitigation portfolio and its specific advantages and the associated specialised scope for application. After many studies and reports, there is a general consensus today that CCS could make an important and necessary contribution to the reduction of CO_2 emissions in a medium-term perspective. Its CO_2 abatement potential, commercial availability within reach and truly adaptive nature are the main arguments put forward. This technology also has a crucial "enabling" role. It would make it possible to continue to use fossil fuels while long-term sustainable solutions of energy supply are under development and experimentation. A credible climate mitigation strategy must take into account that a significant number of economies in industrialised (*e.g.* Germany) and emerging countries (*e.g.* China and India) are likely to remain for some time based on fossil fuel energy in order to secure a sufficient energy supply. Widespread deployment of CCS technology will therefore be necessary to achieve the targeted reduction in CO_2 emissions by 2030. The critical contribution of CCS was identified and underlined by the Intergovernmental Panel on Climate Change (IPCC, 2007) [for its potential to reduce global greenhouse gas emissions substantially and to account for one-quarter of the targeted reductions. Most global energy forecasts to limit global warming to 2°C are based on large-scale deployment of CCS as of 2015-20.

Comparative studies of deployment and costs of alternative greenhouse gas mitigation technologies (IPCC, 2005; Stern, 2006; IEA, 2009) illustrate how CCS could be a major contributor to emissions reductions. The IEA's *Energy Technology Perspectives* (2008) estimates that about 19% of the necessary reduction between 2010 and 2050 could come from CCS (equally divided between industry and power generation). CCS would be the third contributor after energy efficiency (24%) and renewables (21%). Moreover, it would be impossible to reach CO_2 reduction targets without using CCS, or at unaffordable cost. The same study estimates that the cost of reducing CO_2 emissions to half their current level by 2050 would nearly double without CCS (USD 394 per tonne *vs*. USD 200 per tonne). CCS technology also proves very efficient from an investment perspective, as it requires a cumulative investment of USD 3 trillion out of the required total of USD 45 trillion (*i.e.* 7%) from now to 2050 to reach the emissions reduction targets to combat climate change, but accounts for 19% of the total reduction. Finally, concerns that CCS will divert investment from other technologies such as renewables and energy efficiency are largely misplaced, as parallel investment in all low-carbon technologies is required to reach emissions reduction targets. Excluding one low-carbon technology family will limit countries' future options to mitigate climate change. CCS deployment must occur in addition, and not in competition, with massive actions to improve energy efficiency and increase the use of renewables.

The potential scope for deployment of CCS derives logically from its technical and economic characteristics. First, it is not a new or nascent technology. It combines a set of component technologies from the oil, chemical and power generation industries which already exist and are commercially available. Second, CCS is a truly adaptive technology and enables the existing productive system, with its large-scale fossil fuel power plants and industrial sites (cement, steel, glass, chemistry), to continue to be economically viable while reducing their CO_2 emissions in a carbon-constrained world. The huge assets accumulated over more than a century will not need to be entirely wiped out and rebuilt. Third, given its capture method and high capital cost, CCS is best suited to large CO_2-emitting sites, with a single source (not dispersed or small sources, such as transport). For all these reasons, the two main targets for CCS deployment are power plants and the largest CO_2-emitting manufacturing facilities.

Market, utility and demand characteristics for CCS eco-innovation

CCS market opportunities are based on the international political commitment to reduce CO_2 emissions drastically by 2050 in order to avoid irreversible climate damage. This context is determined and can be

summarised by two graphs: first, the reduction in the volume of CO_2 emissions to be achieved by 2050 to fulfil climate political commitments and the relative contribution by technology or sector; second, the curve of the abatement cost (of avoiding 1 tonne of CO_2 equivalent) associated with each available technology or public instrument. As discussed, CCS could play a substantial role in this climate mitigation policy for a set of specific targets.

The first is the energy sector and fossil fuel power plants. The power industry is the largest emitter of greenhouse gases (25% of the total) but also has high reduction potential. The installed base is largely old coal-fired power plants. For example, in the EU, 50% of coal-fired plants are more than 30 years old, and 80% are more than 20 years old (Reinelt and Keith, 2007). In Denmark, Germany and the United States, more than 50% of electricity generation is based on coal. Coal is currently coming back as a crucial source of energy for three main reasons: price rise lower than that of oil and gas, the largest reserves of fossil fuel, flexibility to balance production according to demand and relative prices (electricity generation, coke conversion for steel plants, production of synthetic oil).

This is particularly true in emerging and developing countries, with economies like China or India likely to rely on coal-based energy for quite some time. They are therefore investing massively in fossil-fuel power plants (at the rate of two plants a week in China in recent years). This defines two distinct markets for CCS in the energy industry: new power plants to be built by 2050, and the retrofit of currently operating plants.

From the perspective of an electricity energy provider, nuclear power and CCS, while technologically unrelated, offer competing alternatives. Both could be used to replace existing coal-fired plants without requiring significant changes in existing transmission infrastructures; both are very capital-intensive and have very low CO_2 emissions; both involve regulatory uncertainties and raise concerns of public acceptance. The unique advantage of CCS is that, unlike nuclear, it can be retrofitted to existing coal-fired power plants. For new power plants, two technologies with similar costs and performance are available: pulverised coal (the dominant one) and integrated gasification combined cycle (IGCC). The latter is still technologically riskier but offers reduced future CO_2 emissions compliance costs as its CCS retrofit cost would be significantly lower than for a pulverised coal plant.

In short, the potential market size (hundreds of existing or planned power plants), the ageing installed electricity generation base which will require huge investment in the next decades, and the political attention to energy issues all over the world explain why CCS research, development

and demonstration efforts have been concentrated in the power sector. All pilot CCS plants operating or under construction today are in that field.

The second main field of application and market prospects for CCS is in manufacturing facilities with high CO_2 emissions, such as steel, cement, oil refining, chemicals, and pulp and paper. However, the methods to be used for CO_2 capture at each of these facilities depend on their specific and often complex production process, in particular whether or not the plant's total CO_2 emissions come from a single source or different and distant individual sources. In many cases, the CO_2 emitted comes from chemical reactions inherent in the operation (cement, steel, chemicals), not the burning of fuel. It requires further purification and the removal of impurities as well as significant modifications of long-established production methods and processes. The three capture approaches (post-combustion, pre-combustion and oxyfiring) with the potential to be used in industrial manufacturing facilities must be adapted to address the specific needs of each sector, and each site will ultimately need a tailored design. Compared to power generation, smaller efforts have gone so far into development of capture from industrial manufacturing processes. The shared rationale and assumptions within the industry and R&D community is that, once significant CCS systems have been stabilised and rolled out at commercial scale for power plants, it will be easier and less costly to derive applications for manufacturing sites, although this is not certain. This nevertheless explains why investment and R&D efforts focus in priority on the power sector.

A third market lies at the crossroads of energy and industry sectors. Called EOR for enhanced oil recovery techniques, it aims at extending gas and oil production through injection into the reservoir of high-pressure CO_2 captured in a power or industrial site in order to increase its exploitation rate. Already deployed on a large scale, this technology results in the storage of about 40 million tonnes of CO_2 a year.

The market for CCS eco-innovation has four main economic features: *i)* business customers (energy and industrial firms); *ii)* significant concentration (a few hundred sites, and an estimated rate of 10-20 new CCS installations a year at the launch of commercial offers, rising to 30-50 in a later phase); *iii)* a two-pronged geographic distribution, with the largest number of opportunities in industrialised countries but growth potential in emerging economies, which are still extending their electricity generation infrastructure; and *iv)* three distinct sub-markets with different customers, competitive environments and economic profitability of CCS investment (power sector, manufacturing facilities, EOR). In this global market, the four key competitive advantages of CCS as a CO_2 mitigation strategy are: compatibility with existing electricity or manufacturing infrastructure;

possible retrofitting of existing fossil plants; maturity and availability of component technologies; and technical synergies (enhanced oil recovery, polygeneration of synthetic fuels and electricity at refineries).

However, considering the time line of the technology, five years after the IPCC special report on CCS pushed for rapid deployment of demonstration plants, there is no fully integrated, commercial-scale power plant using CCS in operation. Commercial offers are not expected before 2015, and more likely 2020. Current investments in CCS today are minuscule relative to those being made in renewables. Currently, the price support for renewables through energy feed-in-tariffs is equivalent to a range of USD 73/tCO_2 (tonnes CO_2) to USD 1 000/tCO_2 for solar power, as compared to the current range for a CCS demonstration project, *i.e.* USD 80-120/tCO_2 (Stern, 2006; McKinsey, 2008). The business opportunities for CCS eco-innovation are therefore very large and attractive, but this is still a nascent market.

Main challenges faced by CCS eco-innovation

Like any eco-innovation, CCS must overcome various technical, economic, political and social barriers for successful and efficient deployment. The four main challenges identified by companies (Alstom, Vattenfall, Fortum, etc.), researchers, business and environmental associations (WCI, E3G, Climate Change) are the following: cost and financial model, system integration of CCS component technologies, regulatory uncertainty, and technical and political concerns associated with long-term CO_2 sequestration. Before examining the policy responses to these problems, this section explores their nature and impact on CCS validation, adoption and diffusion.

Cost and financial uncertainty

Expected short-term CO_2 prices on the market for emissions permits are too low to recoup the costs of initial commercial-scale CCS demonstration projects. For sources such as power plants, capture is the dominant cost element, accounting for 70-80% of total costs. The capture costs strongly depend on the level of concentration of the CO_2 stream. All three technical options have high capital and operating costs, and reduced energy efficiency compared to existing modern plants without CO_2 capture. New equipment and a significant increase from 1% to 30% in energy use (to separate, compress to 110 bar, and transport CO_2) explain this cost differential. The uncertainty of the CCS financial model has two dimensions. First, how will the additional cost of CCS be (at least) compensated by avoiding costs for buying CO_2 emission allowances, typically with the EU emissions trading

system (ETS)? The overall economic and financial outcome of CCS investment will crucially rely on the future design of the ETS (quota allocation, allowance mechanism, resulting price for the tonne of CO_2 emitted). Second, while the business community agrees that the cost of CCS technologies will likely decline as a result of technological change, learning by doing and economies of scale, the rate at which equipment cost and energy efficiency losses will decrease with the large-scale deployment of CCS technology is largely unknown.

While CCS may reduce emission rates of coal-fired power plants by 90%, its expected abatement costs vary from EUR 31/tCO_2 to EUR 80/tCO_2, as Table 4.3 illustrates in the case of Germany.

Table 4.3. Estimation of costs for CCS in power plants in Germany (EUR/tCO_2)

Stage	Lignite	Hard coal	Gas
New CCS plants in 2020 (pilot and demo)			
Capture	20	41	84
Transport	5	5	5
Storage	6	6	6
Total	31	52	95
New plants in 2030			
Total	30	48	87
Retrofitted plants in 2030 (built in 2005-20)			
Total	33	52	> 100

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

Cost estimates for CCS with post-combustion capture in power plants are based on the earliest technological configurations, using an amine separation process. This solution was not designed for CCS but was adapted from other applications in the chemicals industry. Other options are now explored that may improve the cost and performance of amine separation. Widely cited estimates may therefore overstate the final real cost of the post-combustion technology effectively deployed on commercial scale in 10-15 years.

To reduce the financial uncertainty associated with CCS investment, there are two main solutions, calling for distinct public policies. First is a price on carbon emissions (either with the emission trading system or with taxes on CO_2 emissions). If the ETS permit price corresponds to abatement costs, this technology becomes competitive. Such a policy would also create

revenues that can be used to subsidise early-stage technology development (either CCS or other mitigation solutions).

The second solution consists in improving in parallel the efficiency and profitability of CCS investment, through scale economies in equipment production once the final design has been stabilised, and new R&D efforts both in CCS technology (better system integration, improvement of the efficiency of each component) and power generation (ultrasupercritical steam power plants with higher working steam temperature and pressure up to and possibly beyond 350 bar and 700°C, IGCC). The target set by many CCS developers and equipment manufacturers (such as Vattenfall or Alstom Power) is to offer advanced power plants with CCS in 2020 with the same net efficiencies as state-of-the-art coal-fired power plants without CCS (around 45%).

Most of the expected cost reduction will likely come not from radical technological breakthroughs, but rather from a continuous process of refinement and incremental improvement of existing solutions. In this respect, demonstration projects in which various solutions can be tested, measured, assessed and compared are crucial to identify the best designs. Past experience with similar technologies (such as gas turbine combined cycle, oxygen and hydrogen production, or pulverised coal boilers) shows that doubling production capacity can reduce capital costs by 10-27% and operating and maintenance costs by 6-27% (Rubin *et al*., 2007). The industry consortium expects, more conservatively, a 12-15% reduction in capital expenditure when doubling production capacity, thereby lowering the abatement cost from USD 80/tCO_2 today to about USD 40/tCO_2 by 2020 and the roll-out of commercial CCS offers.

The financial model for CCS has finally to consider investment in complementary infrastructure (CO_2 pipelines). This cost is estimated in Germany at EUR 1 million per km and a pipeline of 2 000 km would be required at the national level to link power plants to the identified potential CO_2 storage sites, for a global investment amounting to EUR 2 billion.

CCS technical challenges: system integration, flexibility and scaling

While each stage of CCS is technically ready today (based on commercial applications used in different industries), several issues remain to be solved: integration of the three successive stages (capture, transport and geological storage),which raises specific problems and R&D needs; design of an integrated system commercially viable and flexible enough to cope with the various needs (industrial processes and power generation, new plants as well as retrofit of existing plants). Compared to other mitigation

techniques, CCS is much more advanced in the power sector than in industrial sectors; in the latter, fuel and electricity efficiency in existing processes can offer CO_2 reductions earlier. Integration, flexibility and scaling are the main technical challenges. The technological context described earlier makes a complex case for defining R&D priorities and scope (either at a company or country level).

For example, the three alternatives for CO_2 capture are not at the same stage of the technological life cycle. While pre- and post-combustion technologies are already mature and economically feasible under specific conditions, the technological path with oxyfuel combustion is still at the demonstration phase.

Given the diversity of initial conditions (between power plants and industrial sites, and within the energy sector between different fossil fuels), there can be no one-size-fits-all solution, optimised and adapted to each case. There is indeed room for CCS product differentiation and the competitive coexistence of distinct technological trajectories. Supporting a wide variety of technological projects and exploring the alternative available routes is essential for public policy and companies' strategies if they are to avoid potential lock-in effects and benefit from the greatest possible flexibility to deal with existing assets and to access a wide world market.

In the case of CCS retrofitting, the conversion of an existing plant for CCS would lead to a direct reduction in output and efficiency owing to the energy requirements of the CO_2 separation process. The final outcome would be a function of this energy penalty, the base plant efficiency, the cost of CCS equipment, and the fraction of initial capital investment to be recovered. In return, a large retrofit market for CCS would increase economies of scale and reduce further the cost of components production.

Regulatory uncertainty

Regulation issues play a critical role in the adoption and diffusion of CCS. The first concerns transport and storage. As storage reservoirs are scarce, the establishment of international and national regulations regarding CO_2 injection and storage is needed. The EU adopted a CCS directive in 2009, which provides a regulatory framework for safe geological storage of CO_2 in member states. A similar regulation is currently pursued in Canada. Some provincial jurisdictions are applying existing regulatory frameworks from the oil and gas sector to address CCS projects. In November 2010, the Government of Alberta introduced legislation to address two significant policy barriers to CCS. *The Carbon Capture and Storage Statutes Amendment Act* would establish an effective system for long-term stewardship of carbon dioxide storage sites and set up a storage rights

process to support optimal site selection. However, no comprehensive regulatory framework for geological storage of carbon has been introduced as in the EU.

Second, the geographical mismatch between capture (chemicals, steel production and electricity generation), located near large cities and populated areas, and storage in distant sites (saline aquifers and natural gas fields) makes CO_2 transport a vulnerable part of the CCS chain (costs, public acceptance, complex regulation, lead times for planning, licensing and roll-out). Transport infrastructure issues must be addressed at an early stage and are as important as CCS demonstration pilot plants. Pipeline corridors are a scare resource and careful planning is necessary in parallel with the in-depth analysis of storage capacities and sites. Who will bear the economic and regulatory risk of decisions on long-term cost-effective roll-out strategies for CO_2 transport infrastructure? As CO_2 pipelines, like any network, raise positive externalities, what is the most efficient regulatory framework for both encouraging investment and avoiding competition bias (discriminatory access and price, foreclosure)?

Public acceptance

Public perception and long-run environmental risks also play a very important role in public policy. The long-term ability of deep saline aquifers or depleted oil and gas reservoirs to contain CO_2 and avoid leakages is unproven. To overcome these risks and gain public acceptance, transparent and credible monitoring and verification of storage sites are essential. Another issue raised by environmental NGOs deals with CCS opportunity costs and the risk of displacing resources that would be better directed to alternative CO_2 mitigation routes (such as renewables or energy-efficiency techniques).

Recent German experience offers an interesting illustration of local reluctance to accept CCS technology. Scepticism about an unknown concept, the traditional "nimby" [not in my backyard] reaction, a belief that the CO_2 stored could explode and burn, the risks of future leakages were the four main issues raised in public debates and consultations. The German debate on CCS was sparked by two concerns: first, carbon leakages from CO_2 storage sites in the future, and second, risk of a technology excuse, just a "PR gag", for coal and utility industries to continue with business as usual. The Asse (nuclear storage facility) scandal, which demonstrated that public licensing also faces accountability problems, and the threat of something "dark unseen in the underground" have been at the core of public concerns in local debates in Germany. This raised opposition based on two main types of arguments: "new hazard (comparable with nuclear)" and "climate

problem can be solved without CCS". Several sociological and political science studies on this empirical case presented insightful proposals, worth considering for future CCS debate in Europe: explain in a transparent and simple way the distribution of benefits; enlarge the framework; demonstrate the accountability of key players; frame and explain a climate policy planning process of good quality; work first on shared understanding and acceptance of the urgency of the climate problem as this does not yet really exist. For example, in the case of CO_2 infrastructure (pipelines), it would be helpful to admit that this creates risks, limited but real, and then shift the debate to how these risks could be made transparent, countermeasures explained, and fair compensation approaches developed.

Since the lack of common knowledge about CCS technology fuels public reluctance and political acceptability, this gives an additional role, beyond their primary technical and economic objectives, to demonstration projects: offering to the general public visible, tangible and real-scale CCS operations.

This section has reviewed the different types of uncertainty or challenges faced by CCS eco-innovation. Table 4.4 gives the German view for each stage of the technology. The field, the targets and the obstacles for public policies to support successful and efficient deployment of CCS are examined next.

Table 4.4. German view of the different challenges to the CCS chain

CO_2 capture	CO_2 transport	CO_2 storage
Technologies	Public acceptance)	Public acceptance
Costs (investment & operations)	Costs (distances	Long-term modelling of storage sites
Commercial plant operation requirements	Infrastructure roll-out	Regulation under conditions of uncertainty
Retrofit vs. newly built	Regulation under conditions of uncertainty	

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

Domestic public policies for CCS

Review of available policy instruments

At the national level, the objectives of policy intervention for CCS are threefold: *i)* to stimulate technology development and to accelerate large-scale commercial deployment, once its key contribution to combat climate

change has been validated; *ii)* to solve the various specific issues presented above; and *iii)* to profit from this new emerging market and business opportunity (*e.g.* to build first-mover advantage to become a world leader in this nascent industry). What are the adequate policy instruments for a technology that is at the demonstration phase and raises specific concerns such as the potential risks of geological CO_2 storage?

CCS can be deployed using support mechanisms equivalent to those provided to other low-carbon electricity options. Previous experience with support schemes designed and implemented all over the world for renewable energy technologies indicates that government action and investment are crucial to bridge the gap between the research and demonstration phase and the widespread diffusion and adoption of a technology family.

Six main policy instruments may be considered:

- CO_2 market price from a tax or an emission trading system (in Europe inclusion of CCS in the ETS as an opt-in installation in a first stage, and possibly later as a single-combustion and CCS installation);
- investment support: subsidies for building demonstration plants (research programmes, capital expenditures);
- feed-in schemes: special tariffs for selling electricity produced in CCS plants (as for wind and solar power generation);
- guaranteed CO_2 price for CCS plants;
- portfolio standard: mandatory requirement for electricity consumers or their suppliers to source a minimum percentage of their electricity from installations in which CO_2 is captured and stored;
- obligation of CCS technology for all new fossil fuel-fired power plant from a given date (2020).

Table 4.5 describes the main advantages and difficulties associated with each policy instrument.

A domestic CCS policy will combine a set of instruments, according to the specific public objectives defined, as well as the distinct features of the country's energy structure, industrial base and R&D capacities. Empirical work on CCS in Canada, France and Germany reveals a privileged strategy, building a demonstration plant, using a mix of supporting instruments. Two other mechanisms are also extensively discussed but not yet implemented: mandatory CCS equipment and inclusion in the Clean Development Mechanism (CDM) system.

The nature of the challenges faced by CCS explains why demonstration plants in the power sector are seen as the best option for public support. Building on the significant body of experience in technological operations, monitoring and safety issues gained through past industrial-scale CCS (*e.g.* Sleipner in the North Sea, Weyburn-Midale in Canada), several prototype projects are now running in the EU and in Canada. The next step is building demonstration plants in order to finalise the choice of technical options and technology design for commercial offers. In autumn 2009, the EU selected 12 plants to be built in Europe in order to have the first commercial plants around 2020. In addition, the European Commission is spending about EUR 32 million on CCS R&D. The Canadian federal budget for research, development and deployment for CCS is nearly CAD 1 billion. The province of Alberta alone has allocated CAD 2 billion to four new CCS projects (Table 4.6).

Table 4.5. Alternative policy instruments for stimulating CCS roll-out

Instrument	Advantages	Drawbacks
CO_2 emissions trading system	Direct and transparent price incentive	Insufficient prices in the CO_2 market to stimulate CCS investment Depressing effect on the carbon price Allocation for transboundary operations Accounting for possible long-term seepage
Investment subsidies	Overcome uncertainty and financial risks raised by the substantial CCS capital requirements (with a focus on capture, the highest capital-intensive stage of CCS)	Reduced incentives for further technology improvement Substantial burden on the public budget
Feed-in tariffs	Simple and continuous monitoring of the intensity (and cost) of public subsidies Allow technology differentiation in public support	Reduced incentives for further technology improvement Substantial burden on the public budget No incentive to reduce electricity consumption
CO_2 price guarantee	Reduced uncertainty Flexible extension to include non-electricity, out of the ETS, sectors	Reduced incentives for further technology improvement Substantial burden on the public budget
Low-carbon portfolio standard	Guarantee that the environmental targets will be achieved	Obligation to introduce a parallel system of tradable CCS certificates Complex definition of the portfolio compliance obligation
CCS obligation	Discrete, stringent, with low information requirements instrument Flexibility in time frame implementation to facilitate phase-out or retrofit of existing power plants	Risk of a failing technology Potential political resistance

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

Accordingly, the ZEP (Zero Emission Fossil Fuel Power Plants) lists 43 large-scale projects in the EU that include CCS equipment (nine in the United Kingdom, seven in the Netherlands, six in Norway and five in Germany) in 2009. In France, one project, started at the end of 2009 in Lacq (a former gas field operated by Total), tests oxyfuel capture on a 30 MW demonstration plant, with local storage in the now empty reservoir. Two complementary research programmes were launched by the French research agency ANR in 2005 and 2006 for a total of EUR 10 million in subsidies.

Table 4.6. Public support for CCS demonstration power plants

Country	Government funding for CCS demonstration	Other funding
Australia	USD 2.2 billion	State USD 0.43 billion) Coal industry (USD 0.86 billion)
Canada	Over USD 3 billion (7 large-scale demonstration projects)	Government of Canada (over USD 1 billion) Government of Alberta (USD 2 billion)
EU	USD 1.5 billion (7 projects)	
United States	USD 3.4 billion (2009 ARRA plan)	

Source: World Coal Institute (2009), *Securing the Future, Financing CCS in a post-2012 World*, London, *www.worldcoal.org/bin/pdf/original_pdf_file/securing_the_future_ccs_financing (12_11_2009).pdf*.

R&D and investment subsidies are the first tool used by government to support domestic CCS demonstration. The selected projects may be based on industrial consortia or public-private partnerships between the government and the industry, such as the Clean Energy Fund and ecoENERGY Technology Initiative (Canada), the Regional Carbon Sequestration Partnerships (United States-Canada), or the Zero Emissions Platform (European Union).

Inclusion in the CO_2 emissions trading system is also likely to play a growing role. It responds to a general demand by industrial firms and environmental organisations. In 2008, a group of stakeholders (Alstom, Shell, Fortum, Vattenfall, SINTEF, E3G, Bellona, Climate Change) suggested a transitional project demonstration mechanism, whereby companies operating CCS demonstration projects would obtain allowances for the full chain of capture, transport and verified storage of CO_2 that would be traded in the EU ETS. A first experiment will be conducted with the 12 CCS demonstration plants selected by the European Commission in 2009, for which 300 million allowances from the CO_2 ETS have been earmarked for future allocation. A deadline for the allowance of the first

200 million has been set for 31 December 2011, with the remaining 100 million being allocated by 31 December 2013.

But public support is not limited to the financial dimension. Given the duration of a CCS project (on average 6-7 years), accelerating the time to market is a major competitive dimension to be considered by public policies. To fast-track the building of CCS projects and accelerate domestic commercial offers, two main public instruments are tested in Europe and in Canada: *i)* shortening the tender process in demonstration programme (*e.g.* a short ten-page expression of interest from bidders and a two-step decision-making process in Canada); and *ii)* building a collective CO_2 transport infrastructure, which is a vital complement to capture systems with the economic features of a public good, hence requiring public regulation and financing (*e.g.* the "Enhance Energy Alberta Carbon Trunk-line", part of an envisioned backbone pipeline system in Alberta for which the governments of Canada and Alberta are providing funding).

In the coming years, two additional instruments may facilitate the post-demonstration phase and the scaling of CCS technology: inclusion in the CDM mechanism and mandatory CCS equipment for new (and later every) operating power plant. The idea is to strengthen a price signal that may not be sufficient in the emissions trading market to ensure the profitability of CCS investment. CCS is recognised under the Kyoto Protocol (Article 2.1-a-iv) as an important greenhouse gas mitigation technology. A crucial issue is the possible inclusion of CCS projects under the CDM mechanism. The criteria for CDM certification are: *i)* voluntary participation; *ii)* real, measurable and long-term benefits for climate change mitigation; and *iii)* provision of additional reductions in emissions compared to what would occur in the absence of the project activity. Verification of emissions reductions from CCS projects can be managed on a case-by-case basis. This supports the idea that CCS indeed meets the objectives and criteria of the CDM, as detailed in the Kyoto Protocol and Marrakech Accords. CCS projects should then be eligible to receive credits under the CDM. This mechanism would address the additional costs associated with CCS investment, and provide a real incentive to deploy this technology.

Along with the traditional economic instruments discussed so far (direct subsidies, CO_2 emissions allowances, CDM), it will probably be necessary to introduce a standard. The specific advantage is to allow precise planning of the timeline of technology adoption, as well as its mandatory dimension. This can only be reasonably considered after stabilisation of the technological and regulatory landscape. This is why it should be implemented at a later stage and why it is not high on the current CCS policy agenda, even though it is already extensively discussed. Meanwhile, the notion of a common standard can be an intermediary option. Many new

fossil fuel plants are expected to be built over the next decade or so before CCS is likely to be commercially viable. Hence the idea of plant "capture readiness", meaning that the plant is initially designed to be later modified to implement CCS when it is commercially viable: close location to geological storage sites, pre-defined space for capture and compression equipment, ability to integrate control systems. This concept is interesting as it offers a means to avoid increased lock-in of CO_2 emissions from new plants built before a large commercial roll-out of CCS. As there is today no broadly shared or universal definition, clear regulation or regulation based on adequate technical definitions will likely be necessary to define "capture-ready" plants and its significance. This work is currently undertaken collectively by all CCS stakeholders in Europe and North America.

Finally, the focus on demonstration plants in Canada and in the EU to show the feasibility of commercial solutions using proven components of the CCS technology should not preclude further R&D efforts into next-generation CCS technologies. Once the concept has been validated and rolled out, new efforts will be necessary to investigate novel technologies and to work to improve reliability, availability, efficiency and flexibility. The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP platform), which is a coalition of various stakeholders supporting CCS, assessed in 2009 the technology blocks and R&D needs and long-term targets for the three main capture routes (*e.g.* chemical solvents, membranes and solid sorbents for post-combustion).

The interesting lesson of the CCS case is the decisive role of timing in policy design and of prior instruments. At each stage of the innovation cycle, one or several instruments are more relevant and efficient, depending on the stage of technology development and the regulatory framework. For example, it would be too early to set mandatory CCS obligations, but this will probably be required in the near future. At the demonstration stage, the priority is to reduce the current level of uncertainty surrounding the technology and to build a predictably credible framework to encourage the large capital investment needed. Also, while feed-in tariffs or CO_2 price guarantees are potential policy options to be considered in general, the prior existence of ETS and CDM mechanisms suggests that the inclusion of CCS into these instruments would be a more efficient, less complex and information-demanding solution. All these elements, depending on initial domestic conditions and the technological development stage, shape a clear hierarchy in the large set of available policy instruments. The comparison of two countries' CCS policy illustrates this important point.

First, however, an additional issue has to be raised. As most of the CO_2 captured in the plants will need transport for storage, investment in networks of CO_2 pipelines is crucial for successful CCS adoption. This raises specific

issues such as definition of transport cost, non-discrimination in access to the transport network, cross-border operations, financing. Such a network exhibits clear features of a public good. Therefore, financing and operation could involve public intervention (regulatory framework, rate definition, control and investment, even if covered by private partners).

CCS policy in Germany

The milestones of the CCS public policy in Germany have been the following:

- Debate on using CCS technologies in Germany started in 2003.
- Since then, the Federal Ministry of Economics and Technology (BMWi) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) are the main institutional actors.
- In the mid-2000s, a major CCS R&D initiative, COORETEC, was launched by BMWi.
- A law on capture, transport, and permanent storage of carbon dioxide was drafted in April 2009.
- Owing to a lack of acceptance by the German public (in particular by the government of the Schleswig-Holstein where most of the planned CO_2 storage facilities are located), the Bundestag postponed in July 2009 the reading of the draft. The future of the draft will be determined by the new government elected in November.

The main result of this active policy is the 2009 German CO_2 Storage Act, which combines the following elements: assessment of storage sites and capacities nationwide; licensing of CO_2 pipelines; licensing of investigation of storage sites; licensing of building, operating and decommissioning of storage facilities; and regulation of non-discriminatory access to CO_2 transport and storage infrastructure.

The driving force and key determinant of German CCS policy is the persistent weight of coal in energy production and electricity generation. Germany is the biggest coal consumer in the EU. Electricity generation is based on hard coal (23%), lignite (24.5%), nuclear (22%), gas and oil (13%), and renewable (14%). Germany has significant lignite and hard coal reserves (41 and 23 billion tonnes, respectively). The mining of hard coal has been subsidised and will be shut down by 2018. Lignite mining is not subsidised and 180 million tonnes were mined in 2007. Plans to withdraw from nuclear power make coal an even more essential source of energy. In

this context, the challenge is to make the use of fossil coal as efficient as possible and to reduce CO_2 emissions radically by developing technologies such as CCS. Therefore, priority is given to the power sector, which fits well with the innovation features discussed above. Vattenfall, RWE and E.ON are at the same time the main energy providers and the leaders of CCS projects in Germany (Table 4.7).

While energy issues are the political priority, economic and business factors in terms of jobs, growth and exports are also considered. In 2008, 46% of CO_2 emissions in Germany were in energy generation, compared to 11% in industry and 10% in industry processes (Schütze, 2009). With these parameters, Schütze estimates the macroeconomic effect of a 15% reduction in power consumption by 2030 and the number of CCS-induced additional employees: the curve reaches its peak in 2025 with 76 000 additional jobs (mostly due to an income effect). With an assumption of constant power consumption, the employment curve rises to 102 000 employees in 2025 and remains at a high level until 2030. The impact on domestic employment could also be leveraged at the international level for energy providers and CCS equipment manufacturers and integrators, considering a global export market of CCS technology estimated at EUR 10 billion for 2020 and EUR 20 billion in 2030 (McKinsey, 2009). The combination of these different motivations triggered national mobilisation to develop and roll out CCS.

Table 4.7. CCS implementation by the three main German electricity providers

Energy provider	RWE	E.ON	Vattenfall
Installed capacity	33 033 MW	23 650 MW	13 378 MW
Coal power plants	13	14	11
Power plants	24	47	23
Energy from coal	62%	39%	60%
Post-combustion CCS	Yes	Yes	Yes
Oxyfuel	No	No	Yes
Pre combustion	Yes	No	No

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

In particular, Germany has gained a pioneering position in oxyfuel, the less advanced but very promising capture technology, as it builds on existing power-cycle technology and can be rapidly implemented. Since September 2008 Vattenfall, a Swedish company, has been testing CCS oxyfuel technology in a 30 MW pilot plant at Schwarze Pumpe in Brandenburg,

close to an open-cast lignite mine and coal-fired power plant. The testing programme will run for three years. The CCS research programme was initiated by the company in 2001, with the objective of developing commercial offers for CCS technology by 2020 at the latest. In the first year of operation of the pilot plant, Vattenfall has verified on industrial scale the principle of the oxyfuel carbon capture process (air separation unit, purification, compression). Approximately 1 400 tonnes of CO_2 have been liquefied and 3 000 operating hours realised through several campaign tests. The plant demonstrated an achievable capture rate higher than 90% with a high level of CO_2 purity. Additional experience and knowledge will be gained during the next three years by testing various technical solutions: different burner settings and geometry, combustion optimisation, compression systems, and co-firing biomass with lignite. In line with the challenges identified above, the objectives of these various experiments are to improve carbon capture rates (*e.g.* with an innovative membrane), minimise the concentration of acidic components in the CO_2 product, prevent corrosion, and increase the flexibility of the solutions implemented (to allow a large variety of solid fuels and burner types and facilitate the retrofit of the largest number of existing power plants).

Another interesting application route for CCS is its potentially efficient combination with cogeneration of heat and power (CHP), which plays an important role in Germany. CCS can be plugged on modern highly efficient power plants with CHP to increase the fuel utilisation rate up to 61% while cutting CO_2 emissions by 25% per kWh in comparison to old coal-fired plants. A real-scale project of this kind is to be conducted by Vattenfall in the new Moorburg power plant near Hamburg, to be completed in 2012, and aims at satisfying half the electricity and heat requirements of the city.

CCS policy in Canada

In Canada, federal and provincial governments have committed, in the last two years, upwards of CAD 3 billion in funding for CCS. These investments support several interdependent initiatives to reduce market barriers and realise the full potential of CCS. Canada already gained experience in the transport and storage of CCS technology with the pioneer Weyburn-Midale project, initiated by Pan Canadian Petroleum, a large oil and gas domestic corporation in 1998. This project involves capturing CO_2 emissions from a synthetic fuels plant in North Dakota, transporting the CO_2 more than 300 km across the Canada–US border via pipeline, and delivering it for CO_2 storage in conjunction with enhanced recovery (EOR) operations. EOR is expected to extend the viability of the oilfield for an additional 20 years. This site also serves as the location for the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project. As a founding member of this

initiative, Canada, and its many private and public sector partners, is contributing to one of the largest international CO_2 measuring, monitoring and verification projects in the world.

This prior experience also shaped public policy towards CCS in the oil and gas sector. As early as 2002, Canada began discussing the potential role of CCS to achieve deep reductions in CO_2 emissions from electric power generation. The domestic weight of the oil and gas sector was underlined as a specific opportunity for CCS under the UN Framework Convention on Climate Change , as the cost of capture is much smaller for non-combustion sources, and even zero for high pressure sources of high quality CO_2 such as natural gas processing and the production of hydrogen used in petroleum refining. Therefore the oil and gas sector is seen as a field able to encourage and test the adoption of CCS technologies while building the necessary regulatory and technological capacity for broader use of CCS. The initial customer base would allow lower costs for CCS equipment through economies of scale and enable its deployment in new power plants and in a later stage to retrofit existing plants.

Demonstration projects launched in Canada aim at validating the entire technical chain and give a more important role than others to the transport (investment in a first network of pipelines in Alberta) and storage steps (Table 4.8). The international prospects for later exports are also stressed and considered, contrary to the German case described earlier, as important as the contribution to domestic reduction of CO_2 emissions.

In addition to supporting demonstration projects, Canada is taking other actions to accelerate CCS deployment, including establishing and strengthening regulation, creating incentives for CCS investment, facilitating sharing of knowledge and best practices, and enhancing public engagement.

Canada is committed to working internationally to ensure that domestic efforts contribute to the overall global advancement of CCS. The Government of Canada is a founding member of the Global Carbon Capture and Storage Institute and is active in organisations that deal with CCS such as the Carbon Sequestration Leadership Forum, the International Energy Agency, the Asia Pacific Partnership, the Major Economies Forum and Clean Energy Ministerial process, the International Energy Forum, and the Asia-Pacific Economic Cooperation. It is particularly important for Canada to co-operate with the United States given the extent of their economic integration as well as the common geology for CO_2 storage that could potentially facilitate cross-border CCS projects in the future. To this end, CCS is one of the three main components to the Canada-U.S. Clean Energy Dialogue.

Table 4.8. CCS large-scale demonstration projects in Canada

As of 27 November 2010

			Federal funding CAD million		Provincial funding CAD millions	CO_2 injection	
Province	Proponent	Project name	Source	Announced/ committed	Announced/ committed	Expected (millions tons/yr)	Starting in
British Columbia	Spectra[1]	Fort Nelson CCS project phase 1	ecoETI & CEF	24.3	3.4	Up to 2.0	N/A
Alberta	TransAlta[2]	Project Pioneer	ecoETI + CEF	342.8	436.0	Up to 1.0	2015
	Shell[2]	Quest Project	CEF	120.0	745.0	Up to 1.1	2015
	Enhance[2]	Alberta Carbon Trunk Line	ecoETI + CEF	63.3	495.0	Up to 1.6	2013
	Swan Hills[2]	In-Situ Coal Gasification & Power Generation	N/A	-	285.0	Up to 1.3	2015
Saskat-chewan	SaskPower[2]	Boundary Dam CCS Project	Budget 2008	240.0	1 160.0	Up to 1.0	2015
	Weyburn-Midale[2]	Commercial EOR operations	N/A	-	-	Up to 2.9	Opera-tional
Total[3]	7 projects			790.4	3 124 4	Up to 10.9	

1. Preliminary studies for a large-scale, integrated project.

2. Large-scale, integrated project.

3. Total project costs are not available for individual projects; however, the total cost of all projects is estimated to be over CAD 7.5 billion.

ecoETI: ecoENERGY Technology Initiative (administered by the Department of Natural Resources Canada).

CEF: Clean Energy Fund (administered by the Department of Natural Resources Canada).

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

Opportunities for international co-operation

Another factor required for advancing CCS is co-ordination and collaboration between the various players: national and sub-national governments, industrial sectors, researchers, international CCS institutions, non-governmental organisations and the public.

The first topic requiring a collective approach between neighbouring countries deals with carbon transport and storage. Given the location of sites that emit CO_2 (power plants and manufacturing facilities) and appropriate geological storage formations, it may be necessary to cross borders to optimise the CCS chain.

The second main field for international co-operation on CCS public policies is R&D and demonstration subsidies. Even if energy providers and equipment manufacturers will likely compete with each other in the future CCS market, they currently share a common interest in the rapid emergence of commercial demand for CCS. Demonstrating the viability of this technology with real-scale projects is therefore a condition all will benefit from. To avoid wasteful duplications and shorten operational delays, it seems logical to focus resources on current projects (*e.g.* 12 in the European Union, 7 in Canada). As some competitors may be excluded from this limited list, a co-ordinated international policy is crucial to disseminate the results among the firms, share the gained experience, and generate positive externalities for all member states financing these projects. Finally, considering the variety of technological trajectories for CO_2 capture, international collaboration on R&D may offer opportunities for a country to maintain a significant presence in each pathway with limited financial resources (*e.g.* cooperation on oxyfuel capture between Germany, Denmark and the United Kingdom). International public policy for CCS is therefore necessary to complement, leverage and improve the efficiency of domestic policies.

Conclusion: The role of initial conditions in policy orientations and timing

Carbon capture and storage is worth considering as a case of public policy design for an eco-innovation for two reasons. First, it is an almost mature technology, a validated concept, which makes it possible to distinguish clearly research and development challenges from all the other factors of successful adoption and diffusion (commercial cost, regulation, demand features). This simplifies the playing field and the comparison of policy instruments available to support this innovation. Technical uncertainty is not absent but is different in nature. While radical innovation calls for specific public approaches, the coexistence of several independent technical trajectories, as in the CO_2 capture stage, shapes an environment in which the volume of R&D effort is not the commanding success factor. Allowing a diversity of technical responses at the firm or country level in this context suggests that different methods and instruments can be applied.

The second result demonstrated by this study is the crucial role of domestic initial conditions in the design of an efficient and relevant public policy. These initial conditions include the energy structure of the economy, the manufacturing base, the existence or not of a carbon tax or an emission trading system, the international dimension of domestic energy providers and equipment manufacturers. When comparing Canada, France and

Germany, one can easily pin down the different economic motivations for a public policy in favour of CCS; this has important consequences for the selection and the efficiency of the instruments to be implemented (Table 4.9). In Germany, the context is dominated by the long-term issue of coal and the need to reduce in an economically viable way, with CCS, local emissions of CO_2 by the power sector. In Canada, which is a large producer and exporter of fossil fuels, demonstrating CCS feasibility is essential to extend the sustainability of its current economic model and to facilitate the smooth transition of its large commodities companies. Finally, in France, where CO_2 is a less important issue in the power sector, since 80% of electricity is generated by nuclear power plants, the main focus for CCS prospects is manufacturing facilities and the retrofit of installed power plants all over the world (the national energy equipment Alstom is a world leader in this field, with a 25% market share in the installed base of power plants). Various domestic initial conditions thus define public priorities and suggest, for the same innovation, different instruments.

Table 4.9. Patterns of domestic CCS policy differentiation

Country	Canada	Germany	France
Relevant economic characteristics	Oil and gas producer and exporter	Majority of electricity generation from coal-fired power plants	Low reliance on oil and gas for electricity generation (nuclear base) Large energy equipment manufacturer
Initial driving force for considering CCS	Reduction of CO_2 emissions and enhanced oil recovery in oilfield	Reduction of CO_2 emissions from a large and continuing coal power base	CCS retrofit exports in the world market leveraging the installed customer base of power plants
Importance of domestic demonstration sites	High	High	Low
Technology criteria	Efficiency, flexibility, reliability, technology readiness	Efficiency, flexibility	Proven techniques, time-to-market, flexibility
Primary public policy objectives	Leverage current technological and industrial advances to competitive advantage	Parallel exploration of the three capture routes	Improve the competitiveness of commercial CCS offers
Main associated preferred instruments	Subsidies for demonstration plants, pilot studies and field trials, and R&D	Inclusion of CCS in the EU ETS system, Mandatory obligation, feed-in tariffs	R&D subsidies, grants, inclusion of CCS in the CDM system

Source: Gilles Le Blanc, CERNA/Mines Paris Tech.

References

Global CCS Institute (2010), *The Status of CCS Projects Interim Report 2010.*

International Energy Agency (2009), *World Energy Outlook*, IEA, Paris.

International Energy Agency (2008), *Energy Technology Perspectives*, IEA, Paris.

IPCC (2007), *Fourth Assessment R*eport, IPCC, Geneva.

IPCC (2005), *Carbon Dioxide Capture and Storage*, IPCC, Geneva.

McKinsey & Company (2009), *Pathways to a Low Carbon Economy*.

McKinsey & Company (2008), *CCS: Assessing the Economics*.

Reinelt, P. and D. Keith (2007), "Carbon Capture Retrofits and the Cost of Regulatory Uncertainty", *The Energy Journa*l, Vol. 48, No. 4, pp. 101-127.

Rubin, E., S. Yeh, M. Antes, M. Berkenpas and J. Davidson (2007), "Use of experience curves to estimate the future cost of power plants with CCS capture", *International Journal of Greenhouse Gas Control*, pp. 188-197.

Schütze, K. (2009), "Impact of the clean coal industry on employment: Country study on Germany", in ETUC, *Climate change, new industrial policies, and exiting the crisis*, London.

Scottish Centre for Carbon Storage (2009), *www.geos.ed.ac.uk/sccs/storage/storageSitesFree.html*.

Stern, N. (2006), *Review on the Economics of Climate Change*, HM Treasury, London.

World Coal Institute (2009), *Securing the Future, Financing CCS in a post-2012 World*, London, *www.worldcoal.org/bin/pdf/original_pdf_file/securing_the_future_ccs_financing(12_11_2009).pdf.*

Chapter 5

Electric cars: Policies in Canada, France and Germany

This case study examines policy issues for electric car eco-innovation in an ad hoc *analytical framework. It examines in turn the complex technological environment of electric vehicles, the expected market and demand characteristics, the specific diffusion challenges faced by this technology, and the domestic policies and instruments implemented to support their larger adoption in Canada, France and Germany.*

Introduction

To reduce greenhouse gas emissions and achieve the global emissions reduction target internationally set for 2050, every sector of the economy must be involved and the widespread, parallel development of every available mitigation technology strongly encouraged. This involves at the same time energy efficiency, renewable power, carbon capture and storage, as well as new transport technologies. In the last case, electrification of vehicles is widely considered a particularly attractive and efficient option. In many countries, the petroleum burnt in combustion engines of individual cars accounts on average for 25-30% of total CO_2 emissions. Therefore, the widespread adoption and use of electric and hybrid vehicles offers a very significant potential for emissions reduction.

Many studies and reports have explored the different obstacles to mass deployment of electric vehicles. Cost issues, technological challenges, psychological factors and uncertainty regarding the recharging infrastructure are usually considered the main barriers to broad diffusion and adoption. But there is a common and more general economic issue at stake: the lack of information. The understanding of demand patterns and sales potential, consumers' needs and preferences, willingness to change travel behaviour, and ownership desire remains quite rudimentary and fragmented. At the same time, there is still a great level of confusion about the performance of electric vehicles owing to the lack of relevant and rigorous metrics for comparison. Finally, a potential and credible timeline for cost reduction and technological improvements is a source of endless controversies, contradictory results and previsions.

Despite, or perhaps because of, this rather imperfect information environment, voluntarist announcements about electric vehicles by industry leaders and governments have flourished at the end of the decade. Several start-up companies, such as Tesla with its emblematic sport electric roadster, claimed to have reached the commercial stage of radically innovative electric vehicles. The largest car manufacturers (*e.g.* Renault, BMW, Chevrolet, Nissan) have replied with a series of new electric models, with market launch planned in 2011-13, and multiplied demonstration models in the largest auto shows. This generated a great deal of interest from the media, which has praised the ongoing revolution in a one-hundred-year old industry severely hit by the 2008/09 recession. Government tax credits and R&D subsidies for low-carbon transport technologies, emissions regulations, fuel economy standards for vehicles, as well as unstable and rising oil prices made the idea of electric vehicles attractive. But, despite these boastful announcements, fewer than 10 000 purely electric cars were

sold worldwide in 2009. And, though significant, the current fleet of 2.5 million hybrid vehicles represent only 0.3% of the total number of cars on the roads worldwide.

This case study examines policy issues for electric car eco-innovation in a revised, *ad hoc* analytical framework. Compared with combined heat and power (CHP), carbon capture and storage (CCS) or biopackaging, the electric car is characterised by a high level of uncertainty regarding economic, technical and political factors as well as consumer behaviour. To overcome contradictory and untestable results and to derive policy orientations, one must reduce the scope of the analysis with a set a basic assumptions. These assumptions are based on a comprehensive literature review of business, academic and policy studies, articles and reports, as well as a series of interviews with companies, institutions, investors and NGOs in the three countries surveyed, Canada, France and Germany. The demonstration and full discussion of these assumptions are beyond the scope of this report, and they should be considered as *ad hoc* axiomatic tools for building the economic analysis. The three assumptions are the following.

The lack of information (about technologies, performance, demand and market features, and competition) constitutes today the primary and basic problem. No serious discussion of the obstacles faced by electric vehicles and the best public initiatives to address them will be possible without a substantial improvement in the understanding of these fundamental elements.

Any attempt to demonstrate the economic profitability of an electric car purchase for the consumer is likely to remain vain and useless. Whatever figures and assumptions on cost reduction are used, the results will still be fragile and unconvincing. Given current conditions, there is no way to justify the extra cost of an electric vehicle in the absence of a radical change in fuel prices, such as the introduction of a carbon tax.

Electric vehicles should not be considered as a new version or a new sub-branch of the auto industry. One must think radically new demand, preferences and usages to imagine innovative offers and the potentially credible associated market. Otherwise, electric vehicles are likely to remain a niche segment for a very long time, as they have been for more than a century. Only truly innovative and radically new designs will support the effective diffusion of this technology on a large scale for a market that has still to be defined and characterised.

In this respect, Daimler CEO Zetsche made an insightful quote from Albert Einstein at the Competitiveness Council in February 2010: after a student noticed that the weekly test was the same as last time, Einstein replied: “Yes, but the answers are different this time”. This paradoxical

remark is particularly relevant when analysing the innovation of electric cars. Though cars have been on the road for more than a century, the sustainability issue and the search for low-carbon transport solutions require a completely different approach, starting with a blank sheet and rebuilding a brand-new model, free from the inherited technical trajectories, product design, industrial organisation and economic arrangements in place for decades.

To put this in perspective, it should be recalled that electric cars are by no means a new concept and product. At the turn of the 20th century, more than a hundred years ago, the fastest car was an electric one and sales exceeded those of cars with an internal combustion engine in the United States. But the long technological and business history of electric cars, with a series of failed expectations, has demonstrated one clear result. Electric vehicles cannot succeed in the market without strong policy support to ensure their cost competitiveness compared with existing fuel cars and to make available the necessary recharging infrastructure.

This report examines in turn the complex technological environment of electric vehicles, the expected market and demand characteristics, the specific diffusion challenges faced by this technology, and the domestic policies and instruments implemented to support their larger adoption in Canada, France and Germany.

Technological and competitive environment for electric vehicles

Different sources of power and different types of engines can be used to run a vehicle for individual transport. Technological variety in types of propulsion dates back to the early days of cars. In the second half of the 19th century, steam machines, petrol combustion engines, and electric motors coexisted. Only after 1910-20 did the internal combustion engine gain leadership and eventually become the sole technological trajectory for the automotive industry.

Since the 1990s, growing concerns about the depletion of fossil fuels, pollution and climate change have reopened the technological landscape, with a search for cleaner low-carbon transport vehicles. Four main solutions were identified: electric vehicles, hybrid vehicles, hydrogen cars, improved highly efficient combustion engines. This technological environment defines the competitive playing field for electric vehicles and the existing or potential scope for substitution.

In short, an electric vehicle uses an electric motor for propulsion with batteries for energy storage. Batteries are recharged externally from the power grid and on board from the brake energy regeneration systems. While

electric engines are both cheap and very efficient, the main drawback is the very low energy and power density of batteries compared to the liquid fuels burnt in internal combustion engines. This translates into limited range and high costs. The first industrial models flourished around 1880 and between 1895 and 1920 electric cars shared the roads with petrol- and steam-powered cars (*e.g.* the New York taxi fleet in 1897).

Hybrid vehicles use both a combustion engine and an electric motor. The battery capacity is limited (1-2 kWh) and is used as a temporary complementary power source to assist the main engine or replace it at low speed. The batteries are charged by the electricity generated by engine and brake energy recuperation. Plug-in models escape the limitation imposed by the vehicle's internal recharging system as they can be recharged from the power grid, which allows increased energy storage and driving range. The hybrid architecture, made popular today by the success of the Toyota Prius at the end of the 1990s, is almost as old as the car industry and was first introduced around 1909 in a failed attempt to combine the benefits of the electric and combustion engine technologies.

Electric and hybrid vehicles share three basic technical advantages. First, their energy and work loop is inherently bi-directional. The power train can convert stored energy into motion but also the kinetic energy of the vehicle back into energy storage through regenerative breaking, something a combustion engine vehicle cannot do. Second, an electric motor is a simpler and more efficient mechanism than a combustion engine. Finally, its torque characteristics are much more suited to the demand curve of a car, with maximum torque at low round per minute when the car needs it for acceleration. It does not require a complex multi-ratio transmission and one or two gear ratios are sufficient. Electronics is required to make the most of its inherent efficiency and mechanical simplicity; this is an area with continuous improvements and decreasing costs.

The third alternative option to be considered is the hydrogen vehicle. Again, this can hardly be considered a new concept, as a hydrogen-fuelled combustion engine was designed around 1800. The hydrogen (compressed and stored in a tank) can either be burnt as a fuel in an internal combustion engine, or react with oxygen in a fuel cell to run electric motors. The second solution was favoured as it potentially allows the benefits of electric technology without its drawbacks. Hydrogen fuel generators can produce electricity in real time on demand without the use of heavy batteries for storage. Hydrogen is considered an interesting energy source because it can be produced without using fossil fuels, and therefore offers clean low-carbon transport solutions. This technology is however controversial. The feasibility of a hydrogen car is not clearly established and massive R&D efforts would be necessary to bring this option to maturity. Despite

significant development spending, some car manufacturers such as Renault announced in 2009 that they would stop their hydrogen projects. In the United States, in 2009, the Energy Secretary S. Chu decided to cut R&D funds for hydrogen fuel cells; the decision is based on the argument that vehicles using this technology would not be available over the next 10-20 years and too many technological breakthroughs are required to make it available.

The main remaining player in the field is Honda, which introduced a fuel cell car called FCX in 1999. In 2008, a second generation FCX Clarity was marketed on a limited scale in the United States (California) and in Japan (government fleet). Honda aims to start mass production using the experience and feedbacks gained with this concept by 2020. The firm claims that hydrogen fuel cell technology is a more viable and efficient long-term solution than vehicles with batteries. To illustrate its continuous commitment, a new model Clarity FCX with significant improvements was introduced in 2010.

Finally, conventional propulsion systems with an internal combustion engine should not be ignored in the technological review. For the next decades, the majority of motor vehicles are likely to remain based on this technology. Also, the potential for further improvements in fuel efficiency and emissions reduction is still large. Since the first oil crisis, multiple innovations (electronic injection, variable valve timing, geometry of the chamber, common rail for diesel) have already made it possible to double the average energy efficiency of the combustion engine. Experts believe that many more improvements can be achieved, in particular for small engines. Small cars with combustion engines launched in 2008 and 2009 offer emissions under 100 and even 90 gCO_2/km, quite comparable with results for hybrids. In addition to improving the internal efficiency of the engine, alternatives to petroleum-based blends, such as biofuels, are explored. While this has the advantage of offering direct emissions reduction with only minor technical changes to existing vehicles, the overall environmental benefits are controversial, especially for the first generation of biofuels (crowding out of agricultural resources, air pollution). Accordingly, although there are significant increases in the efficiency and emissions of existing technologies, the gains do not match the expected increase in future demand for vehicles.

This review demonstrates the variety of distinct technological trajectories for propulsion systems. Each of the alternative solutions is based on a different critical element (battery, fuel cell, combustion engine), with little or no R&D scope economies. Even the batteries for pure electric and hybrid vehicles differ, as detailed below, and face distinct R&D challenges and priorities. In such a proliferating technological environment, there is

great uncertainty. The risks of following a given trajectory increase, but so do the potential competitive advantages and economic rents. This shapes a complex strategic game, with newcomers exploring radical alternatives, on the one hand, and, on the other, incumbent firms, with their large accumulated assets, divided between taking a leading exploratory role to rapidly leverage their market power in this emerging sector, and an imitative behaviour to avoid the costs of search-and-try errors and protect their historical brand.

Market, utility and demand characteristics for electric cars

The economic utility of electric vehicles has two dimensions: first, the classical consumer demand for a product, usually classified in the car market; and second, the collective environmental benefits from the reduction of emissions of greenhouse gases. In a context of incomplete and heterogeneous information, there are no clear and robust results available for either.

In terms of demand and market prospects, the range of estimated market size and share of electric vehicles over the next 10, 20 or 40 years is incredibly large. The many reports and studies published on this topic cover the entire spectrum of possible outcomes. Figures vary from a long-lasting niche of a few percent and several hundreds of thousands of electric vehicles sold in 2050 to a 50% market share for hybrids and electric vehicles (ACT scenario by the IEA, 2009) and even 65% for hybrids in industrialised regions (Greenpeace, 2010). This is no surprise given the extreme level of technical, economic and regulatory uncertainty about electric vehicles. The market estimations are the expected result of the implementation of the desirable policies suggested in the reports, rather than an analysis of consumers' preferences, willingness to pay and substitution dynamics. To overcome these limitations, two interesting sources may be considered: short-term predictions from car companies and governments, and qualitative results from surveys of car customers about the potential future purchase of electric cars.

Short-term evaluations are worth considering because they build on existing technologies, public instruments, industrial projects and the continuation of observable trends. They converge on a significant but still small market for electric vehicles, made of a large majority of hybrid cars. In 2020, the market size of electric vehicles would amount to 1.5% according to Volkswagen, 3% according to Valeo and 5% according to PSA. Renault makes the most optimistic estimate, a 10% market share. Industry forecasts for 2020 are in line with studies by consultants such as Global Insight (0.6% share for electric and 0.7% for plug-in hybrid vehicles) or

PricewaterhouseCoopers (electric vehicles reaching 2-5% of the light vehicles market). In the United States, Deloitte (2010) estimates that sales of electric and hybrid vehicles will remain modest on the US market, at between 2% and 5.6%. Governments presenting the "green" dimension of their economic recovery plans announced in 2008-09 ambitious national sales targets for electric and hybrid vehicles. In the three countries examined here, the penetration targets are 2 million vehicles in France, 1 million in Germany in 2020, and 500 000 in Canada in 2018. These figures imply slightly higher market shares for electric vehicles in annual sales of cars but the order of magnitude remains the same, under 15-20% in any case.

The consensus on the limited size of the estimated market in ten years has important consequences for the potential for scale economies, a crucial factor for the widespread diffusion of electric vehicles. For example, with Deloitte's medium forecast (*i.e.* total sales of 465 000 electric vehicles in the United States in 2020), with five main competitors on the market and two electric models offered by each, this means production per model of only 46 000, a volume far too small to effectively trigger scale economies and to recoup development and manufacturing investment.

Longer time horizons are in fact necessary to reach mass production and diffusion levels. Wyman (2009) estimates that sales of pure electric cars could amount to 3.2 million in 2025 with a total market share of electric and hybrid vehicles of 16%. In 2030, electric vehicles would comprise nearly 20% of the global market for light vehicles (8.6% market share for plug-in hybrids, 9.9% share for battery-electric) according to IHS (2010). According to McKinsey's 2009 mixed technology scenario, global sales of hybrid and electric vehicles would be 42% in 2030 (compared to only 16% in 2020), which corresponds to 37 million and 3 million vehicles, respectively.

Consumer surveys offer an interesting complementary qualitative view on future markets for electric vehicles. Most illustrate how current demand patterns are primarily shaped by preferences derived from conventional cars. The reason is the lack of precise, credible and validated information about electric vehicles. Hence, the main barriers for adoption found in every consumer survey are high price, limited range and smaller vehicle size. First, the majority of customers are largely unfamiliar with the technologies of electric vehicles. Only hybrids, after massive marketing and advertising efforts by pioneering manufacturers such as Toyota, benefit from a clear image and recognition. The general lack of knowledge about electric vehicles results in many wrong preconceptions and translates into a great deal of confusion regarding charging, safety, ranges and driving constraints. First and foremost, electric vehicles are considered less versatile and convenient than liquid-fuelled cars. According to Deloitte (2010), this is the main reason why, in a business-as-usual scenario, with no significant change

in public intervention and given customers' attitudes towards cars and their use, market shares in the United States for hybrids and electric vehicles could reach 8-10% but no more than that.

Interestingly, the Deloitte survey demonstrates how comparisons with cars with existing combustion engines drives expectations and needs regarding range, rather than effective transport requirements. While about 85% of the sample had daily requirements below 100 miles, only 20% would consider purchasing an electric car with that range, and 70% would expect a minimum range of 300 miles. This figure is not artificial; it corresponds more or less to the range of a traditional car on a tank of gas. People thus take a full tank of gas as their reference, and the driving freedom and convenience it represents for them. Similar results are found in Europe, where 50% of trips are less than 10 km and 80% less than 25 km.

This illustrates how consumer behaviour and acceptance of electric cars will be a key element of future demand. Today, it is very difficult to forecast changes that may occur in the next decades in consumers' willingness to change travel usages and their driving patterns, and in the acceptability of radically different types of vehicles and new ownership rules. With such uncertainty, information on individual preferences, the relative size and characteristics of early adopters and mass consumers, are lacking or too incomplete and fragmented to achieve a rigorous understanding of future demand patterns.

Regarding the likely impact of electric vehicles on emissions reduction, the final outcome strongly depends on the type and source of electricity generation. This issue has been thoroughly explored in country studies, such as that of WWF on Germany (2009). In the best case, with 20 million cars, the overall saving in domestic emissions would only be 25 million tonnes, that is, 2.4% of total emissions.

Several studies have tried to evaluate the carbon footprint of electric and hybrid vehicles on a lifecycle basis, including the source of electricity used for the batteries. The overall benefits are highly dependent on the charging regime and the structure of the power network. This affects in particular the relative environmental performance of pure electric and hybrid vehicles. The less carbon-intensive the electricity grid, with a larger share of renewables, the more savings can be made by an electric vehicle compared to a hybrid one. If additional power demand from electric vehicles triggers supply by marginal coal plants, then hybrids offer better results than pure electric or plug-in hybrid vehicles.

From a public policy point of view, while the potential of electric vehicles for cutting emissions is clearly significant and attractive, the cost factor should also be considered. A study by the Boston Consulting Group

(BCG, 2009) estimates that optimisation of internal combustion engines would offer a 12% improvement in emissions, at a cost of USD 140 per percentage point of emission reductions. Electric vehicles have a potential four times higher (50%) but at a cost of USD 280 per percentage point.

Main challenges faced by electric cars

In every study of electric vehicles, the same three main hurdles are cited: cost, range and charging infrastructure. Logically, many emphasise batteries and the necessary massive R&D effort to improve their performance. But, though necessary (see below), technological progress in batteries cannot alone solve all the problems. There is a more general and complex issue of information about electric vehicles. On multiple occasions in the past, electric cars were declared to be the future. This long story of failures and deceived hopes is the logical source of scepticism regarding the real prospects of mass production of electric vehicles for the market. The next sections examine how the main challenge for electric vehicles is simultaneous uncertainty about cost, standards, performance, and supporting infrastructure; each item is discussed separately.

Cost and financial uncertainty

The price and cost differential for electric vehicles compared with conventional cars is a major element, likely to last during the next decades. The range varies according to estimates and studies but remains substantial in every case. An electric car on average costs USD 7 000 to USD 20 000 more than the comparable vehicle with an internal combustion gas engine (PricewaterhouseCoopers). Cost modelling (Wyman, 2009) indicates that average costs for an average battery electric vehicle are 2.5 times higher than those for a car with a combustion engine, and the ratio for hybrid cars is 1.5. Technological innovation, process optimisation, product design simplification and scale economies are expected to result in significant progress along the cost curve, but the gap should remain significant in 2025, with a differential estimated at 70% and 30%, respectively, for the two types of vehicles.

The main factor driving up the price of electric vehicles is the durably high cost of batteries. The cost of the average automotive lithium-ion battery in 2010 with available technologies is around USD 1 000/kWh (as sold to car manufacturers). A battery cost model developed by BCG (2009) suggests that the cost could decrease by 60-65% to USD 360-440/kWh (based on a world market forecast of 14 million electric cars sold in 2020, including 11 million hybrids). IEA (2009) estimates that mass production of the lithium-ion battery could drive costs by 2012-15 into a range of

USD 300-600/kWh. But even at the lower level of this range, this means that an electric vehicle with 25 kWh of capacity, a minimum requirement, would have a battery cost of USD 7 500.

The problem is that consumers today are unwilling to pay for this price differential. Their price preferences and expectations are driven by comparisons with conventional cars. Electric vehicles do not benefit from a quality premium, as did flat screens, which were widely and rapidly adopted despite prices two to four times higher than conventional television sets. Customer surveys indicate converging and homogenous results. In the US market examined by Deloitte (2010), 73% of customers did not expect to pay more than USD 35 000 for an electric car. Only 18% would consider a purchase with a price above USD 40 000. Indeed, the majority (55%) would want prices under USD 30 000. In Wyman's survey in Germany, only 14% of car buyers were ready to pay more for an electric car, and the acceptable premium was only EUR 2 200. Under these conditions, in the large car market segment corresponding to the VW Golf, an automaker would lose EUR 12 000 on a battery electric vehicle despite an electric car premium.

Basic economics explain these results. A cost/benefit analysis of the purchase of an electric car must compare the higher acquisition price with future savings in fuel costs over the car's entire life. The difficulty is not only standard risk aversion, preference for the known, and correct valuation of later gains. In addition, the cost savings are highly uncertain, subject to unstable market conditions and changing regulatory frameworks, and potentially small. Many studies have tried to compare the total cost of ownership of an electric vehicle with ownership of a liquid-fuelled combustion engine car, using assumptions about rises in fuel prices and the expected lower cost of electric cars. Results are mixed, fragile and when positive, much too limited to capture consumers' adhesion. An example in Wyman (2009) indicates that the 46% cost disadvantage in 2010 could become a 10% gain in 2025, mainly due to the 50% increase in fuel cost for a combustion engine vehicle and a 30% reduction of the acquisition price and associated depreciation (under assumptions of four years' usage and 15 000 km a year). Even the most optimistic assumptions cannot overcome the unfavourable economic conditions and inherited fiscal bias in favour of fossil fuel. The value of the savings in oil consumption and emissions offered by an electric vehicle is not sufficient to compensate the high upfront cost of the batteries. Only a general carbon tax or a fiscal treatment of combustion engine cars could correct the existing bias and effectively value the savings in carbon emissions. Therefore, the financial viability of electric vehicles cannot result solely from the reduction of manufacturing costs and uncertain scale economies.

Technical challenge: improving battery performance of the electric car

Current technological debate and the definition of priorities revolve around the issue of batteries. This is logical, considering, as explained above, that car buyers apply to electric vehicles the criteria and standards they are used to in terms of range, safety, driving comfort or performance. To reach an expected range of 200 to 300 miles will require significant breakthroughs in battery performance. However, there is a risk in isolating this issue from other relevant issues and hoping that a new wave of innovation in batteries would alone ensure the commercial success of electric vehicles. Given the overall level of uncertainty about electric vehicles, the direction, objectives and priorities of R&D in the field of batteries are not straightforward. They are in fact highly dependent on technological choices, economic models and the desired characteristics of vehicles. The following elements illustrate this crucial point for public policy makers.

The previous section implies that reducing battery cost per capacity is logically the main priority. But other dimensions of the battery's performance are likely to play an important role as well: plugging efficiency, number of charge-discharge cycles, total calendar life, deterioration of performance over time, sensitivity to weather and temperature conditions, safety, disposal and recycling. For about 200 years, power storage made little progress as most R&D and innovation in the energy field focused on generation systems and technologies. In the 1980s and 1990s, the spectacular growth of mobile electronic devices (music players, mobile telephones, laptop computers) triggered an intensive wave of innovations in which Sony played a pioneering role. This resulted in the emergence and rapid dominance of the lithium-ion family of battery technologies. Patent filings related to energy storage increased 17% a year between 1999 and 2008, twice as fast as during the previous ten years, and most were for lithium-ion technologies (BCG, 2010). Plans for modern electric vehicles naturally intend to build on this technological base and improvements in energy storage.

But there is still no ready-to-use battery technology that meets the many, often contradictory objectives of an electric vehicle: durability, capacity, life expectancy, safety, weight, recharge rate. Massive R&D efforts are necessary and the question is less one of financing than of relevant and efficient organisation. The key challenge raised by multiple performance objectives is to find an optimised trade-off among the different aspects under severe cost constraints. Presently, the family of lithium-ion batteries offers the best prospects for optimising at the same time specific power

(W/kg) and specific energy (Wh/kg). But this electrochemical configuration covers a range of different battery types and technologies. And no solution has so far emerged that has a clear-cut edge over the other configurations. For example, nickel, cobalt and aluminium offer very good performance in terms of calendar life and cycle life, but they require a high voltage charge and there are still safety concerns. In contrast, lithium-polymer chemistry is considered a safe and reliable process but the life expectancy of the battery is rather short. The best compromise between the different performance parameters has yet to be found and validated on an industrial scale. To do so, exploratory research is clearly necessary to test various electrode materials, high voltage electrolytes, cells and module design. At the same time, the highest levels of safety must be guaranteed and publicly demonstrated, as this is a critical aspect of future acceptance of electric vehicles by consumers. The hazards of high-energy batteries are well known and should be controlled with adequate design, choice of materials and quality control.

Uncertainty about alternative technological trajectories to explore is reinforced by diverging goals and technical priorities for pure electric cars and hybrid vehicles. The optimisation of energy storage capacity is crucial for the former, while the increase in power density is the primary objective for the latter. The duty discharge cycles also differ significantly, raising distinct technological issues. Batteries for hybrid vehicles are subject to many intermediate and shallow cycles according to the successive phases of power assist and regenerative breaking during travel. But the shift to an all-electric mode (after stops for example) will involve a sudden and deep discharge cycle. Batteries for pure electric cars are subject to a more linear functioning mode with a repetition of deep discharge cycles. The mode of recharging also implies different objectives: a slow recharge could be acceptable for overnight in the home garage, but faster recharge rates are imperative during the day (in parking lots, and more importantly, on highways). This might result in the parallel development of different battery technologies for the two categories and hence reduce the potential for scale economies.

The current industrial organisation of the auto and electric industries also raises new and serious co-ordination and strategic issues. The number of battery manufacturers with significant technological and manufacturing capacities is limited. And entry barriers for newcomers, such as start-ups with innovative approaches, are quite high, owing to the cost of R&D, capital investment and access to inputs. Lithium and the other necessary rare earth metals for batteries are very concentrated geographically, which could result in supply bottlenecks. Car manufacturers would have to set up partnerships with battery producers to secure future supplies and to access

innovation in this critical field. This marks a radical departure from the historical industrial organisation of the car industry, whereby the main auto companies built vertical integration of engine production in their own factories or in joint ventures. Only the Chinese BYD is involved in both car and battery production, as it was originally a battery company and later entered the automobile sector.

In summary, the large, fragmented and open technological scope of battery configurations, the divergent needs for electric and hybrid vehicles, and the disaggregated industrial organisation make the definition and prioritisation of R&D a much more complex task than for other eco-innovations. Competition and strategic interaction between the players involved, and the economic interests at stake, could prevent for a while the selection and validation of an optimised solution. This is why the economic future of electric vehicles, and supporting public policies, cannot solely rely on technological efforts and R&D programmes.

Standardisation issues

The ongoing multiplication of public and private initiatives, car development plans in the industry, research projects on battery technologies, and pilot-charging infrastructures raises an additional danger for the widespread adoption of electric vehicles: the lack of standardisation may prevent the emergence and consolidation of a real market. Such phases are definitely not new and largely result from the very nature of a radical innovation. Competition among many different product designs, technological solutions and business models during a proliferation period actually ensures that the most efficient and desirable solution will emerge and later become a standard on the market. The history of the auto, aircraft and pharmaceutical industries illustrate this point. However, specific economic features of electric vehicles call for a minimum level of standardisation at an earlier stage.

First of all, there is today no established and consensual metrics for describing electric vehicles and for comparing their performance and costs in a rigorous manner. Since their driving cycles are different from those of combustion engine vehicles, metrics such as effective driving range on electricity are necessary. Specific measurement criteria should also be defined and introduced for emission levels as well as the safety of electric vehicles, taking into account features such as driving profiles, weight, parking locations or connection with the electricity grid.

The second major field calling for standardisation initiatives deals with the interface between electric vehicles and the power grid. Contrary to other cases of eco-innovation such as CCS, CHP or biopackaging, the adoption of

electric vehicles fundamentally relies on the existence of a complementary collective infrastructure to recharge batteries of pure electric and plug-in hybrid cars. Therefore, a significant level of compatibility is required to ensure that the different models can access the grid in their home country as well as neighbouring ones, in order to allow exports and trade and to avoid costly and inefficient proprietary systems.

Investment in the enabling (re)charging infrastructure

The last key challenge faced by electric vehicles (both pure ones and plug-in hybrids) is their critical reliance on a comprehensive and efficient infrastructure to recharge on-board batteries. As in every case of network externalities, this raises the classic "chicken-and-egg" problem with the need to build up a minimal critical size to allow further adoption of the new product. In the early days of the car industry, this played a major role in the success of internal combustion engine vehicles, as petrol stations were easy and less costly to roll out throughout the country. The situation is of course quite different today as electricity is available everywhere. However the successful roll-out of a recharging infrastructure requires huge new investment, standards which ensure grid access for every type of electric vehicle, and new monitoring and management tools for the power grid. In each case, information is the central economic issue.

Each charge station costs USD 800 to USD 1 200. A recharging area with 15 slots and the associated infrastructure is therefore estimated to cost around USD 100 000. In the case of France, with about 30 000 petrol stations, and assuming that an equivalent density would fulfil the demand from electric cars (whose range is typically shorter but duplication of sites can be reduced as the recharging infrastructure can be considered an essential facility without competing offers), the minimal investment would cost several billion dollars. Other estimates are much higher, with costs amounting to tens or hundreds of billions of dollars for a single country. In any case, the financing of this necessary complementary infrastructure is a major issue. Without the ability to recharge an electric vehicle easily, quickly and cheaply, consumers' reluctance about this new technology will not vanish. This is why a step-by-step approach is often considered the most promising and viable: first, facilitate home charging overnight and invest in stations in public parking places in urban areas, then focus on highways and main travel roads, and finally fill the remaining geographical gaps to allow seamless transport with an electric vehicle from any point of the territory to any destination. The distribution of the resulting investment costs between public authorities, energy utilities, car manufacturers and final consumers has yet to be established but this is largely a negotiation process, taking into account potential future revenues (for utilities and manufacturers) and the

necessary distinction between several successive stages (initial roll-out, critical size build-up, widespread deployment).

A second crucial element is the necessary standardisation of the interface between the vehicle and the grid. Setting standards at the scale of continents for plug types (connectors and cables), recharging protocols and communication software is necessary to reach the desired level of scale economies, to ensure compatibility and competition between the products offered, and eventually to create the largest possible market for the products. The choice of the plugs and connections in public charging areas (home or stations) must also address security issues. It must take account of the current normative levels for the safety of electrical installations applied today in Europe. The expected increase of power levels in electric vehicles with high voltage batteries and the location of numerous stations in residential areas accessible to children add two specific constraints. Several initiatives have already suggested possible solutions to counter the current multiplication of individual un-coordinated settings. An open consortium, EV plug Alliance, was formed in spring 2010 by Gimelec, Scame and Schneider Electric to promote the use of a unified connecting system throughout Europe to charge electric vehicles. The proposed solution consists in standardising a detachable connexion cable with a different plug at each end. The IEC (the international standard organisation for electric devices) defined three possible types of connectors to charge electric cars. In North America, the Society for Automotive Engineers (SAE) is a key standards development organisation.

Finally, efficient connexion of electric vehicles to the grid requires new and standardised information flows to monitor and manage the resulting demand, power load and peak periods. The additional energy demand induced by a growing fleet of electric vehicles will strongly depend on usage features, driving patterns, customer behaviour, pricing schemes, etc. However, information is lacking today to anticipate and measure precisely the power demand induced by electric vehicles. It can only be obtained with field experiments and consumer feedback. In such a context, ongoing research and investment in smart grids could considerably facilitate and enable the future inclusion of electric vehicles, if this issue is integrated early enough in the design and technical configurations implemented.

Given the huge economic interests at stake, innovation could also offer alternative or facilitating solutions. Two well-known examples illustrate this possibility. The first is the original business model set up by Better Place, based on a mixed network of charging stations and automated battery exchange stations. The prototype system was presented in Japan in May 2009. It uses robotic trays to remove a depleted battery and replace it with a full one in about a minute, with passengers staying in the car. The company,

which built partnerships with Renault, Subaru and Mitsubishi, intends to invest in a stock of batteries and the infrastructure and then sell consumer subscriptions, similar to cell phone plans. The model, though very simple and attractive in substance, is criticised essentially because of the strategic role of batteries and standardisation issues. However pilot experiments are already carried out or scheduled to start soon in California, Canada, France, Germany and Israel. The second example deals with the potential use of the electric car as an integrated power management device for the customer. In spring 2010 at the New York International Auto Show, a partnership was announced by Ford and Microsoft to create a computerised link between houses, electric cars and utility companies. The electric car system will be used to manage home energy use and offer power savings. The first product is the software system Hohm by Microsoft and will be installed in the new all-electric Ford Focus to be launched late in 2011. Real-time information exchange with the local utility will determine the best time to recharge batteries. Optimising demand would reduce peak power load and the need for additional power capacity. In the future, with the increase in battery capacity, the idea is also to use the car to power home appliances.

National public policies for electric cars

Review of available policy instruments

In such a confusing environment, marked by a proliferation of alternative technological trajectories, simultaneous challenges, and an overall high level of uncertainty, the definition of the relevant public policies and instruments is particularly complex. They should avoid "cherry picking" and the *ex ante* selection of winners that may result from instruments that support a particular technology, architecture or even company, as this may have irreversible effects and lead to technological lock-in and economic rents. At the same time, waiting for the optimal solution to emerge is not a satisfactory policy. A race has started worldwide to gain a commanding position in this emerging and potentially huge market. Every industrialised and emerging country (China, Japan, United States) has launched intensive policy support for electric vehicles, with sometimes new and unexpected co-operation. China and the United States are for example pursuing a joint initiative on e-mobility. A minimum level of co-ordination is essential. But the multiplication of initiatives and supporting actions could also be counterproductive, with wasteful competition between countries and firms (especially across the EU). Previous sections have demonstrated the lack of information regarding technologies, demand patterns, costs and economic models for electric vehicles. In such an environment, one may argue that defining and

implementing a public policy is impossible and premature. The priority should be to produce the necessary missing information and encourage a strong dynamics of initiatives, trials and experiments to explore the full scope of possible alternative options.

In the same line of reasoning, IEA (2009) underlines the role, and the urgent need for, standardised and rigorous information on the demand for and technical features of electric cars, so as to base policy decision making on transparent, comparable and evaluable quantitative cost/benefit analysis. Accurate information on technical and usage characteristics and performance is also clearly necessary to raise consumer awareness and confidence in these products.

A large number of policy instruments could play a role in promoting electric vehicles: differential treatment (preferred access to restricted city centres, fast lanes or parking spots, reductions in highway tolls, car taxes); public procurement (government fleets, public transport); fiscal incentives for the purchase of an electric vehicle or investment in the recharging infrastructure. Some or a combination of these are tested and implemented in many countries. But, given the current state of knowledge, their efficiency is doubtful and ambiguous. An OECD study (2010) on patents for alternative fuel vehicle technologies (between 1983 and 2007) offers insightful results in this respect. Among the potential instruments to support innovation in this field, it undertakes an empirical analysis of three of these measures (public R&D, standards and fuel prices). The econometric results demonstrate that the most efficient instrument is a technical standard (such as vehicle fuel efficiency standards or mandatory emissions caps). The elasticity of inventive activity in electric vehicle technologies with respect to a standard is positive, though relatively inelastic. In contrast, fuel prices, and more interestingly, increases in public R&D budgets have relatively minor effects.

This suggests that indirect measures are probably more relevant and better suited to the present environment. To begin with, the diffusion of electric vehicles could benefit greatly from ongoing public research, development and investment in smart grids. Real-time information sharing is necessary to introduce sophisticated charging systems using power from batteries for peak power and load balancing, restricting charging in times of peak demands, or differentiating day/night and even hour tariffs. Another example can be found with car-sharing initiatives. Growing congestion and pollution in dense urban centres offer specific opportunities for electric cars in car-sharing programmes. Two factors in particular offer favourable conditions: parking spaces for recharging batteries and the small typical travel length in cities. This overcomes the usual limitations of electric vehicles: recharging time and range.

Finally, clarification of the respective role of pure electric vehicles and hybrid cars should be considered a central element of public policy. Most current domestic initiatives intend to promote both categories in parallel. But, given their size, urban density and share of renewables in electricity generation, some countries might give priority to pure electric vehicles and reach critical size in that market as fast as possible. Others might use the sales and progressive accumulation of a fleet of hybrid cars to accompany the roll-out of the domestic recharging infrastructure, initiate scale economies in battery production, and help reduce the sales and operating costs of pure electric vehicles, to make possible their mass diffusion in a second phase.

The review of the three national cases illustrate the different experimental and exploratory phases in the diffusion of electric vehicles: driven by industry (Germany), provinces and cities (Canada), and the government and public agencies (France).

Electric car policy in Germany

A National Platform for Electric Mobility was announced in May 2010 by the German government, with the support of domestic car manufacturers and energy utilities. The objective is 1 million electric cars by 2020, or one out of every 45 cars on the roads. But no specific funding has been decided, despite calls by the auto industry for state-funded incentives and investment in a network of recharging stations. New plans and experiments come first from the industry and the main car manufacturers.

During the Geneva Auto Show, Volkswagen unveiled an ambitious electric vehicle strategy. The first European car manufacturer announced a two-stage plan, based first on hybrid vehicles (Touareg in 2010, Jetta for the United States and Golf for Europe in 2012), followed by the launch in 2013 of four electric models: Golf blue e-motion, Up blue e-motion, Jetta blue e-motion and Lavida for the Chinese market. The strategic objective publicly announced by the company's chairman is to reach a target of 3% of sales with electric vehicles (*i.e.* about 300 000 cars) by 2018 and to become a market leader in this emerging segment. The distinct aspect of Volkswagen's strategy, compared with Renault, Ford or Toyota, is that the introduction of electric technologies builds on existing, familiar and successful models rather than brand-new vehicles.

BMW follows a radically different approach. It plans to launch its first series-production electric model in 2013 with the Megacity electric car. The electric engine is not the only innovation of the model. In order to reduce the weight significantly, carbon fibre composites will be massively used for the structure. A sophisticated regenerative breaking system is also announced.

All these elements combined are expected to achieve a range of 160 miles per charge. Usage data and insights collected from a field test with 600 Mini electric models are used in the development phase to fine-tune the technical features of the model. To reduce risks for the reputation of the corporate brand, the Megacity will be marketed under a new sub-brand, as BMW did with the Mini in the 1990s to enter the lower small-car market segment.

With Daimler also involved in electric car innovation, the three main domestic players in the German car industry are playing a leading role in defining the direction of R&D and the design of electric models, and in testing consumers' reactions in the market to their differentiated offers.

Electric car policy in Canada

As Canada is one of the rare countries in which electricity is mostly produced from renewable resources (hydropower, and increasingly wind and solar energy), a massive transition to electric cars for individual transport makes sense and offers great potential to reduce CO_2 emissions. Electricity pricing is considered a major means of achieving this objective; differentiated tariffs during peak and off-peak periods aim, for example, to curb demand for electricity for charging batteries, to draw power from fully charged vehicles in peak times, and to avoid the need for additional capacity. As a result of a larger green electricity grid, it is estimated that an electric vehicle would on average reduce greenhouse gas emissions by 85% compared to a gasoline-powered vehicle. In fact, the reduction potential ranges from almost 100% in provinces like Quebec and Manitoba to a much lower 45% in Alberta, where a large fraction of the electricity is still generated from coal-plants.

An industry association, Electric Mobility Canada, was set up to promote all forms of electric vehicles. It associates firms from the car industry (Ford, GM), utilities (Hydro Quebec, Manitoba Hydro), major fleet users, universities and research organisations. A directory was compiled of some 160 organisations in Canada that are significantly involved in electric mobility (most are located in the Montreal, Toronto, Winnipeg and Vancouver regions). The next step consisted in drafting a technology roadmap for electric vehicles in Canada, jointly edited by the Electric Mobility Association and Natural Resources Canada in 2009 to identify and prioritise critical technology needs and the associated necessary R&D to 2018.

In the field, the leading role is played by provincial and municipal authorities, which have launched pilot projects to explore and prepare widespread diffusion of electric cars, in association with electric utilities and car manufacturers. Hydro Quebec formed a partnership with Mitsubishi to

test the performance of 50 plug-in MiEV electric cars in the town of Boucherville in 2010-13. In 2009, another partnership was formed between Better Place and the government of Ontario to develop a plan for an electric charging network, combining charging spots and battery exchange stations. The power for the Better Place network will be provided by Bullfrog Power, a retailer of fully renewable electricity. A local partnership was also formed with Macquarie Group (financial and investment services) to develop the investment plan and timeline for the infrastructure's roll-out.

For the region, which is one of the largest auto manufacturing areas in North America, the transition to a new model for the car industry is a major economic, social and political challenge. Ontario actually owns 4% of General Motors. The province of Ontario established an Electric Vehicle Incentive Program, effective 1 July 2010, with incentives from CAD 5 000 to CAD 8 500 for the purchase or lease of a highway-capable plug-in hybrid or battery electric vehicle. This would in effect reduce the price of the next electric Chevy Volt by 25%, bringing it to the average price consumers are willing to pay for a mainstream car (CAD 30 000). The vehicles will also get a green licence plate which allows them to use high-occupancy dedicated lanes at any time and whatever the number of passengers. The programme also includes the provision of some public electrical recharging facilities in certain parking facilities owned by the Government of Ontario and the transit authority in the Greater Toronto Area. These decisions go with an ambitious objective: to reach 5% of electric cars by 2020. Given the size of the province car's market, this translates in a sales target of 18 000 electric cars.

In 2009, Vancouver's council mandated charging infrastructures for electric cars in new homes. This completes an ordinance calling for 10% of parking spots in new condominiums and multi-unit residential complexes to be fitted with 240V charging stations. After broad discussions on the best mix of policies to foster electric use, and despite several pilot programmes of public charging stations, it was decided to focus on basic home access to fast electric charging to give potential consumers of electric cars an easy and simple way to charge their vehicle overnight. Fast charging stations are considered vital for electric cars to leave their current niche as a curiosity and luxury and to become a full-fledged transport solution. This requires a revamping of the entire high voltage grid, with new transformers, new panels, new distribution centres, and, consequently, large investment by utilities.

All these examples demonstrate that, in the absence of an integrated and comprehensive national policy, the electric car is mostly dealt with at the municipal and provincial levels. While this makes possible many

decentralised experiments and initiatives, it results in huge discrepancies and sometimes contradictory moves.

Electric car policy in France

Though France was clearly not an early player in the field of electric vehicles, an ambitious national policy was launched in 2008-09, with announced goal of 2 million electric cars on the roads by 2020. The objective is to leverage already low-carbon electricity generation from the installed base of nuclear plants and to improve the competitive position of the two domestic car manufacturers in this emerging market. The distinct feature of the French strategy for electric vehicles is the key role of the state and national programmes. The orientations and selected players are defined by the administration. The strategy combines public investment in the charging infrastructure (EUR 1.5 billion for a million charging points, 90% of them in private homes and the remainder in car parks and roadside sites), procurement by the administration and major companies of 100 000 electric vehicles by 2015, and subsidies or grants for R&D and manufacturing investment (such as Renault's battery factory in Flins with a EUR 125 million capital investment from the national strategic investment fund FSI and an additional loan of EUR 150 million from the government). The financing of these different initiatives will largely come from a EUR 35 billion state loan for future technologies and growth decided in 2009.

Conclusion

Electric vehicles have been considered a promising technology at repeated intervals over the last century. They systematically failed to live up to expectations, however, owing mainly to unfavourable comparisons with internal combustion engine cars (price, range, charging infrastructure, safety). Oil depletion and concerns about climate change offer them a new window of opportunity. But there is still a great level of confusion and uncertainty, mainly due to the lack of rigorous information. Understanding of demand patterns and sales potential, of consumers' needs and preferences and willingness to change travel behaviour and type of vehicle, and of the comparative performance of electric vehicles remains quite rudimentary and fragmented.

In this context, defining a relevant and efficient public policy to support the widespread adoption of electric vehicles is very complex and indeed almost impossible. One must in any case avoid "picking winners", creating irreversible effects and future technological lock-in. Indirect measures are more relevant and less risky than direct support instruments. Given the huge

economic interests at stake, a worldwide race has started and initiatives from industry, local authorities or national governments have flourished everywhere.

In devising future instruments and measures, policy makers should consider three main objectives in order to reduce the current high level of uncertainty along every dimension (technologies, economic models, usage and demand patterns, costs) of electric vehicles. A first would be the production and dissemination of standardised information on the performance, characteristics and consumption of electric cars. To do so, close monitoring and exploitation of various ongoing local initiatives could be a very valuable source of information. Second, while unrelated, the introduction of environmental taxes (either fuel taxes or carbon tax) is necessary to correct the existing bias in favour of conventional cars and ensure the economic profitability of the purchase of an electric car; this is not possible under current conditions, despite expected scale economies and technological innovation. Finally, investment in supporting infrastructure will be critical. This confirms the relevance of the concept of technological trajectory: the impact of public policies (including public investments) on the development pattern of electric cars will depend on economies of scope for R&D and opportunities for substitution across market segments.

References

BCG (2009), *Batteries for Electric Cars. Challenges, Opportunities, and the Outlook to 2020*.

BCG (2010), *Batteries for Electric Cars. Challenges, Opportunities and the Outlook to 2020*.

Deloitte (2010), *Gaining Traction. A Customer View of Electric Vehicle Mass Adoption in the U.S. Automotive Market.*

Greenpeace (2010), *Lowering the bar: how the car industry can improve efficiency targets*, *www.greenpeace.org/raw/content/eu-unit/press-centre/reports/lowering-the-bar-for-cars-20-05-10.pdf*.

IEA (2009), *Technology Roadmap Electric and Plug-In Hybrid Electric Vehicles*, IEA, Paris.

IHS Global Insight (2010), *Battery Electric and Plug-in Hybrid Vehicles: The Definitive Assessment of the Business Opportunity*, January, *www.ihsglobalinsight.com/Highlight/HighlightDetail17605.htm*.

OECD (2010), "Innovation in Electric and Hybrid Vehicle Technologies: The role of prices, standards and R&D", Working Party on National Environmental Policies, Environment Directorate, internal working document, OECD, Paris, May.

Oliver Wyman (2009), "E-Mobility 2025: Power play with electric cars", Munich, September, *www.oliverwyman.com/ow/pdf_files/ManSum_E-Mobility_2025_e.pdf*.

WWF (2009), *Impact of electric cars on power stations and carbon dioxide emissions in Germany*.

Chapter 6

Biopackaging: What role for public policy?*

Although clear benefits could be gained from the widespread adoption of biopackaging, research on the potential scope and instruments for public policies to support its development and deployment has shown that these could only play a minor and secondary role. This case study explores the two main reasons for this.

* This case study draws on interviews with the following companies: Nestlé, Danone, Bonduelle, L'Oréal, Europlastics and Zenith International.

Introduction

Biopackaging refers to a specific class of packaging solutions, characterised by two main "green" features: biodegradability (the product will break down or compost) and sustainability (it is produced from a renewable resource such as corn, wood pulp or vegetable oil). These properties broadly define three different material classes: synthetic and biodegradable, bio-based and biodegradable, bio-based and non-biodegradable. There are today three dominant chemical technologies for renewable biopackaging: polylactic acid (PLA), polyhydroxyalkanoates (PHA) and thermoplastic starch (TPS). Biopackaging is a growing part of the chemicals industry, although it only represents a small fraction of the very large volume of packaging manufactured every year. The increase in world production is however quite significant: from 20 000 tonnes of biodegradable polymers in 1995 to 600 000 tonnes in 2008. Biopackaging has many uses in the food, drink, cosmetics and pharmaceutical industries with a wide variety of applications, including flexible films, bags, trays, netting, bottles, cups, labels, tubs and blister packs.

Benefits of biopackaging eco-innovation

Biopackaging (also often called bio-plastics) is a genuine eco-innovation that offers multiple benefits to the industry as well as final consumers. First of all, from an environmental perspective, it takes less energy to produce and it generates fewer carbon emissions. For example, polylactic acid (PLA) production (*e.g.* for bottles) requires 20% to 50% less fossil energy than traditional plastic production. Biopackaging is also entirely compostable in industrial facilities and it does not require incineration of plastic wastes, which can release carbon dioxide as well as various harmful chemicals into the atmosphere. Finally, contrary to conventional petroleum-based plastics, which take a very long time to degrade and must be stored in landfill sites if not incinerated, biopackaging with biodegradable properties offers a green solution. Health issues reinforce these environmental benefits. Today, plastic packaging leaches out chemicals called phthalates into the food or water in plastic bottles. Because it increases the levels of oestrogen in humans and food chains, phthalates are considered dangerous hazards which may cause cancer including breast cancers and low fertility in men. Biopackaging on the contrary is made from natural raw materials largely consumed for centuries by humans and is unlikely to be harmful to people's health.

While clear benefits could be gained from the widespread adoption of biopackaging, research on the potential scope and instruments for public

policies to support the development and deployment of biopackaging established that such policies could only play a minor and secondary role. This report explores the two main reasons for such a result.

Biopackaging market prospects limited to niche segments according to the industry

Despite multiple announcements in biopackaging initiatives, the main food, drink and cosmetics producers as well as large retailers have little economic interest in the extensive adoption of this technology, with the exception of a few specific niches.

First and foremost, despite the rising price of oil and oil-based products, packaging made from biomaterials is still three to four times more expensive than conventional plastics. This extra cost cannot easily be passed on to consumers, among whom there is very little awareness of biopackaging and associated willingness to pay for its superior environmental performance. Many retailers (Sainsbury, Leclerc) undertook a disappointing and unconvincing experiment several years ago with the introduction of compostable carrier bags, which were massively rejected by consumers.

Second, despite technological advances, biopackaging materials offer inferior performance compared to oil-based packaging. They tend to have a weaker barrier to gas and moisture, low resistance to heat (cannot be microwaved) and a short shelf life. Carbonated beverages lose their sparkling character quickly in PLA bottles.

Finally, from a strategic perspective, biopackaging clearly does not top the environmental agenda of retailing firms. With the main pressure coming (or expected to come) from carbon taxes or emissions trading systems, transport is largely viewed as the priority, and optimisation of logistics is the main field for short-term improvements, innovation and investment. The story is similar in agro-industries, which focus on food and drink manufacturing processes in terms of carbon dioxide emissions. In parallel, in terms of green marketing and brand recognition, a range of other measures are seen as easier, faster and less costly to implement than biopackaging: organic offers, fair trade supply chains, product labels, sponsoring of events and associations, sustainable development corporate reports.

The result is that biopackaging is widely seen in the industry as an attractive but rather medium- to long-term solution, owing to the present unfavourable competition with alternative environmental projects. Another, though secondary, argument is the risk of supply bottlenecks and shortages, because of a limited number of active players and insufficient production capacity to fulfil fast-growing demand for biopackaging materials.

There are however some well-known, largely mediatised biopackaging initiatives: Sainsbury (organic fresh food, meat), Biota Water and Belu Water bottles, Volvic and Evian plastic-neutral bottles by Danone Waters, and Tesco (organic fruit) in the United Kingdom. A close examination of these initiatives, together with interviews with the companies involved, shows that all these applications correspond to very specific niches, for which the above-mentioned drawbacks of biopackaging are irrelevant. Fresh and organic products (*e.g.* fresh fruits, vegetables, bread, prepared salads) are the main target for biopackaging solutions. In this case, the performance properties of biopackaging are not a serious problem as there is no particular need for high barrier properties, heat resistance or long shelf life. Moreover, retailers can use biopackaging as a marketing and competitive opportunity to target a specific, environmentally conscious consumer group. Biodegradable packaging and organic products clearly go hand in hand and it is likely that the type of customer who buys fresh and organic products will also be the type of customer who cares about the environment and may be willing to pay a little more. As organic products are already priced at a significant premium, the extra cost is less a problem for retailers and can more easily be absorbed without increasing prices.

However, the firms involved explain that the technical and demand conditions are quite specific and that they do not intend to adopt biopackaging materials on a larger scale. Without significant technological progress to improve barrier properties of biopackaging and proper monetisation of environmental benefits, they consider current economic incentives too small to trigger mass investment and deployment. Other market niches will certainly be explored (such as prepared meals using innovative PLA produced from D- or L-lactic acid which can resist heat up to 175°C) and will support the growth of the biopackaging production but the process will be slow and limited.

The pending issue of the management of biopackaging waste and recycling

The second crucial challenge faced by biopackaging, according to all the players interviewed, deals with the end-of-life stage of these products. The absence of a waste management system is a major concern, as the recycling and sustainable features of biopackaging are a crucial aspect of its environmental benefits. Organising an optimised waste management system for biopackaging is a complex challenge for several reasons. First, it is strongly dependent on local and regional regulations, the total volume on the available market, and the specific composition of waste streams (retailers' offers and local consumption patterns). Second, an efficient and smooth

articulation has to be found with the local infrastructures for collection and recycling (plastic, glass, paper) in place in many countries. For example, compostable bottles, *e.g.* made of corn, should be separated from conventional plastic and PET bottles, with a distinct collecting network and recycling system.

Home composting is an efficient and simple solution but it is costly and cannot be implemented everywhere, especially in dense urban areas. So far there are very few municipal composting systems. As a result, biopackaging materials will likely end up in landfills where a fraction of them will not break down. Technological and R&D efforts aim at finding innovative solutions, for example using nanotechnology. Nano particles added during the foaming process used to manufacture biodegradable plastics (such as PLA) could increase water permeability and speed up the breakdown of materials in compost as well as storage systems.

Another environmental option to be considered is a closed loop system, such as the one organised for the plastic neutral water bottles scheme launched by Danone Waters in the United Kingdom for its Volvic and Evian brands in February 2009. The objective is to save 5 000 tonnes of PET in the short term. Several partnerships have been set up with councils for waste collection by the firm's partner, Greenstar. The PET is then converted in Dijon, France, and reused to package new bottles after a sorting, cleaning and melting process. Such a concept could be applied to biopackaging to ensure that full the environmental benefits are effectively realised.

However, as noted above, the fact that existing schemes focus on carbon or pollution emissions does not allow for a fair and quick monetisation of the environmental benefits associated with biopackaging. The classic "chicken and egg" problem in terms of increased biopackaging production and the existence of waste management systems cannot easily be solved by financial transfers or public subsidies, supported by future expected savings. A persistently large price differential and poor valuation of end-of-life products combine to drastically limit the viable scope for biopackaging.

In this context, the definition of a relevant and efficient policy is a complex issue, as most available economic instruments only affect the use of biopackaging materials indirectly. For example, when considering the waste problem, there is a general consensus that the management schemes implemented over the last two decades have improved the recycling ratio, but have not necessarily reduced the total volume of packaging produced. In France, the *Point vert* label, which has been in place for 18 years, has made it possible to increase the fraction of recycled packaging material up to 63% in 2009. But the volume of domestic waste has grown to 46 kg per capita.

Even if the collection and the recycling of waste reach a high level of efficiency, no sustainable and truly positive environmental benefit can be gained without significant improvements in the upstream stage. This calls for specific incentives to reduce the weight of packaging and make recycling easier. But then, the volume of inputs in the waste management system will decrease, and this may weaken the economic and financial viability of the recycling systems in place, which are based on the processing of a specific volume of waste.

This case illustrates the potential conflicting interests of policy initiatives carried out separately at different stages of the global value chain. At the European level, the Landfill Directive permits the burning, the mechanical biological treatment, and the composting of organic waste elements. While each solution contributes to the overall objective of reducing organic waste, there is no specific incentive for separate waste collection. A final element is the potential divergence between European and national regulations and policy instruments. For example, in the Packaging Directive, organic recycling does not count for the "back-to-plastics" recycling quota, although it does in Germany. France has suggested that bioplastic bags should be mandatory in the retail sector. But this is not compatible with European free trade arrangements and the Packaging Directive.

Conclusion

Biopackaging offers an innovative and sustainable solution, based on biodegradable features and production from agricultural renewable resources, to the growing demand for packaging materials in the food, drink, cosmetics and pharmaceutical industries.

Despite rapidly growing production, its usage still remains marginal and restricted to specific market niches, where its technical properties and demand patterns offer a favourable and profitable ground for adoption. The main reasons are, on the one hand, insufficient economic incentives for producers and retailers to choose this technology owing to its high cost and poor valuation by consumers, and, on the other, the lack of specific waste management systems for recycling.

As a result, the potential public policy instruments for supporting increased use of biopackaging (such as pilot programmes, R&D subsidies or differential taxation) are unlikely to be sufficient to overcome the lack of incentives for industry. In fact, most of the players involved in the biopackaging business consider that under current conditions economic profitability cannot be achieved with economic instruments. Therefore, only

a mandatory target or norms for biopackaging use could support faster adoption and market growth.

References

Callegarina, F., J.-A. Quezada Galloa, F. Debeauforta and A. Voilleya (1997), "Lipids and Biopackaging", *Journal of the American Oil Chemists' Society*, Vol. 74, No. 10, pp. 1183-1192.

Haugaard, V., A.-M. Udsen, G. Mortensen, L. Høegh, K. Petersen and F. Monahan (2001), "Potential Food Applications of Biobased Materials. An EU-Concerted Action Project", *Starch/Stärke*, Vol. 53, No. 5, pp. 189-200.

Chapter 7

Solar tiles in Portugal: Linking research and industry

This case study focuses on solar tiles, a niche in the solar photovoltaic energy domain. Solar tiles are tiles equipped with photovoltaic (PV) cells that convert sunlight into electricity. The specific focus is the solar tiles being developed by a Portuguese consortium of companies, research institutes and a governmental agency.

Introduction

This case study focuses on a niche in the solar photovoltaic energy domain: solar tiles. Solar tiles are tiles equipped with photovoltaic (PV) cells that convert sunlight into electricity. It looks specifically at the solar tiles that are being developed by a Portuguese consortium of companies, research institutes and a governmental agency. The discussion will focus on the Solar Tiles Consortium, the basics of the technology underlying the innovation and the history of solar tiles in Portugal, the characteristics of eco-innovation in Portugal, public strategy and modes of intervention, the prospects for the future, and the lessons learned from this case study.

The Solar Tiles Consortium

The Solar Tiles Consortium is a Portuguese R&D consortium of nine parties from industry, research and the government. Research parties provide knowledge on PV, ceramics and the testing of renewable energy concepts. Industrial parties have a large knowledge base and experience with ceramic wall and roof tiles. The National Energy Agency ADENE participates in the project. The main objective of the consortium is to "develop functional laboratory scale prototypes, with high efficiency, of integrated photovoltaic ceramic products such as building wall tiles (including roof tiles and wall tiles) that incorporate thin film photovoltaic through deposition" (Solar Tiles Consortium, 2009).

In light of this objective, several goals have been identified:

- develop multi-functional ceramic products with higher added value, for facades and roofs;
- enhance co-operation and develop synergies between industrial companies and research institutions;
- increase the competitiveness of the ceramic industry, specifically roof tiles and wall tiles, through product added value, product development and solutions suitable for sustainable construction;
- promote development of the photovoltaic industry by incorporating advanced knowledge and thus raising the technological level of the industry.

Prototypes to be developed are intended to have high aesthetic quality as well as high technical performance. The main technical problem is to achieve proof of concept for photovoltaic thin-film deposition on ceramic materials. The consortium also intends to contribute to a new type of

building architecture based on eco-design concepts. This includes the use of photovoltaic ceramic materials on facades and building coverings, considered as multi-functional products combining functions such as covering, energy production and aesthetics. Specific outcomes of this project should include:

- development of an appropriate architectural ceramic substrate for thin-film deposition;
- definition of technological and aesthetic requirements;
- definition of product architectures compatible with technological and desired aesthetic requirements;
- production of amorphous silicon and microcrystalline cells on a ceramic substrate suitable for deposition, as well as compatible encapsulation;
- development and testing of functional laboratory prototypes;
- evaluation of industrialisation constraints, in particular regarding upscaling of laboratory processes and the product architectures developed.

The goal is thus to explore technological options and to develop a laboratory prototype. The solar tiles are not yet on the market, nor are they fully designed. The eco-innovation is still at a laboratory phase; in a strict sense these solar tiles are not yet an innovation.[1] The technology and knowledge underlying the "eco-innovation" bring two bodies of knowledge together: PV and ceramics. The PV cell has to be applied to an alternative substrate, and the ceramic has to be made inert so it does not influence the solar cell. The next section presents the technological framework for solar tiles.

Basics of the technology

Main characteristics, technological background

Solar tiles are tiles equipped with a solar cell that generates electricity from incident sunlight. Solar tiles have a double functionality: they protect the roof and walls of a building from heat, cold and rain and they convert sunlight into electricity.

The idea to integrate PV in buildings seamlessly has been present in the development of PV for decades (Bahaj and Ward, 1994; Yang *et al.*, 1994; Okuda *et al.*, 1994; Bahaj and James, 1997). The Strategic Research Agenda of the PV Technology Platform still identifies the integration of PV (ease of

use, flexibility, aesthetics and lifetime) as an important driver for the development of PV (PVPT, 2007).

A range of ideas and inventions carry the name "solar tiles". When considering the design and appearance of a solar tile, the differences between solar tiles are often large. A typology of solar tiles can be made, based on their resemblance to conventional tiles.[2] On this basis, three kinds of solar tiles exist: tiled solar panels,[3] solar panels shaped in the form of tiles,[4] and conventional tiles enhanced (*e.g.* coated) with solar cells.[5]

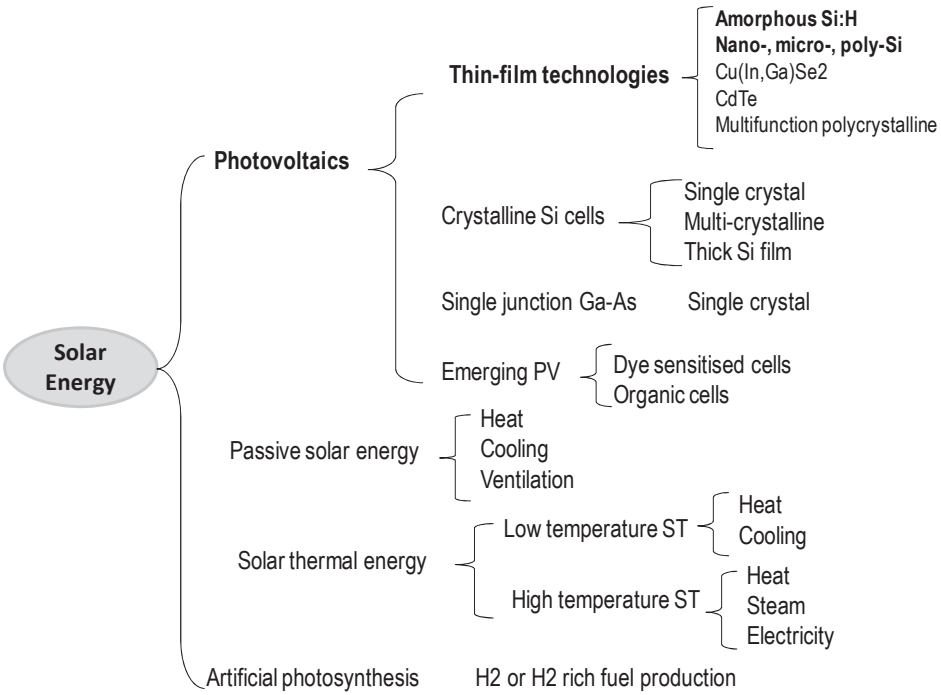
The Solar Tiles Consortium aims to develop traditional ceramic tiles featuring a solar cell (the third type of solar tiles in the typology). The aim of the innovation currently under development is to manufacture wall and roof tiles that generate electricity, but do not look significantly different from traditional tiles. Because solar tiles are an integrated construction material, their look and colour are an important part of design requirements. Differences with normal tiles should not be observable or should be part of the aesthetic design of the roof. Therefore, one of the design requirements is that the tiles have warm colours that combine easily with the traditional tiles used in Portuguese construction.

The aim of the development of solar tiles is to combine photovoltaic solar technology, a technique to convert sunlight to an electric current, with the conventional technology of ceramic tile manufacturing. The envisaged innovation is a clear example of what Schumpeter called *Neue Kombinationen*, *i.e.* a combination of established technologies; the specific combination of technologies adds value to the conventional technologies or services.

The innovation of solar tiles is part of the solar energy regime. Figure 7.1 gives a concise overview of the domain of solar power, highlighting the technological options of the Solar Tiles Consortium. The alternatives under investigation by the Solar Tiles Consortium are highlighted in bold.

Thin-film cells promise the best results on solar tiles, because they have the least impact on the design and appearance of the tiles. Thin films have the advantage of promising (partial) transparency and they can be applied to curved substrates. Furthermore, they are produced by deposition techniques[6] which can be relatively easily applied to an alternative substrate (other than glass).

Figure 7.1. An overview of solar technologies



Source: Technopolis Group.

The Solar Tiles Consortium has three technological options for the development of the solar cells:

- The first option is carbon-enhanced amorphous silicon. The advantage of introducing carbon in silicon cells is that it adds extra freedom for controlling the properties of the material and the film can also be made transparent to visible light. Moreover, the addition of carbon increases the cell's band gap and conduction, thus its efficiency.
- The second technological option is to combine microcrystalline and amorphous silicon. Adding microcrystals to the amorphous silicon cell increases the cell's band gap and thus its efficiency.
- The third option is to produce solar cells based on nano-sized silicon crystals through which proper band gap engineering can be performed, allowing enhancement of the light collected and thus overall efficiency in staked-type devices.

The three options offer similar advantages. One of the main aims of the Solar Tiles Consortium is to find out which technological alternative offers the best practical performance in terms of aesthetics, efficiency, resistance and design.

Added value and competition

Solar tiles offer added value at several levels. At the highest level, the main added value of solar tiles is that they are a source of renewable energy. There are a number of reasons to integrate systems based on renewable energy: rising oil prices and the impact on energy bills; the future exhaustion of sources of fossil fuels; the global warming potential of fossil fuels; the dependence on oil-producing countries; and issues relating to waste and the proliferation of nuclear power.

The most important drawbacks of renewable energy (and specifically of solar tiles) when compared to fossil fuels are price, integration to the grid, and stage of development (solar tiles are still in the R&D phase). However, the added value of solar energy (including solar tiles) includes low maintenance, long lifetime and the availability of the sun. While solar energy is still rather expensive when compared to renewable energy sources such as wind power, the gap is closing.

Especially in Portugal, the environmental conditions for solar power are very interesting. Portugal is one of the European countries with the highest availability of solar radiation: after Greece and Spain, it has the highest geographical potential for exploitation of solar energy with more than 3 000 hours of sunlight a year in the south of Portugal. Or, as the Minister of Economy put it: "Not using Portugal's vast natural resources for energy would be like Venezuela not using its oil."[7]

In the last few years, the Portuguese public system has invested in solar power. In 2008, Portugal saw a dramatic increase in the amount of PV installed during the year and also in Portugal's cumulative installed PV capacity. About 50 MW of grid-connected applications were realised and cumulative installed capacity jumped from close to 18 MW to 68 MW. The annual market grew by several hundred percent over each of the previous two years. Until now, grid-connected centralised systems account for 91% of the cumulative installed capacity in Portugal; grid-connected micro-generation PV is thus still relatively unimportant.

When comparing solar tiles to conventional PV, the added value of solar tiles is their low aesthetic impact. Solar modules are considered visually unattractive and disturbing to the design of buildings. Therefore, the main added value of solar tiles is that they are more appealing to buyers of

housing and buildings, the construction sector, and architects. Solar tiles offer an integrated solution and thus raise fewer implementation and adoption barriers for construction workers, etc. The efficiency of thin-film PV cells (which are used on solar tiles) is however rather low compared to other types of PV. The efficiency of the thin-film carbon cells is about 12%, whereas traditional crystalline silicon cells achieve efficiencies of almost 25%.

Solar tiles compete at several levels with alternative energy sources:

- At the highest level, the energy system at large, the price of the cheapest energy sources (*i.e.* fossil fuels and nuclear power) is a benchmark for energy technologies. The external costs of fossil fuels (*i.e.* the cost of CO_2 removal) as well as the political climate are in favour of renewable energy sources.
- In the field of renewable energies, competition in Portugal is strong in the field of large renewable energy plants. Wind energy is the largest and cheapest renewable energy source and the capacity of large PV plants has grown impressively over the last four years. The output and efficiency of solar tiles will not (soon) compete with renewable energy plants. However, because of the ambitious renewable energy plans in Portugal (and in the EU), large plants alone are not sufficient and a diverse set of renewable energy sources, including a niche market for PV micro-generation, is supported.
- According to interviews, competition in Portugal will be especially severe on this niche market. Solar thermal installations are backed by national standards for the construction of new buildings. Conventional PV is also a strong competitor: these cells are currently better developed and cheaper. The Solar Tiles Consortium does not want to compete on price; the design of the cells should be the decisive factor.

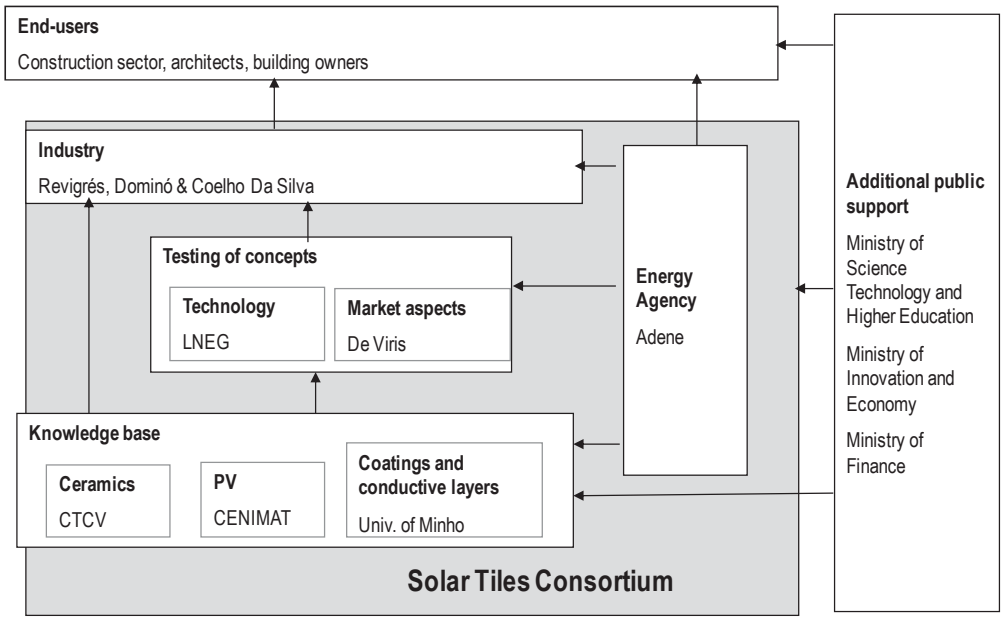
Solar tiles compete not only on the energy market but on the tile market as well. Both wall tiles and roof tiles are culturally important goods in Portugal (and to a certain extent for the whole Mediterranean region). The recent economic crisis has put the market for tiles under pressure: the construction of new buildings has decreased. The successful development of solar tiles may create an interesting competitive advantage for tile producers and lead to new niche markets.

Technological competence, developments and challenges

The composition of the consortium

The aim of the Solar Tiles Consortium is to deposit solar cells on the traditional tile material, Azulejo ceramics. The history of solar tiles is thus a rather short one. The idea of developing this kind of solar tiles was born in an informal Portuguese network which has resulted in the current consortium. In 2008, actors from the PV research area, the ceramics research area, the (environmental) engineering area and the energy agency decided to work towards a traditional Portuguese tile enhanced with solar power. With help of the Energy Agency ADENE, the actors formed the consortium which brings together important Portuguese players in the area (Figure 7.2). The Solar Tiles Consortium has existed since 2009. Although the development of solar tiles only started recently, the consortium draws on long-established bodies of knowledge on PV and ceramics in Portugal.

Figure 7.2. The innovation system of solar tiles in Portugal



Source: Technopolis Group.

For the development of ceramic substrates, the consortium relies on a large knowledge centre: the Portuguese Technological Centre for the Ceramic Sector (CTCV). CTCV has experience in the testing of ceramic

materials. Also, CTCV promotes the integration of skills and results from the companies involved, as three ceramic companies are part of the consortium: Revigrés, Dominó and Coelho da Silva. Dominó and Revigrés have the know-how for manufacturing processes and ceramic vitreous and porcelain tiles products, respectively. The expertise of Coelho da Silva is ceramic roof tile types (flat curve).

As regards third-generation photovoltaic materials and the associated cell architecture, two national and international research centres are part of the consortium: New University of Lisbon (CENIMAT – Centre of Materials Research) and University of Minho Functional Coatings Group. CENIMAT will focus mainly on the development of thin films or nanocrystalline polymorphous solar cells, while the University of Minho will focus on the development of conductive oxide materials. Both are components of a photovoltaic solar cell.

The functional and aesthetic quality of the resulting laboratory prototype is ensured by the involvement of De Viris and INETI (now LNEG). De Viris focuses on the functional and aesthetic specification and ensuring compliance with that specification. LNEG (the former INETI) provides performance testing of resulting prototypes, according to national and international certification standards.

Finally, national and international dissemination of this product is ensured by ADENE, the Portuguese Energy Agency. ADENE's role is to support the development of renewable energy, by setting standards, supporting development projects and communication on renewable energy. ADENE is in charge of the national energy efficiency plan which targets a 9% energy savings by 2016. In ADENE's plan to realise that target, it backed a broad set of technologies, including solar tiles. For the Solar Tiles Consortium ADENE offers institutional support; it has for instance advised the Consortium on where to find a subsidy for its activities. Moreover, ADENE gives visibility to the initiatives at the political level (both national and international).

Several parties are not (yet) included in the project; they are shaded in grey in Figure 7.2. Until now, the Consortium focuses on ceramics and knowledge. Potential users of the innovation (*e.g.* engineers and architects) are not yet participants, nor, remarkably, are PV-producing companies.

The Solar Tiles Consortium is an all-Portuguese effort. Until now, no international parties have been involved. However, many actors are part of larger international networks. The research institutes are closely connected to their international counterparts. The solar technology and nanotechnology domain is an especially close international research community. The tile manufacturers are also linked internationally.

Challenges

In terms of technology development, the solar tiles project starts from the product specification to be introduced on the market, considering that the product will require continuous improvement after a successful proof of concept. Specifications will be tailored to fulfil the requirements of a functional laboratory prototype, the ultimate development goal of the project. To achieve proof of concept, the Solar Tiles Consortium deals with a range of technological challenges. The main current challenges are:

- The researchers aim to deposit a thin film of silicon (about 10 mm) on classic Azulejo ceramic material, the type of ceramics traditionally used in Portugal to cover the facades of houses. In an initial test, its performance on ceramics is about 70% of its performance on a glass substrate. In order to improve performance, the consortium has to address issues related to the porosity of the ceramic material. This requires "passivating"[8] the ceramics on which they deposit the solar cell in order to minimise the influence of impurities from the substrate on the film. Therefore, they have to identify the best ceramic substrate and find the best compatibility between the solar cell and the tile as well as the best way to deposit it on the roof or wall tile.
- A related issue is the protective capsule that will make the final panel water-, dirt- and corrosion-resistant. Different technological options are available and need testing.
- For the embedding system, the electrical connection between the ceramic tiles is a hurdle. Techniques have to be developed and tested to connect the cells on the tiles to each other and then to connect the solar tiles to the inverter and battery. This is a very important issue, because the design must be as simple as possible to implement for it to be adopted by the construction sector and architects.

Given these scientific challenges, the consortium strives to minimise chain effects in order to raise chances for adoption and implementation. If the tile-producing industries have to invest in a completely new production line, this would vastly decrease the chances of success. Similarly, the solar tiles need to fit into current practices in the construction sector; if the construction sector has to make large investments in new knowledge and know-how, or if the tiles are not very user-friendly, this would drastically minimise the chances of successful deployment.

For now, no legal or political barriers exist. The political climate for renewable innovation in Portugal is good, and funding for the research has already been awarded.

To sum up, development of solar tiles in Portugal is still in its inception phase. Currently, accumulated knowledge is being used to develop the proof of concept. This requires exploring and testing different alternatives. The Solar Tiles Consortium is now searching for the best available option, to result in a proof of concept at the termination of this project at the end of 2010.

Eco-innovation in Portugal

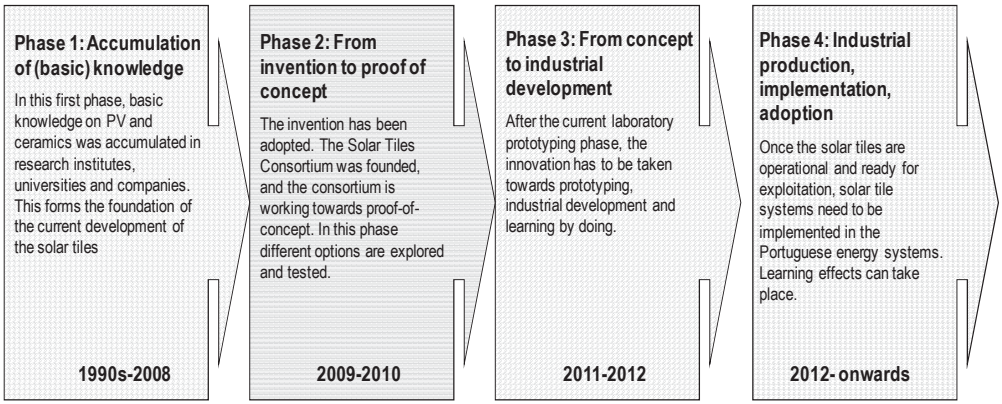
Although the term eco-innovation as such is not often used in Portugal, attitudes towards eco-innovation are clearly positive, especially for innovations aimed at preventing carbon dioxide emissions in the energy sector. Portugal launched a National Energy Efficiency Action Plan in 2008, Portugal Efficiency 2015 (PE2015). PE2015 is a framework that packages a policy mix aimed at energy savings by increasing energy efficiency and implementation of renewable energies. The policy covers four specific fields: transport, residential and services, industry and state, and three cross-cutting action areas including behaviour, taxes, incentives and financing. The residential and services sub-programme may have an effect on the development of solar tiles when solar tiles are ready for installation. Relevant goals that might influence the development of solar tiles are the programme's aim to have 75 000 homes produce electricity (165 MW) by 2015. Currently, the consortium does not identify the programme as a measure that affects the development of solar tiles. However, PE2015 might have a positive effect on the take-off phase of solar tiles in the near term.

With regard to solar power, the policy tradition has changed drastically in the last decade. The focus has shifted from fossil fuels to renewable energy sources. The current goal of the government is to be at the forefront of countries with a renewable energy system.

Public strategy and modes of intervention

Figure 7.3 displays the different phases in the development of the solar tiles eco-innovation. As the development of solar tiles is relatively young – it officially started in 2009 – only two phases can actually be studied, the last two phases are foreseen.

Figure 7.3. The development phases of solar tiles



Source: Technopolis Group.

The first phase took place before the formal start of the project. During this phase, knowledge was accumulated on thin-film silicon PV, on ceramics and on nano-coatings and layers. In this pre-development phase, the accumulation of knowledge was supported by traditional science policy, *i.e.* traditional funding for academic research at the university of Minho and the University of Lisbon. CTCV accumulated knowledge and expertise on ceramics. CTCV is a private, not-for-profit organisation, founded through a agreement between industry associations and the Ministry of Economy of Portugal. Its main goal is to provide technical and technological support to the ceramics, cement and glass industries and advanced materials.

With the start of the solar tiles project, the development of the eco-innovation started (phase 2, the present solar tiles project). By the end of this phase (end of 2010 or early 2011) the consortium plans to have proof of concept and to begin prototyping and further development of the eco-innovation (phase 3).

To obtain insight on the different phases and the relevant eco-innovation policy instruments, the first two phases were studied in detail and the support currently available for the following phases were explored. The interviews focused on the first two phases and then on what the next steps will be and how current policy can foster the eco-innovation. Current and future public policy as regards solar tiles and perceived policy gaps are discussed in the following sections.

Current policy phase with regard to solar tiles

Phase 1: Basic knowledge accumulation

In this phase, innovation policy is important for guiding basic research towards strategic knowledge accumulation. The identification of the relevant instruments is beyond the scope of this study, as they are traditional science and research policy instruments rather than innovation instruments. The research actors mentioned that their research activities can be funded via traditional channels for scientific research. The Portuguese science foundation, FCT, also offers grants for research projects. For solar tiles, accumulated knowledge about carbon thin-film solar cells is very important for creating opportunities to develop solar tiles. Just as important is accumulated knowledge about ceramics (CTCV) and nanocrystalline structures and coatings.

Phase 2: From invention to proof of concept

This phase is the start of the development of an innovation trajectory: competing concepts are tested and a selection is made. The Solar Tiles Consortium is currently in this phase. Portugal has various instruments to foster eco-innovations.

A first set of instruments includes generic innovation incentives. The Solar Tiles Consortium is supported by NSRF, the National Strategic Reference Framework of Portugal, 2007-13. The consortium's total budget is EUR 2 million; about EUR 1.2 million are EU Structural Funds, distributed via NSRF. The amount of matching funds from the consortium partners varies from 50% to 75%. The only partners not receiving any public support via the consortium are De Viris and ADENE. The NSRF sets five development goals. A sub-priority is to produce electricity from renewable energy sources, photovoltaics in particular. In the development phase, ADENE supported the consortium's application to the NSRF. The aim of applicants must be the development of renewable energy sources; regional development criteria must also be addressed. Projects are selected on the basis of a set of criteria defined by the Ministry of Economics and Innovation and the Ministry of Environment, Spatial Planning and Regional Development. In addition to the criterion of the envisaged development of renewable energy sources, the selection criteria were: quality of the project (consistency and reasonableness of the project team); contribution to the competitiveness of the companies involved; contribution to national/regional economic development; and innovativeness of the project.

A second incentive for innovation that is relevant to eco-innovations such as solar tiles is the Fund for Innovation Support (FAI). The Ministry of

Economy and Innovation and ADENE set up FAI in 2008. FAI has EUR 76 million available to support technological research projects, pre-industrial development projects and science communication actions. The main aim of FAI is to support technology and innovation in renewable energy and energy efficiency as well as technology transfer. It is an important, relatively new instrument that could have been crucial to the development of an innovation such as solar tiles.[9]

Consortium interviewees indicated that the support by the national government via Structural Funds (75% of total funding) is sufficient to establish proof of concept for the solar tiles. Although evaluations of the innovation incentives that can be used for solar tiles were not available, the interviewees considered the available instruments effective.

Nevertheless, there are still barriers that endanger the development of the innovation. First, innovation entails technological risks: it is possible that the technological challenges will not be overcome in time. This could damage the project's momentum, especially on the industry side (industry is essential from phase 3 onwards). Furthermore, all interviewees mentioned the need to manage expectations regarding solar tiles. Now that the consortium has received support, attention has turned to the actual innovation. However, the solar tiles will need further development before they can be marketed. Many interviewees expressed concern about these expectations; the solar tiles are not yet ready for commercial use and need further development. Expectations should be realistic, in order to avoid a letdown after a period of increasing expectations. This can be hard; several people have tried to order solar tiles because of messages in different media on the project. However, it will take (at least) 2-4 years to bring the solar tiles to the market.

Future public policy for solar tiles

This section discusses the future of the solar tiles, as foreseen by the interviewees.

Phase 3: From concept to industrial development

The next phase in the development of solar tiles in Portugal is to bring the proven concept of phase 2 to industrial scale. In the further development of the innovation, the emphasis will shift to more applied and industrial research as well as engineering. Several working prototypes have to be developed, and the integration of the system with current practices in the building sector has to be explored in depth. Simultaneously, the industry will have to develop ways to produce the solar tiles industrially. In this phase an important factor is whether the solar tiles are easy to produce. If

tile manufacturers have to install completely new production lines, this would decrease the chance of success drastically.

For this phase, the interviewees expect that the innovation will need further support. According to the interviewees, the important instrument will again be an innovation incentive. A high level of industry commitment is also necessary. Industrial parties need to embed the solar tiles in their portfolio in order to take the essential step towards industrial development. A crucial factor for success in this phase is the result of phase 2. In order to obtain find public funding as well as industrial interest, there needs to be a clear proof of concept.

Phase 4: Industrial production, implementation and diffusion

Once a working prototype is designed, the solar tiles are ready for production. In this phase, market aspects are of high importance. The interviewees see the creation of a niche market as a first step for this innovation and the start of production of the solar tiles. Once the solar tiles are in production and as demand and sales rise, economies of scale will emerge and the costs of solar tiles will decrease drastically. Because renewable energies are still more expensive than fossil fuels, instruments for market creation are needed, according to the interviewees.

Several instruments already favour renewable energy innovations. The instruments for micro-generation of energy are valuable instruments that ensure a market for renewable energy.[10] The set of instruments consists of generic instruments – which stimulate micro-generated renewable energy in general – as well as of instruments that typically back a specific innovation. The instruments that are already fully operational, and which will be essential to the development of solar tiles, according to our interviews, are the micro-generation law, the related feed-in tariff and tax incentives for renewable energy.

The micro-generation framework (DL 363/2007), known as "Renewables on Demand", became fully operational in April 2008 and was the year's major new policy initiative for PV. This framework is specifically designed for electricity consumers and consists of two regimes: the general regime, applicable to any type of micro-generation (or cogeneration) source, with a maximum interconnection power of 5.75 kW; and the special regime that applies exclusively to renewable sources, with a maximum interconnection power of 3.68 kW. Both regimes are supported with feed-in tariffs, the former defined annually by the national energy regulator. Under the second regime, a reference feed-in tariff of EUR 0.65/kWh (kilowatt hours) applies, reduced to 95% of its previous value for each additional 10 MW of capacity installed. The feed-in tariffs are guaranteed for 15 years,

or when a total production of 21 GWh (gigawatt hours) a year is reached. In making the solar tiles a success, the Solar Tiles Consortium sees an important role for the micro-generation law and the feed-in tariff, which can help to overcome the financial gap between fossil fuels and more expensive renewable energy innovations such as solar tiles.

Until now, the feed-in tariff is perceived as a successful way to overcome market failures without harming market mechanisms, *i.e.* the best available and cheapest ways to produce renewable energies are selected by default. In principle the instrument is thus perceived to be very effective. The feed-in tariffs have proven to be effective in other countries as well (see Box 7.1). However, some issues have arisen with regard to the practical use of this instrument. In order to receive the feed-in tariff, energy-producing households have to apply for national quota. However, as the amount of allowed feed-in is rather limited so as to guarantee the efficient functioning of the grid, there is often no quota available. Interviewees indicate that the supply of micro-generated electricity is much higher than the proportion allowed. Actors that generate electricity have to apply monthly for the feed-in tariff, and the maximum amount of electricity to be fed in is often reached quickly. The interviewees indicate that this support measure should be enlarged and a larger amount of feed-in should be allowed in order to overcome the market failure of renewables.

A second support measure to overcome market failure is a tax incentive for renewable energy equipment. VAT reductions, ranging from 12-20%, are offered on renewable energy equipment with a maximum of EUR 730 for solar energy equipment. Until December 2009, the Portuguese government gave a 50% investment subsidy for solar installations for households and a 65% investment subsidy to community actors, such as sports clubs. The interviewees appreciate the incentives, as they will decrease the initial investment needed to install solar tiles, once the innovation is on the market.

In summary, Portugal has a mix of instruments that will probably influence the development of solar tiles. The interviewees believe that the current package of incentives for eco-innovation in the energy domain is in principle sufficient to develop innovations. They indicate that the instruments aimed at stimulating the development of markets (feed-in, standards and subsidies) would especially benefit the implementation of solar tiles. For instance, the recent micro-generation law gave PV on buildings a boost. This support measure is very beneficial for renewable energy eco-innovations such as solar tiles. Joyce (2009) documents the recent dramatic increase in installed PV power, which is mostly due to the construction of large PV plants (such as Serpa and Moura). As of 2008, the installed capacity of PV in domestic use grew strongly. The data for 2008

are still being processed, but total cumulative PV power will be 63 MW and micro-generating PV installations will produce about 3.5 MW (6%). However, the interviewees stressed the need to increase the monthly quota for the feed-in tariff in order to keep this instrument relevant for their project. Because of the long economic payback time, rate of return guarantees are crucial for this kind of measure. Instruments that back other technologies can hamper the future development of solar tiles: solar thermal heating is obligatory in new constructions in Portugal – this could influence the demand for solar tiles.

Box 7.1. Feed-in tariffs in Germany

The *Erneuerbare Energien Gesetz* (EEG) of 2004 supported renewable energy technologies no longer with loans but with feed-in tariffs. These tariffs vary for PV between EUR 0.40/kWh and EUR 0.55/kWh delivered to the electricity grid (guaranteed for 20 years). Every year government support decreases to encourage the industry to reduce production cost (*i.e.* economies of scale). This policy measure appealed strongly to the general public and resulted in very rapid growth of installed capacity and thus economic growth of the industry.

As a result the German industry gradually took over the world market for PV that had been dominated by the Japanese until 2005. Since 2000 the German PV industry has doubled every year in terms of turnover, employment and PV capacity produced. In 2008 about 57 000 people were employed in the German PV industry and German PV manufacturers generated a turnover of EUR 5.2 billion. So, the value of this policy for the success of PV in Germany is thus considered to be very high.

Source: Technopolis Group.

Perceived gaps in public policy

Several interviewees emphasised that the set of instruments for solar tiles is large but incomplete. They also suggested that legislation such as enacted in other countries would be beneficial for integrated solutions. In France the feed-in tariffs are higher for renewable energy concepts that are architecturally integrated. From the viewpoint of the Solar Tiles Consortium this could be an interesting option for Portugal as well. Extra stimuli are also needed to prevent the nimby ("not in my backyard") issues surrounding renewable energies. Integrated solutions are often more expensive, because they need more adjustments over the innovation chain. Integrated solutions need to fit into the current system; they affect the installation routines of the construction sector, the electricity installation sector, and architects and

building owners. If the solar tiles require these actors to make large modifications, this will create an obstacle to implementation. Especially now that the construction sector has to incorporate the installation of solar thermal installations, standards for PV might be necessary to implement the solar tiles in the construction sector.

The interviewees also see a gap in public policy for buildings. Currently, the legislative standards for new buildings require a building to be equipped with a solar thermal installation. If this standard is maintained it could affect the adoption of solar tiles. The interviewees would like to see this standard changed. Obviously the Consortium would benefit greatly from a technology-specific standard for solar tiles. The Portuguese government (ADENE) backs a broad range of renewable energy technologies, so it would be more likely for the current technology-specific standard to be broadened to a technology-prescriptive standard that supports all types of renewable energy. The standard should define a building's capacity to produce renewable energy. This would strengthen competition between renewable energy sources and traditional market mechanisms (investment price and rate of return) would operate to select the best renewable energy option possible. The consortium would favour this if it were broadened to include PV (or solar tiles) for new buildings.

Prospects for the future

Not surprisingly, the interviewees are very positive about the future of solar tiles in Portugal. A main success factor stressed in every interview was that tiles are entrenched in the Portuguese building sector. Both wall tiles and roof tiles are a clear presence in Portuguese architecture. The interviewees believe that there is strong demand for solar tiles that look like the original tiles used in Portuguese buildings, which feature warm colours and classic shapes. For this reason, the interviewees believe that the current solar tiles (which are often tiled panels, or tiles in unconventional colours) will be less successful.

Another success factor that is often mentioned is the constituency of the consortium, as it consists of industrial partners from the ceramics sector and knowledge institutes from the ceramic, PV and coating sectors. Also the government is present in the consortium via ADENE. However, until now, the demand side of the innovation system is only mildly involved in the project, with the inclusion of De Viris. End users (*e.g.* architects, construction companies) are neither consulted nor involved. Given the focus of the consortium on user friendliness and attractive design, it would be a logical next step to reinforce these user-producer interactions, for instance by demonstration projects. To date, no partner from the PV industry is

involved in the consortium. At this stage, the consortium considers universities the most necessary partners because the main issue is early-stage R&D on solar cells and ceramics. In a commercialisation stage, the consortium will need a partner from the PV market. Currently, it is considering two options. One is to include an actor from the PV industry in the consortium. As of 2008 there are at least three Portuguese PV companies working with c-Si modules. Another option is to create a spin-off company that will operate on the PV market.

Lessons learned

Current situation

Solar tiles are a clear example of a – still potential – eco-innovation. First, it addresses the current environmental and societal issues surrounding the use of fossil fuels. Second, its development can lead to regional economic development in the Portuguese tile industry, and thus can boost the use of this traditional product which currently faces difficult (economic) times. Third, it addresses a societal issue, as solar tiles are an integrated solution; they will have a small impact on current architecture. The traditional look of buildings in Portugal in particular, and in the whole Mediterranean zone, can be preserved.

The Solar Tiles Consortium started its activities in 2009. Its activities are enabled by the choice to support renewable energy in Portugal, PV in particular, under the National Strategic Reference Framework. Furthermore, without the strong commitment of ADENE at the start of the process, it is questionable whether this development would have taken place. The support for highly applied research activities in the renewable energy sector led to the development of new concepts and a potential innovation. However, because the development of solar tiles is very new, it is as yet too early to know whether this will lead to the diffusion of an eco-innovation.

The Solar Tiles Consortium can be seen as a public-private partnership (PPP), as it connects research and industry, public and private actors. The main question was to find out whether and how the partnership would operate effectively and efficiently. In the case of the Solar Tiles Consortium, this question cannot yet be answered, as the consortium has not yet produced clear results that would make it possible to assess the efficiency and efficacy of the partnership. Nevertheless, the interviewees expressed high expectations regarding the development of solar tiles by the consortium.

The consortium is satisfied with its internal management: there is a clear distribution of tasks, which reduces transaction cost and facilitates co-

operation. Moreover, there is, as yet, no competition between the different partners. In the future, IPR issues are to be expected, but these will be dealt with through negotiations between the partners that are still involved at that time. Public support and the clear distribution of tasks also create momentum: without the consortium, many individual actors would not have pursued the development of solar tiles with such dedication.

Public partners currently play a small role in the work of the consortium. Nevertheless, ADENE played a pivotal role in starting up the consortium and will try to play an important role in transferring knowledge and in dissemination of the work at the end of the project. ADENE is however not exclusively committed to the development of solar tiles. Portuguese policies for renewables foster a diversified package of technologies, all of which are backed by ADENE. For ADENE, solar tiles are one of several pathways to more sustainable energy provision. This implies that ADENE is also supporting technologies that compete with solar tiles.

The projected future

In order to address synergies between eco-innovation policies and other policies and developments, the interviewees were asked for their expected effect on the development of solar tiles. There are instruments to address market failures and overcome the typical barrier for eco-innovations: their higher price compared to current solutions. Portugal offers a mix of instruments, including long-term incentives (feed-in tariff), short-term incentives (VAT reductions) as well as the development of legislative instruments (standards for buildings). The members of the consortium foresee that solar tiles will benefit greatly from this policy mix when they become eligible (this is not yet the case for some standards in the construction sector). The policy mix addresses the main barriers for users of the eco-innovation: the high initial investment, as well as the relatively high price per unit of energy produced. Once the solar tiles are produced in larger quantities, the price of solar tiles will decrease through economies of scale and performance will improve through learning by using. The interviewees emphasise that the start of the implementation of an eco-innovation is crucial.

Notes

1. If an innovation is defined as "a successful introduction of a new thing or method", then the solar tiles discussed here are not yet an innovation. They are an invention rather than an innovation, as they are not yet adopted or implemented.
2. Regional differences are large. This case study considers solar tiles from a Portuguese perspective.
3. For example: *www.solar-panel-home.net/wp-content/uploads/2009/08/2837793931_fa894b4bb8_o.jpg*.
4. For example: *http://evoenergy.files.wordpress.com/2008/08/evo-solar-tiles-6.jpg*.
5. For example: www.*greenzer.com/blog/blog_image_store/2009/06/terra-cotta-looking-solar-tiles.jpg*.
6. Until now the most commonly used techniques are vapour deposition techniques, but roll-to-roll and inkjet technologies are currently being developed. The latter allow easy large-scale industrial production. Moreover, the cells are easier to shape, which makes them well suited for application on curved roof tiles.
7. *www.nubricks.com/archives/1845/portugal-puts-its-energy-into-renewables/*.
8. *i.e.* making it non-reactive to another material prior to using the materials together.
9. However, the Consortium had already found financing via NSRF; actors supported by NSRF are excluded from FAI support.
10. More incentives exist in the field of solar energy, but they are not applicable to this innovation; the renewable energy stimulation package only applies to power plants and large energy-producing innovations.

References

Bahaj, A.S. and P.A.B. James (1997), "Photovoltaic roof tiles: design and integration in buildings", Paper presented at the BEPAC + EPSRC Conference, Abingdon, England.

Bahaj, A.S. and S.C. Ward (1994), "The Solatile: a fully adjustable and integrated photovoltaic roof tile", in *Proceedings of the 12th European Photovoltaic Solar Energy Conference*, pp. 1097-1100.

Joyce, A. (2009), "Photovoltaics – Portugal's Brief Report", *www.eupvplatform.org/fileadmin/Documents/MG/090209/MG_090209_07.1_Update_onPortugal.pdf*.

Okuda N., T. Yagiura, M. Morizane, M.Ohnishi and S. Nakano (1994), "A new type of photovoltaic shingle", in *Proceedings of the IEEE First World Conference on Photovoltaic Energy Conversion*, pp. 1008-1011.

PVTP (Photovoltaic Technology Platform (2007), "A Strategic Research Agenda for Photovoltaic Energy Technology", *www.eupvplatform.org/fileadmin/Documents/MG_SRA_Complete_070604.pdf*.

Solar Tiles Consortium (2009), Development of Photovoltaic Solar Systems on Ceramic Roof and Wall Tiles, *www.solar-tiles.eu/*.

Yang H.X., R.H. Marshall and B.J. Brinkworth (1994), "An experimental study of the thermal regulation of a pv-clad building roof", in *Proceedings of the 12th European Photovoltaic Solar Energy Conference*, pp. 1115-1118.

Part III

Case studies on selected public-private partnerships for eco-innovation

Chapter 8

The UK Carbon Trust: A public-private partnership for eco-innovation

The case study on the Carbon Trust looks at the use of a public-private partnership to develop and diffuse eco-innovation. It considers the advantages and potential disadvantages and risks and the external and internal coherence of its operations as well as the results and impact of the structure and the conditions necessary for its efficient functioning.

Rationale and objectives

Rationale and a short history

The United Kingdom was one the first countries to announce a climate change programme in late 2000 and to initiate a low-carbon policy. In 2001 it introduced the climate change levy to provide a price signal to encourage non-domestic energy consumers to improve their energy efficiency and thereby reduce their carbon dioxide emissions. The levy was announced in 1999 in order to give business a two-year notice before its implementation. The climate change levy was designed to be "fiscally neutral".

The idea of the Carbon Trust was suggested by the government's Advisory Committee on Business and the Environment, which was set up to advise it on business-related environmental issues. The proposed body was to support business in improving energy efficiency by advising on how to use existing technologies and by supporting development of new low-carbon technologies. The Advisory Committee put forward two options to the government: a company limited by guarantee and a non-departmental public body (NAO, 2007).

Recommendations to ministers by both the leading departmental teams (Department of the Environment, Transport and the Regions – DETR; Department of Trade and Industry – DTI) and the Advisory Committee opted for an "arm's-length" entity, similar to the Energy Saving Trust, which was already in operation and judged to be effective. Feedback from the business community clearly indicated that it would have greater trust in advice from a private-sector company than from a public-sector organisation. The primary objective of business was to create the right delivery mechanism for the business sector to maximise the effectiveness of initiatives to reduce carbon dioxide emissions (interviews in 2010)

The process of setting up the Carbon Trust was relatively fast. The decision to establish the new organisation was taken at the level of the prime minister's office with ministers heading DETR and DTI directly involved. A working group was formed of three officials and one seconded staff from KPMG. Its task was to prepare the legal documents necessary to register a new entity in accordance with the United Kingdom's Companies Act.

The Carbon Trust (CT) was set up by the government in spring 2001 as a not-for-dividend private company limited by guarantee with a remit covering the whole of the United Kingdom. The vision outlined for the Carbon Trust by Prime Minister Tony Blair in 2000 was that it would "take the lead on low-carbon technology and innovation in this country and put Britain in the lead internationally".

The main rationale behind the Carbon Trust was that businesses and the public sector alike faced the market failure resulting from the lack of market incentives to improve energy-efficiency and develop clean energy technologies. The mission of the Carbon Trust was to help businesses and public organisations to reduce their emissions of carbon dioxide through improved energy efficiency and the development of commercial low-carbon technology. The need to do so received further support from the finding of the former Energy Efficiency Best Practice programme that about 20% of energy purchased was being wasted.

In 2001, the Carbon Trust issued a first draft strategic framework setting out its plans. It was drawn up after a series of workshops and consultations with individual stakeholders. Over the first three years, the Carbon Trust received GBP 95 million from the climate change levy, plus an annual GBP 17 million inherited from the Energy Efficiency Best Practice Programme.[1] In 2002 the Carbon Trust took over the management of most of the programme from the DETR, the predecessor of the Department for Environment, Food and Rural Affairs (DEFRA). It also manages and promotes the government's enhanced capital allowances (ECAs) scheme and the list of energy-efficiency technologies qualifying for ECAs.

Main objectives and targets

The mission of the Carbon Trust is "to accelerate the transition to a low carbon economy by helping organisations reduce their carbon emissions and developing commercial low carbon technologies". A key challenge was to balance support for technologies with great long-term potential in terms of carbon savings with measures, which are, in the short term, more cost-effective.

The Trust initially set itself three key objectives:

- to ensure that UK business and the public sector contribute fully to meeting ongoing targets for greenhouse gas emissions;
- to improve the competitiveness of UK business through resource efficiency;
- to support the development of a UK industry that capitalises on the innovation and commercial value of low-carbon technologies nationally and internationally.

The Carbon Trust's targets were indicated in the context of the overall UK carbon emissions reductions target. The overall goal was to reduce carbon dioxide emissions by 20% until year 2010, that is, from 592 million tCO_2 (tonnes of carbon dioxide) a year in 1990 to 474 million tCO_2 a year in

2010. Business was to account for 27% of the carbon reduction target. The Carbon Trust target was to save 4.4 million tonnes of carbon a year by 2010 (NAO, 2007).

Organisation and governance relations

Organisational structure

Legal status

The Carbon Trust was set up by the government in March 2001 as a not-for-dividend private company limited by guarantee. As such it cannot distribute profits to its members; all profits have to be reinvested in the business. The board members are not held personally accountable for company operations. At the time of designing the Carbon Trust some considered the option to create it as an adjunct to an existing entity, the Energy Saving Trust, but the Advisory Committee on Business and the Environment did not support this option because it did not feel this would give business "sufficient confidence" in the new entity. The private company model was seen as a guarantor of independence; the "arm's-length" status of the new organisation formed the basis of a close relationship with the business community.

Executive bodies

The Board of Directors

The Board of Directors is the highest decision-making body of the Carbon Trust. The board is composed of 18 members: three executive directors (employees of the Carbon Trust) and 15 non-executive directors. Five non-executive directors represent government departments (funding central government departments and the devolved administrations). A further ten non-executive directors are independent stakeholders from industry, trade unions and non-governmental organisations that contribute independent expertise and external views. Box 8.1 lists the Board members.

The Investment Committee and the Preliminary Investment Committee

The Investment Committee consists of members drawn from the Carbon Trust's Board. The Committee is responsible – subject to the overall direction of the Board – for overseeing all the investment activities of the Carbon Trust. In particular, it decides on investments of less than GBP 1 million and recommends (or not) investments above GBP 1 million to the Board for authorisation. The decision of the Investment Committee is

final and bidders cannot appeal it. The Preliminary Investment Committee consists of four senior staff and takes decisions on smaller investments.

Staff and external consultants

Core staff

The core staff of the Carbon Trust consists mainly of former employees of major private players in the field of low-carbon technologies and equity investment. Employee numbers (including executive directors but excluding non-executive directors) increased from 151 at 31 March 2008 to 194 at 31 March 2009. There were also two staff members on secondment from other organisations for a total of 196 staff (Carbon Trust, 2009a). Similarly to private corporate structures, most of the organisation's administrative functions were at first contracted out, together with the management of the accredited energy consultants used to provide energy advice (House of Commons, 2008).

Consultant accreditation scheme

In 2006, the Carbon Trust launched its own consultant accreditation scheme. Previously, it had used consultants accredited by the Energy Institute to deliver much of the advice and support it provides to organisations. As of 2009, Carbon Trust relies on 480 accredited consultants.

Corporate structure

The Carbon Trust has developed into a large corporate-like structure with a number of wholly or partly owned subsidiaries. The organisation has two main commercial arms: Carbon Trust Enterprises Ltd, which develops new businesses, and Carbon Trust Investments, which is the venture capital investment subsidiary of the Carbon Trust.

The subsidiaries of Carbon Trust are all part of the Innovations, Investments and Enterprises activities and were set up from 2003 on the advice of the Carbon Trust's auditors to improve governance and increase the transparency of tax treatment by separating out each part of the business with the potential to make a profit and to allow the subsidiaries to have a visible commercial focus (NAO, 2007).

The Carbon Trust has three principal directly held and wholly owned subsidiary companies: Carbon Trust Enterprises Limited (CTEL), Carbon Trust Investments Limited (CTIL) and Carbon Trust Fund Management Holdings Limited (CTFMHL).

Box 8.1. Composition of the Carbon Trust Board of Directors

Sir Ian McAllister	CBE Chairman
Ian Stephenson	OBE Deputy Chairman, Chairman of Carbon Trust Enterprises Limited, Director IT, HR and EHS, Johnson Matthey plc
Tom Delay	Chief Executive Officer
Rosemary Boot	Finance Director
Michael Rea	Chief Operating Officer
Dr. Neil Bentley	Non-Executive Director, Business Environment CBI
Sir Richard Brook	Non-Executive Director, The Leverhulme Trust
Dr. Colin Church	Non-Executive Director of Carbon Budgets and National Climate Change Delivery, DECC
John Edmonds	Non-Executive Senior Research Fellow at King's College, London University (formerly General Secretary, GMB and President, TUC)
Olive Hill	Non-Executive Director of Technology and Process Development, Invest Northern Ireland
Edward Hyams	Non-Executive Chairman, Energy Saving Trust
Colin Imrie	Non-Executive Deputy Director, Energy Markets, Business, Enterprise and Energy Directorate, Scottish Government
Dr. Paul Jefferiss	Non-Executive Group Head, Climate, Carbon and Environment, BP (formerly Head of Environmental Policy, RSPB)
Hugh McNeal	Director for Low Carbon Business Opportunities, Department for Business Innovation & Skills
Chris Mottershead	Non-Executive Vice-Principal (Research and Innovation), Kings College, London University (formerly Distinguished Advisor, BP)
Lucy Neville-Rolfe	CMG Non-Executive Corporate and Legal Affairs Director, Tesco PLC
Matthew Quinn	Non-Executive Director, Department for Environment, Sustainability and Housing, Welsh Assembly Government
Timothy Weller	Non-Executive Chair of the Carbon Trust Audit Committee, Chief Financial Officer, United Utilities PLC

Source: Carbon Trust website, *www.carbontrust.co.uk* (January 2010).

The Carbon Trust Enterprises Limited (CTEL)

The Carbon Trust Enterprises Limited exists to undertake the Carbon Trust's commercial activities primarily through its joint ventures and subsidiaries. The latter include notably (Carbon Trust, 2009a):

- Joint ventures:
  - Insource Energy Limited (64.2% of the issued share capital): A renewable energy developer of an integrated energy supply and waste management business providing tailored, on-site solutions for food and drink manufacturers in the United Kingdom.
  - Connective Energy Limited (40% of the issued share capital): A renewable energy business looking to develop a UK low-carbon heat supply business.
  - Partnerships for Renewables Limited (51% of the issued share capital): A renewable energy developer working with public-sector bodies to develop, construct and operate on-site renewable energy projects in the United Kingdom.
- Subsidiaries:
  - The Carbon Trust Footprinting Company Limited (100% of the issued share capital) focuses on engaging with businesses seeking to measure, reduce and communicate the carbon impacts of their products and services. It labels products with the carbon footprint embodied in a product in bringing it to the shelf and acknowledges a commitment to reduce that footprint over a specified period. The carbon label was introduced for the first time in the United Kingdom in March 2007.
  - The Low Carbon Culture Company Limited (100% of the issued share capital) provides consultancy services to help companies to achieve cost and carbon savings through active carbon management.
  - The Carbon Trust Standard Company Limited (100% of the issued share capital) focuses on providing organisations with certification of their performance in taking action to reduce their carbon emissions, with the endorsement of the Carbon Trust Standard.

Carbon Trust Investments Limited (CTIL)

Carbon Trust Investments invests in the United Kingdom's clean energy technology industry. It typically co-invests between GBP 250 000 and GBP 3 million per transaction leveraged with other private sources of funding. As of March 2009, the Carbon Trust held through Carbon Trust Fund Management Holdings Limited (CTFMHL) a 40% interest in CT Investment Partners LLP (CTIP) and through CTIL a 50% interest in the Low Carbon Seed Fund LLP.

The Carbon Trust Investment Partners LLP (CTIP) advises the Carbon Trust on its investment activities and employs the Carbon Trust's investment team. This is to separate investment advice activities from the Trust's provision of grants and other publicly funded support. The CTIP occupies a separate part of the Trust's offices, although senior staff from both sides meet on various committees. The Carbon Trust has recently reorganised the CTIP. The Carbon Trust now holds 40% and the executive partners hold 60% of the CTIP's share capital. In April 2009, the Carbon Trust took over the Low Carbon Seed Fund LLP, enabling both its venture capital and seed capital investment activities to be conducted directly (Carbon Trust, 2009a).

The report of the National Audit Office (2007) highlighted a potential conflict of interest, namely that CT Investment Partners staff could influence publicly funded research and development or incubator support for emerging businesses which they, in time, may back by way of investment and thus may earn carried interest. The Carbon Trust confirmed that it has put "Chinese Walls" (for example, physical separation of offices within the same building) in place between the people making the grants and those making the investment decisions, and that it would put in place further safeguards to address this risk if the investment fund is subsequently launched.

Carbon Trust Fund Management Holdings Limited (CTFMHL)

The Carbon Trust Fund Management Holdings Limited is a holding company which owns the Carbon Trust's economic interest in the CTIP. The CTIP is authorised and regulated by the Financial Services Authority to undertake designated investment business. It is a partnership between the CTFMHL and the investment management team as executive partners. The CTIP provides investment advisory services to CTIL and the company (Carbon Trust, 2009a).

Organisational culture

The Carbon Trust prides itself on its "business ethos" and on its functioning as a private-sector company. One Carbon Trust director confirmed this with a characteristic statement: "In terms of ethos, we are very much a private sector company, so we do everything in a very businesslike, professional way" (Policy Innovations, 2009). The organisation openly sees itself as a part of the business community and collaborates closely with key players in the low-carbon field (interviews in 2010).

The interviewed stakeholders confirm that the Carbon Trust has developed an organisational culture characterised by a business focus and a "fast pace" of delivery. The Carbon Trust staff mentions an "electric and dynamic atmosphere" that is very different from that of government departments. The difference between the Carbon Trust and a government department is partly a reflection of how the respective entities view and deal with risk and partly the availability of specialist staff from, for example, the clean energy technology community, the private equity funds or the big companies. One respondent pointed out that one of the side effects of being a business-like environment is the relatively high rotation of experts working for the Trust. Nonetheless, this does not put the overall level of expertise within the organisation at risk, as newly hired staff are at least as experienced in the field as their predecessors. One may refer to it as "continuity of expertise". By contrast, the career rotation of staff in government departments collaborating with the Trust may bring in civil servants with little or no relevant experience in the field.

When asked about how their "low-carbon" mission differentiates them from other players in business they remarked: "When we contact business partners we put business opportunity upfront and the green bit away" (interviews in 2010). The Carbon Trust understands very well that its reputation as a part of the business community is the key to its success. When the Carbon Trust works towards its mission of a shift to a low-carbon economy it does so from perspective of the business sector rather than public sector.

Governance relations

Relations with key stakeholders

Relations with government

As a private company, the Carbon Trust is legally independent from the government and enjoys a high degree of autonomy in designing and delivering its operations. The Grant Offer Letter from the Department of

Energy and Climate Change (DECC) (previously DEFRA) provides the flexibility the Carbon Trust needs to do its job. It is more than would typically be given to non-departmental public bodies.

Formally, the Department's influence over the Carbon Trust is restricted to commenting on its annual business plan and raising issues at quarterly board meetings (NAO, 2007). The government's role in the Board meetings was described in interviews as "steering and guiding" to remain in line with current government policy. Government has a very limited influence, however, on the actual choices of technology areas to be targeted or on the specific design of the Carbon Trust's instruments. In addition, the Carbon Trust provides all of its founders with a quarterly report on progress against the objectives set out in its business plan, and meets its founders quarterly to discuss. The Carbon Trust also engages its founders as stakeholders when developing significant new initiatives.

At the end of the day, it is the government that decides the Carbon Trust budget. This can be seen as an ultimate control tool in the hands of funding departments. The fact that the Carbon Trust budget is confirmed on an annual basis and the three-year budget indication does not constitute the government's commitment limits the Carbon Trust's horizon. The Carbon Trust realises that its allocation from government depends on many factors which it cannot control and sums it up as follows: "We don't know the other factors that are governing the decision and we don't know where we sit in the hierarchy of the department policy" (interviews in 2010). However, since the launch of the Carbon Trust in 2001, its budget has increased year on year – a reflection, in part, of the importance the government attaches to tackling climate change and moving the United Kingdom to a low-carbon economy; it is also in part a recognition by the government of the success the Carbon Trust is having achieving its objectives.

The formal system of checks and balances between the government and the Carbon Trust is complemented by frequent informal working contacts between the two organisations. Frequent working meetings and encounters at various events offer innumerable opportunities to find consensus between the two sides as well as to share early signals about possible future developments.

Box 8.2. A snapshot of governance arrangements of other UK public-private partnerships in the field

The National Industrial Symbiosis Programme (NISP) was set up to develop collective solutions in the area of resource efficiency and is funded by the Environment Department (DEFRA) and regional development agencies. Its work programme is agreed with DEFRA, a representative of which also attends board meetings.

The Energy Saving Trust (EST) advises businesses, public-sector bodies and the public on energy efficiency and is funded by government. DEFRA and the Department for Transport are members of the company and have the right to attend board meetings. The EST consults the departments on its work programmes.

The Waste and Resources Action Programme (WRAP) is funded by DEFRA to help reduce waste and boost recycling. The department is represented on its Board and endorses its work programmes.

Source: Technopolis Group.

Relations with business

The Carbon Trust prides itself on its independence and its close contacts with business and equity investors. The stakeholders often underline that the Carbon Trust enjoys a high level of trust and has a strong reputation in the eyes of business. The fact that it was established as a private, independent company is often mentioned as a key factor in building that trust.

According to the report of the NAO (2007), the private-sector status of the Carbon Trust has allowed the management team to build close relationships with potential investors, to recruit staff with business expertise who are experienced in taking business proposals forward, and to respond quickly and flexibly to changes in market conditions.

Furthermore, the Carbon Trust's "arm's-length" relationship with government has enabled it to take the opportunity to explore a range of innovative options for reducing carbon dioxide emissions. Also, the Carbon Trust believes that its customers and private investors were more willing to share information with them as well as to commit their funds when they recognised that the Carbon Trust was independent and as such would not share their confidential business data with government (interviews in 2010; NAO, 2007). Furthermore, the results of Carbon Trust analyses (*e.g.* by the Insights or Innovations team) are regarded as more trustworthy by business

than government sources owing to the independent status of the Carbon Trust (interviews in 2010).

Access to information and confidentiality issues

Although it is publicly funded, as a private company the Carbon Trust is not subject to the Freedom of Information Act on environmental issues. The organisation has, nonetheless, published data and reports on its activities which were judged not to have any commercially sensitive information. The level of access to information on Carbon Trust activities is agreed in partnership with private partners and as such is considered on a project-by-project basis (interviews in 2010).

Budget and financial arrangements

At the outset, the Carbon Trust was funded mostly from the UK Climate Change Levy, a tax on non-domestic users of electricity, gas and coal. The remainder came from funds voted by the UK Parliament. Over the next two or three years, the funding route was consolidated so that all the Carbon Trust's funding now comes from funds voted by the UK Parliament (interviews in 2010). With the creation of the Department of Energy and Climate Change in October 2008, it became the company's main government funding department.

Government grant funding is approved annually and drawn down monthly in advance. Grant funding from Invest Northern Ireland and the FCO (the Foreign and Commonwealth Office) is received in arrears. The Carbon Trust is notified of its indicative budget for three years for planning purposes, but this information does not constitute an official government financial commitment.

Income in 2008/09 was made up of: grant claimed from DECC, DEFRA, FCO and the devolved administrations; separate funding for the interest-free energy efficiency loans scheme in Northern Ireland; and interest income on the Carbon Trust's own funds (Table 8.1). Other sources included sales in commercial subsidiaries, sales to expert advice customers and investment transaction fees (Carbon Trust, 2009a).

The company has grant funding of GBP 103 million for 2009/10 from DECC, DEFRA, the Department for Transport, the Foreign and Commonwealth Office and the devolved administrations. This funding does not include additional funding announced in the 2009 Budget of up to GBP 83.9 million to expand the company's interest-free energy efficiency loans scheme in England and up to GBP 54.5 million to provide further funding to Salix Finance Limited to administer a new public sector loan

scheme in England without a requirement for matching funding. Subject to that change, future activity will largely continue the programmes undertaken in 2008/09, but on an enhanced scale where additional funding has been provided. The retained profit for the period was GBP 1.991 million (2007/08, GBP 3.368 million).

Table 8.1. Income structure of the Carbon Trust, 2008 and 2009

	31 March 2009, GBP thousands	31 March 2008, GBP thousands
Grant income		
DECC	80 325	83 542
Invest Northern Ireland	3 376	2 688
The Scottish Government	5 169	9 570
The Welsh Assembly Government	4 965	4 415
DEFRA	800	–
FCO	120	–
Grant funding provided for interest-free loans		
DECC	12 000	5 474
Invest Northern Ireland	2 000	1 214
Total grant receipts and grant income receivable	108 755	106 903
Movement in deferred income	(18 629)	(13 323)
Total grant income	**90 126**	**93 580**
Finance income		
Bank interest	1 407	1 116
Unwinding of discount on interest-free loans	2 425	1 786
Net gain on deemed acquisition and disposals of group undertakings	162	2 777
Dividend income receivable	387	–
Total finance income	**4 381**	**5 679**

Source: Carbon Trust (2009a), *Annual Report 2008/09*, The Carbon Trust, London.

The Carbon Trust's funding thus comes primarily from the UK government. The organisation is also actively pursuing other funding sources and mechanisms (interviews in 2010; Policy Innovations, 2009). The most obvious sources are private capital leveraged by Carbon Trust

operations, notably through the Technology Accelerators (the Offshore Wind Accelerator is the most successful), and profits from the venture capital arm. The Carbon Trust has also started to consider other sources of funding including philanthropic sources and foreign investors.

Main types of activity

Main areas of activity

The Carbon Trust recognised two strategic needs: to deploy energy-efficiency technology at mass scale to reduce carbon emissions now and to develop new and emerging low-carbon technologies to reduce future carbon emissions. In essence, the organisation exercises two parallel streams of activity divided according to the time horizon of expected carbon savings:

- Carbon Now to cut carbon dioxide emissions now and to benefit from immediate cost savings and increased business efficiency. This is done by providing companies and the public administration with expert advice, finance and accreditation, and by stimulating demand for low-carbon products and services.
- Carbon Future to find ways of cutting carbon emissions in the future and to capture the commercial opportunities and economic benefits of doing so. This is done by supporting early-stage pre-commercial, pre-venture capital (VC) low-carbon technology development through project funding and management, investment and collaboration, and by identifying market barriers and practical ways to overcome them.

Both Carbon Trust representatives and government stakeholders point to the challenging nature of discussions on how to balance the allocation of resources between short-term and longer-term carbon savings.

The Carbon Trust is organised into five business areas: Insights; Solutions; Innovations; Enterprises; Investments. The following sections introduce each of the areas and their main instruments. The final subsection is devoted to the international dimension of the Carbon Trust operations.

Insights

In terms of its policy advice activities, the Carbon Trust informs key decision makers on opportunities and threats relating to climate change mitigation, including explaining market opportunities and developments. This is achieved by delivering new, fact-based analysis for business, investors and policy makers, which helps set out the decisions required and the economic opportunities created.

An example is a report, *Focus for Success – A New Approach to Commercialising Low Carbon Technologies*, which aims to answer a number of key questions concerning technology support in the United Kingdom. First, it considers whether the United Kingdom should lead in commercialising new technologies. Second, it discusses how to make the United Kingdom more attractive for developing and deploying low-carbon technologies. Finally it looks at the scale of investment required and the potential benefit for the United Kingdom (Carbon Trust, 2009a).

Solutions

Carbon Trust provides advisory services to all business and public sector organisations in the United Kingdom, irrespective of size, sector or carbon footprint. Carbon Trust has developed a new carbon-saving advice service (Carbon Survey) for smaller businesses which meets their specific needs and should help them to gain substantial cost savings. The support offered through this improved service focuses on providing smaller organisations with a one-day on-site carbon survey to identify low or no-cost energy efficiency measures quickly. Carbon Trust then delivers a concise report on how to implement these actions and indicated further services that it might be able to offer. In 2008/09 Carbon Trust carried out over 3 000 on-site carbon surveys to give tailored advice to businesses of all sizes (Carbon Trust, 2009a).

The Carbon Trust also runs an interest-free loan scheme for small and medium-sized enterprises for energy-efficient equipment as part of Solutions for Business. It also provides revolving funds and zero interest loans for public-sector organisations through the publicly funded Salix Finance, an arm's-length company of the Carbon Trust. Since the start of the scheme in 2003 Carbon Trust has offered nearly GBP 80 million in interest-free energy efficiency loans to businesses, saved over 500 000 tCO_2, and approximately GBP 80 million for the enterprises involved.

The company also manages the Energy Technology List (ETL), which specifies enhanced capital allowance (ECA)-qualifying equipment. Over 14 000 products are currently listed on the ETL. In 2009 three new technologies were added to the list: uninterruptible power supplies, close control air conditioning and air–to-water heat pumps (Carbon Trust, 2009a).

The Carbon Trust recently launched the Clean Tech Revolution campaign to raise awareness of opportunities relating to innovation in the low-carbon area. The campaign will actively highlight the economic benefit that the United Kingdom can capture from taking a leading position in commercialising key low-carbon technologies and, through an innovation

awards programme, will showcase examples of British low-carbon innovation.

Innovations

Applied research

The Applied Research Open Call is a public competition which has been run three times a year since 2002. It is open to all types of organisations and any technology area that could save carbon in the future. The call is very competitive. Only about 10% of the applications received are offered grant funding and commercialisation support. The funding supports highly innovative applied research and development and commercialisation and provides face-to-face advice on how to exploit the work and develop a successful business proposition. As of 2009, the Carbon Trust had offered a total of over GBP 24 million in funding to 175 innovative projects. This investment has attracted additional commitments of almost GBP 30 million from the private and public sectors (Carbon Trust, 2009a).

Technology acceleration

The Technology Accelerator is "a portfolio of directed projects set up and wholly or partly funded by the Carbon Trust to support sectors which have significant long-term potential to reduce carbon emissions, but whose potential is constrained by barriers to commercialisation" (Carbon Trust, 2009a). In its review, the NAO (2007) underlined that the accelerators are particularly well designed to fill what could otherwise be a barrier to the development of commercially viable low-carbon technologies. The NAO also noted that the Carbon Trust's co-ordination of businesses and researchers to collaborate on the accelerator projects appeared to be unique in the UK policy landscape and that the focus on applied research and commercial development rather than on basic research and academic achievement meant it supported a range of projects different from other sources of grants (such as those supported by research councils).

Carbon Trust currently runs eight accelerators focused on a variety of technologies or challenges, including: Advanced Photovoltaic Challenge, Algae Biofuels Challenge, Biomass Heat Accelerator, Buildings Accelerators, Industrial Energy Efficiency Accelerator, Marine Energy Accelerator, Marine Renewables Proving Fund, Micro Combined Heat and Power Accelerator, Offshore Wind Accelerator, Polymer Fuel Cell Challenge, Pyrolysis Challenge.

The biggest accelerator project addresses offshore wind energy. It was set up in collaboration with five European utilities in Norway, Denmark,

Germany and the United Kingdom. The aim of the accelerator programme, with an overall budget of GBP 30 million (GBP 10 million from the Carbon Trust), is to scale up generation of electricity from current-generation offshore wind turbines and to reduce costs by at least 10%.

In the Low Carbon Buildings Accelerator, the Carbon Trust has been working closely with a range of major refurbishment projects in order to understand the barriers to achieving a low-carbon building and how to overcome them. It published in 2009 some of the lessons from that work in a guide for clients and project managers.

The Industrial Energy Efficiency Accelerator aims to identify new carbon savings opportunities in complex manufacturing processes and to demonstrate to industry how these can be achieved in practice. In 2009 pilot projects were carried out with three very diverse sectors: asphalt manufacturing, plastic blow-bottle moulding and animal feed manufacturing. Each technology field presented different, industry-specific challenges.

The Carbon Trust launched in October 2009 the Polymer Fuel Cells Challenge, a UK bid for a breakthrough in fuel cell technology, which aims to accelerate the commercialisation of breakthrough UK technology that could achieve mainstream cost-effective (mass) production of cars and buses powered by fuel cells, as well as provide electricity and heat in homes and businesses. The aim is to drive forward the commercialisation of UK fuel cell expertise, which should play a crucial role in the Clean Tech Revolution both by cutting carbon and creating jobs and economic value (Carbon Trust, 2009b).

Incubator scheme

Carbon Trust also supports the development of low-carbon technologies and companies that are further away from commercial readiness. Its business incubator scheme helps companies with promising low-carbon technologies become attractive to investors. As of 2009, the scheme had helped to incubate 82 businesses which had gone on to raise around GBP 84 million in private investment (Carbon Trust, 2009a).

The incubator activity is a publicly funded activity and is not part of the investment portfolio *per se*. It is part of the continuum of innovation support that the Carbon Trust provides, from R&D through applied research and directed research (House of Commons, 2008).

Enterprises

The Carbon Trust creates and develops low-carbon enterprises in markets which have the potential to deliver significant carbon reductions and financial returns for the United Kingdom but in which barriers to rapid deployment exist. It aims to prove their commercial viability and provide co-investment and strategic opportunities to partners who can bring the skills and capital investment to complement those of the Carbon Trust. For example, the Carbon Trust is working with HSBC to build the Partnerships for Renewables (PfR) joint venture, which aims to deliver 500 megawatts (MW) of onshore wind power on public land over the next five to eight years. The Carbon Trust also created two 100% owned companies, the Carbon Trust Footprinting Company and the Carbon Trust Standard Company, to commercialise its carbon reduction label and its standard to verify an organisation's good carbon reduction performance.

The Carbon Trust designed the Carbon Reduction Label to help companies communicate the impact of their carbon footprinting work to consumers. Companies that display the Carbon Trust's Carbon Reduction Label (on pack, online or elsewhere) are making a commitment to reduce the carbon footprint of their product or service. In June 2008 the Carbon Trust introduced the Carbon Trust Standard to address a problem of business "green washing". The carbon standard is only awarded to companies and organisations that measure and reduce their carbon emissions annually. The standard has been deemed by the UK government evidence of early action in respect of the introduction of the government's Carbon Reduction Commitment (CRC). Achievement of the standard will help companies demonstrate robust early action in the scheme. To qualify, organisations must show an absolute cut in emissions for one to three years, depending on their size. They must commit to achieving further year-on-year cuts. The standard is one of only two early action metrics recognised under the CRC, a market-based emissions reduction scheme for large energy users, including retailers, local authorities and engineering and manufacturing firms (Environmental Data Services, 2009a, p. 8).

Published in October 2008 by the British Standards Institution (BSI), co-sponsored by the Carbon Trust and DEFRA, the PAS 2050 is the first international standard for companies to measure the carbon footprint of their products and services. The Carbon Trust is now working with the World Resources Institute and ISO to support the global harmonisation of product carbon footprinting standards. Alongside PAS 2050, the Carbon Trust also published the Code of Good Practice for communication and reduction associated with product carbon footprinting, and "Product Carbon

Footprinting: the New Business Opportunity", for organisations considering carbon footprinting activities.

Investments

The Carbon Trust acts as a minority co-investor on commercial terms in the early-stage low-carbon technology sector by seeking to leverage funds from the private sector into new companies. The organisation invests between GBP 250 000 and GBP 3 million in clean energy companies, from the seed stage through to growth capital. As of 2009, the Trust had invested in 12 businesses, together with additional investments made through the Low Carbon Seed Fund LLP. The organisation has committed GBP 25 million to venture capital activity and has invested GBP 12.2 million, leveraging total private funding of GBP 108 million (Carbon Trust, 2009a).

As of October 2009, the Carbon Trust was to inject up to GBP 18 million in additional funding over the next 12-18 months into the UK clean energy sector to help plug the financing gap faced by early-stage UK clean energy businesses. The purpose of the fund is to make direct equity or equity-related investments in UK early-stage, low-carbon technology companies that demonstrate commercial potential. Against a backdrop of declining investment in the sector it represented more than a quarter of the United Kingdom's entire venture-capital clean energy investment in 2008, which stood at GBP 66.5 million, its lowest in over five years.

The function of the investment management team is to make investments using their funding in an area in which there is an acknowledged market failure at the very small, early-stage end of the technology company market (House of Commons, 2008). The Carbon Trust Investments team is in a completely separate part of the organisation. The employees of Carbon Trust Investments are not party to any of the funding decisions that are made in terms of R&D grant funding to low-carbon technology businesses generally, in order to ensure a clear separation between the R&D funding and investments as venture capital.

International dimension

The Carbon Trust's international activity aims to maximise its impact in terms of its mission by:

- increasing the potential for carbon savings, recognising the scale of global carbon emissions relative to the United Kingdom;

- leveraging the experience gained in the United Kingdom to achieve emission reductions more quickly than would otherwise be the case;
- sharing the fixed costs for developing and maintaining Carbon Trust know-how and systems.

The Carbon Trust's goal over the next few years is to achieve a step-change impact on carbon savings, now and in the future, and to attract the private-sector investment required to accelerate the move to a low-carbon economy. The budget for its international activities comes from the Carbon Trust's allocation from the Department of Energy and Climate Change. The department has agreed with the Carbon Trust that the international dimension is a legitimate element of its work.

The Carbon Trust has been active in developing a strategic international presence to look for business partners as well as for additional sources of revenue. In June 2009, the Carbon Trust Board approved the establishment of Carbon Trust International Ltd, a wholly owned subsidiary of the Carbon Trust to further its international objectives. The Carbon Trust works in the following countries:

- Qatar: In November 2008, the Carbon Trust signed a Memorandum of Understanding with the Qatar Investment Authority to explore opportunities for low-carbon collaboration and to create a clean tech fund designed to invest primarily in UK companies.
- China: The Carbon Trust has signed a framework agreement with the China Energy Conservation Investment Corporation (CECIC) to create a GBP 10 million joint venture to accelerate the development and deployment of low-carbon technologies. The aim is to open new Chinese markets for innovative UK low-carbon technologies and businesses as well as to support China's efforts to move to a low-carbon economy while opening up new commercial opportunities for low-carbon businesses in the United Kingdom. During 2008/09 the Carbon Trust opened a representative office in China and commenced expert advice activities funded by the Foreign and Commonwealth Office (Carbon Trust, 2009a).
- Florida, United States: In July 2008, the Carbon Trust agreed to work with the governor of Florida on innovation in low-carbon technology and ways to help reduce emissions in the near term; in 2010, the Carbon Trust appointed a head of operations in the United States to be better able to respond to increasing US interest in the Carbon Trust model.

- Australia: The Carbon Trust has a contract with the Australian government to help set up the Australian Carbon Trust announced by the Australian Prime Minister, Kevin Rudd on 4 May 2009.
- Global dimension: Working with the UK Department for International Development, the Carbon Trust supports the concept of climate innovation centres to be located in developing countries which aim at accelerating the deployment of new technologies through research, product development, adaptation, testing and demonstration. This proposal has been introduced in the UNFCCC climate negotiations by the Indian government and has received the support of the United Kingdom and other governments. The centres could be funded by public-private partnerships (PPPs) between the international community, host governments and the private sector and would focus on technologies that meet the specific needs of developing countries. While further research is needed, the paper's authors suggest that an initial investment of USD 2.5 billion over five years could fund five regional centres and leverage up to USD 25 billion in private-sector assets. The concept of "transferring" low-carbon technologies from rich countries to developing nations, which has been the standard approach in climate discussions, has not proven productive. Climate innovation centres are expected to be more successful in leveraging technologies and overcoming barriers.

Classifying Carbon Trust measures

The measures implemented by the Carbon Trust can be structured according to a typology of supply-side and demand-side measures.

Supply-side measures include: equity/debt support; research and development; demonstration and commercialisation; education and training; networks and partnerships; information services; provision of infrastructure.

Demand-side measures cover notably: regulations and standards; public procurement and demand support; technology transfer.

The Carbon Trust's activities cover to some degree almost the full scope of the proposed typology. This wide coverage allows the Trust to take a systemic approach and to plan their interventions in different parts of the value chain. Table 8.2 presents the instruments classified according to their supply or demand focus.

Table 8.2. Classification of Carbon Trust measures

	Type of measure	Carbon Trust activity
Supply-side measures	Equity/debt support	• "Solutions" Interest-free loan for small and medium-sized enterprises and for public sector organisations "Investments" Low Carbon Seed Fund LLP
	Research and development	• "Innovations" Applied research call Research accelerators
	Demonstration and commercialisation	• "Innovations" Technology accelerators
	Education and training	• "Solutions" Training through the work of accredited consultants Clean Tech Revolution campaign "Innovations" Business incubators (advisory services)
	Networks and partnerships	• "Innovations" Public-private partnerships built for individual technology accelerators
	Information services	• "Solutions" Advisory services The Energy Technology List (ETL) "Insights" "Technology accelerators" Published reports and studies
	Provision of infrastructure	-
Demand-side measures	Regulations and standards	• "Enterprises" Carbon Trust Standard PAS 2050 "Insights" (*indirectly*) Studies on potential impacts of regulations
	Public procurement and demand support	• "Enterprises" Carbon Reduction Label
	Technology transfer	- Climate innovation centres (CICs)

Source: Technopolis Group.

Expenditure per area of activity

The Carbon Trust invested nearly 72% of its total annual expenditure in 2008/09 in its "Carbon Now" line of activity, which consumes by far the

biggest part of the budget. Total expenditure for "Carbon Future" activities amounted to GBP 18.8 million compared to about GBP 66 million for "Carbon Now". The single most expensive item in the budget is expert advice (GBP 35 million).

That said, probably the most relevant trend in Carbon Trust expenditures in recent years has been the significant reduction in funding allocated to "Carbon Now" and the increased budget for "Carbon Future" activities. As Table 8.3 illustrates, expenditure for "Carbon Future" grew by nearly GBP 4 million whereas that for "Carbon Now" dropped by GBP 7.8 million between 2008 and 2009. Another related trend was the increase in spending on accreditation services: the Carbon Trust Footprinting Company Limited and the Carbon Trust Standard Company Limited cost GBP 5.6 million compared to GBP 2.0 million in 2007/08. These changes were in line with the Carbon Trust's strategy as well as the recommendations of external reviews. In the longer term, the Carbon Trust is planning to maintain the level of the "Carbon Now" expert advice activity while using less of its government grant funding, since larger customers have begun to co-fund expert advice services. The degree of intervention using "Carbon Now" instruments will be reconsidered in light of the carbon reduction commitment energy efficiency scheme (CRC) as it becomes established.

Over the next five years, the Carbon Trust has planned a shift in the balance of its activities, away from providing publicly funded support to large businesses and towards innovation, new low-carbon technologies and new business models and ways of doing business. It is estimated that the work already undertaken to support emerging technologies would reduce carbon dioxide emissions by between 13.7 million and 20.7 million tonnes by 2050 (House of Commons, 2008).

Internal co-ordination and coherence

The Carbon Trust is characterised by close collaboration between different teams working in various areas of activity. Its flat organisational model and physical proximity allow for better co-ordination than in many government departments which often implement similar instruments using separate programmes funded from different budgetary lines (interviews in 2010). The links between different teams are further strengthened by internal mobility. For example, the former director of the incubation programme moved to the venture capital arm. Another factor helping internal collaboration is the organisation's relatively small size, at least compared to any UK government department.

Table 8.3. Carbon Trust expenditures by type of activity, 2008 and 2009

	2009, GBP thousands	2008, GBP thousands
Carbon Now		
Expert advice	35 055	39 533
Finance	10 181	14 367
Accreditation	5 595	1 977
Opening markets now	15 232	17 958
Total Carbon Now	66 063	73 835
Carbon Future		
Opening future markets	7 487	5 119
Technology commercialisation	9 403	7 799
Investment	1 871	1 971
Total Carbon Future	18 761	14 889
Total programme expenditure	*84 824*	*88 724*
Other management and administration expenditure	3 439	3 296
Change in fair value of investment portfolio	1 518	3 702
Discount on interest-free loans	2 396	2 438
Total expenditure for the financial year	*92 177*	*98 160*
Activity not included in expenditure		
Net effect of investment made less fair value fluctuations	3 203	(1 533)
Remaining effect of interest-free loans	17 939	18 094
Total activity for the financial year	*113 319*	*114 721*

Source: Carbon Trust (2009a), *Annual Report 2008/09*, The Carbon Trust, London.

There is an historical link between the Innovations and Insights team which work in close proximity. In fact, many areas addressed in the "Innovations" area started in the "Insights" team (interviews in 2010). The latter does the initial stakeholder analysis (including consultations), gap analysis (determining the occurrence of market failure and intervention rationale) as well as the assessment of the potential for risk reduction (as an effect of introducing the planned intervention, *i.e.* the value added of the intervention). This analytical approach can lead to identifying possible interventions to reduce the identified market failures and gaps in public intervention.

There is also a very close "symbiotic" link between the incubation arm ("Innovations") and the early-stage venture capital activity ("Investments"). The latter supports companies with sufficient commercial maturity. Companies with growth potential, but premature for early-stage investment, are offered the opportunity to be referred to the incubator service teams that can advise them on the next steps in their development.

Activities which address adjacent phases in the technology development process tend to have closer links than those dealing with less proximate phases. The links tend to be very close across the "Carbon Future" line of activity. On the other hand, the Innovations team's relations with the Solutions team are less close, as the former addresses technologies in stages that are too early to be considered for instruments implemented in Solutions areas (*e.g.* inclusion on the Energy Technology List).

Impact assessment

Approach to internal impact assessment

Internal impact assessment is performed by the dedicated Impact Assessment Team. The team is part of the corporate structure of the organisation and as such is separate from the business divisions that deliver carbon savings. The Carbon Trust has significantly developed its own methodology for measuring the impact of its operations. Work on improving the assessment is continuous.

The methodologies used to measure the impact of the "Carbon Now" and "Carbon Future" activities are different. The measurement for "Carbon Now" activities (notably "Solutions") is believed to be relatively straightforward (interviews in 2010).

The expert advice and finance activities are focused on shorter-term CO_2 emission reductions. The Carbon Trust reports on implementation of CO_2 and energy-saving measures made by their customers during the year. The expected effects of all of the "Carbon Now" activities implemented by the Carbon Trust via its subsidiaries and accredited consultants are first established for a representative sample of customers and then projected onto the entire customer base. The reported impacts of the Carbon Trust were challenged by the external evaluation of the organisation which argued that the actual savings were significantly lower; the attribution of effects was also questioned.

In contrast, "Carbon Future" activities focus primarily on catalysing market development to accelerate the deployment of new and emerging low-carbon technologies which are to deliver longer-term CO_2 emission reductions. The Carbon Trust's assessment is based on a model of potential

future impact. The impact assessment of the "Investment" and "Innovations" areas is considered as most challenging owing to uncertainty of prospective carbon saving. The analysis focuses on the assessment of the likelihood and the time it will take the assessed emerging technology to reach the market, the projected level of market penetration and the effectiveness in term of carbon savings (interviews in 2010).

The Low Carbon Technology Assessment (LCTA), first published in 2003 and revised in 2007, provides a way of ranking the technical potential for future carbon dioxide savings of a wide range of low-carbon technologies in relation to the Carbon Trust's intervention (NAO, 2007). Drawing on the LCTA, the Carbon Trust has designed a future impact estimation tool to estimate carbon savings going forward. Its aim is to inform decisions on projects initiated in-house, such as the Accelerators, in order to identify technologies in which the United Kingdom has a competitive advantage. In such assessments, the carbon metrics are combined with the projected commercial returns.

In general, for both its expert advice and finance activities, the Carbon Trust monitors and reports: an estimate of its overall impact in terms of implemented CO_2 emission reductions on an annual basis; its programme cost-effectiveness on an annual and lifetime basis; and the lifetime cost-benefit of its activities, taking into account programme costs and an estimate of the costs and benefits to customers.

The Carbon Trust calculates its cost effectiveness in delivering CO_2 emission reductions over two time periods: annualised cost effectiveness (programme costs divided by annualised CO_2 emission reductions of all implemented recommendations) and lifetime cost effectiveness (programme costs divided by lifetime CO_2 emission reductions of all implemented recommendations).

To capture the fact that CO_2 emission reductions are most beneficially achieved when the cost to business is less than the financial savings that result from reduced energy use, the Carbon Trust also calculates the cost and benefit of its activities, taking into account the financial costs and benefits to its customers in addition to the costs its incurs:

> *Cost benefit = net present value of Carbon Trust programme costs, customers' implementation costs and customers' energy cost savings divided by lifetime CO_2 emission reductions of all implemented recommendations.*

Annual and quarterly assessments and reports

The Carbon Trust undertakes an annual assessment of its impact at the end of the financial year. This assessment reports: *i)* the total CO_2 saved as a result of the actions customers of the Carbon Trust have taken; *ii)* the potential CO_2 savings from its investments and funding for developing low-carbon technologies; and *iii)* the level of efficiency with which these have been achieved. The results of the impact assessment are presented in the performance assessment section of the Annual Report. In addition, the Trust provides reports against the performance metrics set out in its business plans for each financial quarter. The results help shape the business planning decisions taken throughout the year.

The Board is responsible for reviewing the effectiveness of the Carbon Trust's system of internal control. An Audit Committee is responsible for monitoring the group's financial reporting and its audit process and for reviewing the system of internal control (including financial, operational compliance and risk management) and making recommendations to the Board as appropriate. Two of the members of the Audit Committee are representatives of government departments. The remaining two members are independent. The chairman of the committee is a chartered accountant. The committee meets four times a year. The meetings are also attended by the company's external auditors (Carbon Trust, 2009a).

The Carbon Trust seeks independent assurance on its impact assessment reporting processes under the International Standard on Assurance Engagements (ISAE) 3000. In 2008-09 the company mandated KPMG to review the application of its impact assessment methodology. This comprised a review of the methodology, including verification of baseline assumptions and their limitations. The review has assured that the estimated savings were reasonable. The traditional financial audit of the use of public money is undertaken by Ernst & Young. Both KPMG and Ernst & Young were selected to perform their roles through a competitive tendering procedure.

One-off external assessments and evaluations

The 2007 report of the National Audit Office (NAO) was the first substantive external review of the Carbon Trust's performance. It focused on the cost-effectiveness of the advice offered to businesses and the public sector and its programme to encourage the development of low-carbon technologies.

The NAO has statutory audit access rights to conduct value-for-money examinations of the Carbon Trust itself but not of its subsidiaries. Private-

sector auditors normally undertake the financial audit of the Carbon Trust's accounts. Nevertheless, the Carbon Trust's management team provided the NAO with full audit access to any papers or individuals within the subsidiary companies in order to undertake the examination.

The NAO commissioned a private consultancy, Morgan Harris Burrows (MHB), to review the initiatives developed by the Carbon Trust to determine whether it was effective in supporting the development of emerging low-carbon technologies, and whether the interventions were sufficiently co-ordinated with other public-sector sources of funding. The review highlighted in particular that the Carbon Trust had put in place strict due diligence procedures and suitable arrangements for ongoing monitoring. Should any of the organisations funded by the Carbon Trust run into difficulties, the extent of any potential loss is limited to the amount invested (NAO, 2007). The MHB report stated "A number of those interviewed have suggested that the Carbon Trust is unique in the world and as such is a model that other countries may emulate. The Carbon Trust 'Brand' and capability has gained a high reputation in both industry and academia; the value of this needs to be protected and enhanced." (MHB, 2007) Another external review was undertaken under the auspices of the House of Commons (2008).

Reported results and impacts

Key results and impacts

According to Carbon Trust's assessments, the organisation's activities have contributed to saving over 23 $MtCO_2$ as of 2009, delivering costs savings of around GBP 1.4 billion (Carbon Trust, 2009a). It has helped to drive around GBP 1 billion of additional investment into the development and deployment of low-carbon technologies, markets, products and services. The organisation supported the development of over 250 new low-carbon technology projects and companies in the United Kingdom. The Carbon Trust Footprinting Company has certified the carbon footprints of over 2 500 products and awarded the Carbon Reduction Label to more than 2 000.

Over the financial year 2008/09, the Carbon Trust supported 30 000 customers, saving companies up to GBP 227 million in direct costs and cutting up to 2 million tonnes of carbon dioxide from their annual emissions. The Trust leveraged in the region of GBP 300 million of private investment into carbon reduction and low-carbon technology projects and delivered carbon savings cost effectively at GBP 4-6 per tonne of carbon saved. The organisation has offered GBP 22.3 million of interest-free energy

efficiency loans to businesses and the Carbon Trust Standard Company has certified 71 companies to the Carbon Trust Standard.

The Carbon Trust also launched three major projects to accelerate the deployment of low-carbon energy technologies, including a GBP 30 million flagship project with the offshore wind industry (Technology Accelerator) aimed at cutting the cost of offshore wind energy by 10%. It has signed a contract with the China Energy Conservation Investment Corporation to set up a joint venture company to help businesses that have decided to establish a presence in Chinese low-carbon technology markets.

In 2007 the NAO praised the Trust for its success in leveraging private funding. For every pound the Carbon Trust had invested in its low-carbon technology innovation programme, the private sector had invested two. Its venture capital arm has been even more successful, attracting GBP 10 of private funding for every GBP 1 invested. The ratios for innovation activities have improved since and now are about GBP 7 for GBP 1. The average financial leverage for all operations is seven to one (interviews in 2010).

Out of all Carbon Trust customers who received specific guidance or advice between April 2005 and March 2006 80% were satisfied with the service received (NAO, 2007). Over three-quarters of respondents considered that they had received sufficient advice to reduce their carbon dioxide emissions, and 76% said that they would not have achieved the same level of energy or carbon savings without the intervention of the Carbon Trust, compared to 20% who said they would have made the same changes anyway.

Barriers to achieving carbon savings

NAO (2007) noted that less than 40% of the potential carbon savings identified by the Trust between 2003 and 2006 were actually achieved. Its survey of Carbon Trust clients found that 60% of organisations had implemented no more than five out of average of 11 recommendations. The Carbon Trust's own research corroborates the NAO's findings. For most businesses, energy costs represent less than 1% of costs and the regulatory pressure to take action is weak. It is not surprising, therefore, that it is hard to secure the necessary management attention; competing priorities for investment, tight payback criteria, perceived risk, lack of funds and the lack of support from senior management were mentioned as the main reasons for not implementing recommendations (interviews in 2010). For the vast majority of businesses, investing in energy-efficiency measures was cost-effective, but 65% still believed that the cost of mitigating climate change was too high. Energy-efficiency measures were crowded out of the

management agenda by investment opportunities perceived as more interesting or offering better returns. Businesses often lacked data on energy usage and so found it difficult to monitor their energy consumption accurately. They relied instead on estimated figures from suppliers, which did not show them how energy had been used within the business, and, therefore, how savings could be made. The assessment notes, however, that the Carbon Trust deliberately includes some demanding measures in its advice to encourage companies to be ambitious in their energy-saving plans (House of Commons, 2008).

The assessment of the effectiveness of the Carbon Trust advice's indicated some deficiencies. According to the House of Commons (2008), encouraging greater take-up of recommendations depends in part upon supporting energy consultants to work more effectively with businesses. The Carbon Trust had developed a consultant accreditation scheme to standardise and raise the quality of advice offered. However, the chargeable rates of GBP 435 for a standard site survey and up to GBP 700 a day for more specialist advice restricted the time that could be spent with businesses owing to the limits on public funding and the restrictions on the level of financial support to individual company to meet European Union requirements for state aid. Any step-change in take-up without a corresponding increase in government funding would thus be likely to depend on franchising specified services for accredited third parties to market competitively.

The NAO concluded that in spite of its efforts to focus its work on the largest emitters, the Trust has worked with only 12% of companies with energy bills greater than GBP 50 000 a year, 30% of local authorities, 40% of universities and 12% of hospital trusts. The NAO recommended the Trust expand its energy-efficiency accreditation scheme to allow companies to verify their emissions reduction claims, and build stronger links with overseas organisations to monitor best practice. The energy-efficiency accreditation scheme has formed the basis for the Carbon Trust Standard.

Referring to Carbon Trust performance, Tom Delay (CEO of the Carbon Trust) said the organisation was successfully targeting the biggest emitters, but "it could not force companies to take up its offers". He added that the Trust had worked with around a third of firms with energy bills greater than GBP 500 000 a year (responsible for around half of UK businesses' emissions) including 52 out of the 100 FTSE 100.

External assessments as well as the interviews conducted for this study also brought to the fore the question of attribution of the reported Carbon Trust results. The issue was raised whether and to what extent it can be established that reductions in carbon dioxide emissions were directly

achieved as a result of the Carbon Trust's intervention or were due to wider fiscal and customer pressures on organisations. The issue was recognised by both the Carbon Trust and the government. The Carbon Trust has been working to develop a methodology to avoid inappropriate attributions and potential double counting of savings reported by different organisations and government programmes. The methodology is under development (interviews in 2010).

Exit strategy

The report of the House of Commons (2008) emphasised that the need for public funding of advice on energy efficiency should decrease as public awareness of climate change and energy prices increase. According to interviews, the "Carbon Now" activity of the Carbon Trust should not be required in a "reasonably short term" as the market starts to offer solutions currently provided by the Carbon Trust (interviews in 2010). In this area of activity there are no technological barriers characterised by high uncertainty. Existing barriers are related to the regulatory framework, cost and absorption capacity of business. Therefore, the Carbon Trust should develop an exit plan to scale back its advice work over the next five to ten years.

The Carbon Trust's policy analysis and commentary on the government's climate change programme in 2006 identified the opportunity to drive energy efficiency investment by regulation rather than by continuing public subsidy. The government's decision to strengthen the regulatory landscape for energy efficiency means that the Carbon Trust can now review its energy-efficiency services and develop its exit strategy as appropriate. The exit strategy in "Carbon Future", where technological uncertainty is high, is less evident, although the same reasoning applies: when market failure is removed the rationale for the Carbon Trust is removed as well.

At the end of the day, Carbon Trust representatives believe that the future operations of the Trust will depend to a large extent on the strategic political choices of the UK government (interviews in 2010). Should the regulatory framework become more stringent, introducing fines for non-compliance with energy-efficiency legislation, Carbon Trust activities currently implemented under "Carbon Now" might be less needed, as companies would be forced to implement changes to avoid penalties. In a less regulated environment (based on voluntary commitments), however, other incentives (*e.g.* interest-free loans) and support measures (*e.g.* advisory services) may continue to be needed. However, companies may still need a source of trusted advisory services.

External co-ordination and coherence

Co-ordination and coherence with other government programmes

The Carbon Trust in the UK policy landscape

The literature review and the interviews tend to confirm that Carbon Trust activities, notably those implemented under "Carbon Future", are different from, but complementary to, other UK instruments (see in particular the review in BERR-DEFRA-DIUS, 2008).

Co-ordination of public policy measures

Government-initiated approaches

The UK government has taken a number of initiatives to co-ordinate its programmes and implementing bodies, including various formal and informal ("behind-the-scenes") co-ordination arrangements. In 2008, three of the main independent, publicly funded bodies – the Technology Strategy Board (TSB), the Energy Technologies Institute (ETI) and the Carbon Trust – created the Low Carbon Innovation Group (LCIG), a strategic collaboration with a shared vision to deliver the United Kingdom's low-carbon innovation goals. The Low Carbon Innovation Group meets regularly to review the strategic direction and content of their respective low-carbon technology programmes and initiatives. The group is to be expanded to include representation from the research councils, the Environmental Transformation Fund and, when relevant, regional development agencies and devolved administrations.

The government admits that the low-carbon policy landscape may not be easy for users to understand. To solve this problem it funded a Knowledge Transfer Network (KTN) on Energy Generation and Supply which is supposed to act as "one-stop shop" for various low carbon initiatives.

Direct co-ordination and collaboration between different initiatives

The existing implementing bodies collaborate with each other directly. The Carbon Trust engages in direct discussions with other initiatives without necessarily talking to the government first, whenever it feels there is a risk of overlap of activities. As necessary, the Trust talks with the government about "missed opportunities" to establish effective collaboration (interviews in 2010).

So far as helping to save energy and reduce carbon emissions is concerned, the Carbon Trust, the Energy Saving Trust (EST) and the energy utilities are

the principal delivery organisations. The EST and the utilities focus on energy efficiency in the domestic sector; the Carbon Trust focuses on business and the public sector. The Carbon Trust and the EST work to manage and thereby avoid the potential for overlap. They are represented on each other's Boards and they co-operate on specific projects, for example:

- The development of engagement strategies for small businesses, and the micro-combined heat and power (CHP) field trials led and funded by the Carbon Trust. EST was represented on the Advisory Committee for the Carbon Trust study on micro-CHP (interviews in 2010.).
- The Community Energy programme run by the EST and for which the Carbon Trust provided strategic and ongoing advice.
- The EST, as a contractor to the government's low-carbon buildings programme, sub-contracted the energy efficiency element to the Carbon Trust because of the strong expertise developed within its Technology Accelerator team.

Examples of other direct collaborations between different initiatives include joint calls for proposals published by the Carbon Trust and the TSB.

Co-ordination with the private sector

The Carbon Trust's commercial activities have been perceived by some businesses as potential competition. Some of the organisations interviewed as part of NAO's 2007 review of the Carbon Trust's Innovations, Enterprises and Investment activities expressed concern about the potential for conflict between the Carbon Trust's intelligence gathering and commercial work.

The Energy Services and Technology Association (ESTA) stated that companies set up by the Carbon Trust (Connective Energy and Insource Energy) compete in the private sector instead of providing a service, such as developing and sharing knowledge of new technologies. According to the Carbon Trust, it seeks to identify opportunities to earn a carbon and commercial return where service provision is non-existent (interviews in 2010). Thus, Connective Energy and Insource Energy work to "create markets that are not yet fully formed" and do not compete with other companies (Environmental Data Services, 2009b, pp. 6-8).

ESTA noted also that some of their members were unwilling to share commercial information with the Carbon Trust as they viewed elements of the Carbon Trust as potential competitors. The association voiced their concern that the Carbon Trust competes with private consultants delivering

similar services such as energy audits (Environmental Data Services, 2009b). The Carbon Trust believes that by providing funding towards the cost of energy audits, it accelerates the delivery of energy-efficiency improvements in a market which has been slow to gain momentum. Through the demanding accreditation requirements for its consultants, it is also raising the standard of service delivery. As the new carbon reduction commitment energy efficiency scheme (CRC) becomes fully established and drives market action through regulatory pressure, the Carbon Trust will review its energy audit services.

Research by the Carbon Trust estimated that the energy advice market is growing at a rate of 20% a year, but that there have been few new market entrants. Some of this growth is likely partly to reflect the Carbon Trust's own market position and increased workload. The 2007 NAO review found that energy consultancies with fewer than five employees claimed that the Carbon Trust accounted for around half of their work, consultancies with between 10 and 49 employees said it accounted for 33%, and those with more than 50 employees said 19%.

Both the ESTA and the Energy Institute believed that the Carbon Trust had not engaged adequately with them to maximise the potential growth of the market and reported some frustration among their member consultants about the potential for future fee-earning work (NAO, 2007). Among the consultants who replied to the NAO survey, 39% expressed dissatisfaction with the Carbon Trust's willingness to listen to their ideas. The ESTA also reported concern among its members about the standardisation of reports, which in their view limits their usefulness.

The Carbon Trust is aware of this criticism but believes that it consults widely with its stakeholders and takes their views into account when planning future work. The organisation has been through a process of re-accrediting its consultants since 2006. This has involved "tightening up" consultant accreditation requirements, and this may have led to a degree of dissatisfaction among some of its consultants (interviews in 2010).

Main findings and lessons learned

This section synthesises the main findings and lessons learned about the mode of operation and the value added by the Carbon Trust model. It discusses both perceived advantages and potential disadvantages (or trade-offs) linked to the model. It makes reference to the framework introduced in earlier OECD work on public-private partnerships, which focuses on issues such as risk-sharing and trust as well as value for money and reducing operational and transaction costs (OECD, 2008).

The mode of operation

High level of autonomy

As a private company, the Carbon Trust is legally independent from the government and enjoys a high degree of autonomy for designing and delivering its operations. Formally, the government's influence over the Carbon Trust is restricted to commenting on its annual business plan and raising issues at quarterly Board meetings. The government has very limited influence on the choices of technology areas to be targeted or on the specific design of the Carbon Trust's instruments. At the end of the day, however, it is the government that decides on the Carbon Trust budget. This can be seen as an ultimate control tool in the hands of funding departments.

Risk sharing between government and private sector

A well-designed risk sharing mechanism is considered a key feature of a successful PPP (OECD, 2008). In the Carbon Trust model, important investment decisions are taken by the Investment Committee (or, for large investments, by the Board) which comprises representatives of both the government and the private sector. The public sector does not interfere in the internal risk assessment processes and methodologies developed by the Carbon Trust. This demonstrates the government's trust in the organisation's technological and commercial expertise.

Through its Innovations and Investments work, the Carbon Trust aims at identifying the risks that inhibit the private sector from moving towards a low-carbon economy. First, it explores why the market is not providing goods and services on "a willing buyer, willing seller basis". Second, it designs interventions to overcome market failure. It works to characterise the risks and barriers and build "stepping stones" whereby business, investors and other partners can share the risks. Risk is reduced by forming partnerships and by applying impact assessment methodologies that allow for analysing expected carbon savings and commercial returns (interviews in 2010). Bringing various parties together is seen as an essential step in understanding the nature of the relevant risks and developing an appropriate response.

Specific risk-sharing arrangements for projects involving many stakeholders are negotiated with all concerned parties on a project-by-project basis. The Trust has developed a capacity to act as a "market catalyst" for initiatives that require risk to be shared by many companies, often including large private corporations (*e.g.* Off-Shore Wind Accelerator). In case of applied research projects, the Trust shares costs and

help to reduce associated risks by providing high-quality technical and professional expertise.

Building trust and engaging business

Owing to its independent status and close engagement with business, the Carbon Trust enjoys a high level of trust in the private sector. The organisation has been successful in establishing itself as a strong brand in the eyes of investors. This good reputation is partly a consequence of its early entry and "pioneer" status in the low-carbon field and partly because of its independently verified positive impact on carbon savings.

The business sector regards the Carbon Trust's arm's-length relationship with the government as evidence of its independence. Therefore, the Trust's advice and reports are seen as more objective than if they had come from a government or other public sector organisation. For example, the Carbon Trust's micro-combined heating and power field trials and subsequent analysis reduced uncertainty among businesses and investors about the potential of the CHP technology application in the United Kingdom.

The Confederation of British Industry (CBI) welcomed the fact that the Carbon Trust did not have to pursue a specific political agenda. A quarter of the customers in the NAO's census of the Carbon Trust's customers, who rated the Carbon Trust as providing better energy advice than others, explained that this was because "they were independent and did not have to promote particular services" (NAO, 2007).

Consolidating expertise and co-producing policy

The interviews refer to the significant influence of the Carbon Trust's analytical work on the policy-making process. By virtue of its reputation the Carbon Trust attracts professionals with substantial experience in the field of environmental technologies and low-carbon investment. External stakeholders point to the high quality of the technological and investment expertise developed by the Carbon Trust and its unique view across the innovation chain. This knowledge base is a clear operational advantage when compared to an ordinary government department, which is typically characterised by a high level of staff rotation and very limited technological expertise.

The government uses the Trust's studies and projections developed through Insights in its own policy programming and regulatory work. The Trust aims at clarifying complex issues and helping stakeholders understand better what the issues and options are to accelerate the move to a low-carbon economy. Examples include, notably, the studies on offshore wind energy or

the potential for the use of micro-CHP (used in planning of the UK feed-in tariffs scheme). Also, the CRC scheme, which is about to be implemented in the United Kingdom, has been a response to the Carbon Trust's work; the Trust's study presented to the government in 2006 proposed a way to address the gap in energy-efficiency policies so they address mid-sized organisations and businesses.

The value added of the model

Value for money and efficiency gains

The Carbon Trust is seen as one of the best programmes in the low-carbon UK policy landscape. The organisation has delivered support for improving the energy efficiency of businesses more efficiently than the former government-run programme. The Carbon Trust is seen as "single organisation with a single purpose" which makes it a very focused delivery body. The company-like organisational structure of the Carbon Trust makes it operate faster than a government department. The private sector model allows the organisation to adapt very flexibly to changing tasks and budgets (NAO, 2007; interviews in 2010).

Furthermore, delivering multiple interventions through one organisation that integrates a number of functions under one roof reduces operational costs as compared to many separate bodies. Among the examples presented in this case study is the close collaboration between investment and incubator teams, both of which benefit from expertise typically developed in the private sector.

Leveraging private capital into a low-carbon economy

Close contacts with business and the strong knowledge base of the Carbon Trust underpin its ability to design and implement market interventions which attract significant portions of private capital. The Carbon Trust investments leverage relatively high amounts of private funds, and the average financial leverage for all operations is seven to one (interviews in 2010). The investment decisions of the Carbon Trust lend credibility to the selected technology developers or start-ups and increases chances to attract further private investment (Kern, 2008; interviews in 2010).

Reduced transaction costs

A well functioning PPP can reduce the transaction costs of the stakeholders involved. The Carbon Trust activities reduce different types of transaction costs for business with a view to removing barriers to a low-

carbon economy. By providing and animating the space in which public and private stakeholders, including research organisations, can meet, the Carbon Trust contributes to reducing transaction costs otherwise carried by individual stakeholders.

In concrete terms, by undertaking analytical work on specific technologies (*e.g.* micro-CHP), managing the Environmental Technologies List (ETL) as well as by its labelling activities (via the Carbon Trust Footprinting Company Limited), the Trust reduces uncertainty and the cost of information search. Furthermore, it optimises bargaining costs in the sense that it is more effective than a government department in reaching multiparty agreements with business stakeholders. The examples of such contracts include the agreements concluded for the Technology Accelerators, notably that of offshore wind energy.

Potential risks to be considered

While reflecting on the potential risks related to the Carbon Trust PPP model, it should be kept in mind that different stakeholders will take different views. For example, the independent status of the Carbon Trust is a clear advantage from the point of view of the business community and the ability to be creative and responsive to the needs of the market, whereas it may appear a challenge and potential risk to public-sector representatives and NGOs that are sensitive to the issue of access to information. Therefore, it is necessary to think about the potential pros and cons of particular PPP models in terms of trade-offs.

Question of control and "public ethos"

The choice of implementing policies through the Carbon Trust places strategic control and day-to-day management of public funds in the hands of a private body. Government stakeholders did not consider this a problem, but rather a logical consequence of the decision to choose a particular PPP model. The government, as founder of the Carbon Trust, retains ultimate control over the organisation as it can terminate its budget. However, the issue of control was considered important by many external stakeholders, notably NGOs (NAO, 2007; House of Commons, 2008).

One interview raised a concern about whether and to what extent the Carbon Trust is a part of the public sector. As it is outside the public sector, the organisation develops its own "culture" which can put it in "a different place [from] where the central government may be" (interviews in 2010). On the other hand, the "culture" the Carbon Trust has developed has enabled it to become a highly effective delivery body focused on one of the government's primary policy objectives.

Issue of transparency in the eyes of the wider public

Another trade-off related to its operational model is that the Carbon Trust does not have to share all information with the general public. An interviewee referred to the Carbon Trust's practice of diversifying and extending its organisation to the point where it loses transparency for its founders and other stakeholders (interviews in 2010). From the point of view of the Trust, its policy on information disclosure is as open as possible having regard to the confidentiality and sensitivity of the material divulged to it in confidence by business partners.

Interaction with businesses providing similar services

Stakeholders raised concerns about whether some of the Carbon Trust's activities (*e.g.* energy audits delivered by the Carbon Trust) might lead to "crowding out" of services otherwise available on the market. The Carbon Trust's goal has been to improve the quality of energy-efficiency advisory services as well as to enhance their accessibility. The stakeholders did not feel, however, that they were sufficiently involved in the planning of the Trust's activity.

The lesson learned is that, already in the planning process, the PPP should actively engage other private actors operating in their field. It should also continuously monitor the market situation (*i.e.* presence of market failure) and analyse the wider impacts of its activities.

Transferability of the model

In general, the potential transferability of the Carbon Trust's PPP model to other countries depends on:

- the readiness and the capacity of government to delegate direct control over policy delivery to an external non-public body (interviews in 2010);
- having an appropriate legal framework involving good governance, public accountability and reporting issues for the PPP (OECD, 2008; interviews in 2010);
- the presence of suitable business partners potentially interested in the public-private arrangement (interviews in 2010).

These requirements limit the transferability of the model to the governance cultures with the experience or the political will to introduce solutions typical of the new public management. Furthermore, Kern (2009) argues that prior to considering applying the model, the political goals for a

low-carbon economy and the capability for innovation in the energy sector need to be taken into account.

This study did not consider the transferability of the Carbon Trust model in depth. The interviews as well as recent successful developments in international applications of the model allow for drawing some tentative conclusions. The most "natural" environments for the model are "Anglo-Saxon cultures" (notably the United States, Australia and Canada). The model also attracted attention from non-democratic regimes with market economies (such as "oil economies") as well as fast-growing emerging countries (*e.g.* China). On the other hand, reservations were expressed about transferability to "Nordic" or "continental cultures" such as France or Germany (interviews in 2010).

Note

1. The Advisory Committee on Business and the Environment argued for a budget of GBP 300 million, that is, 20% of revenues from the climate change levy (Environmental Data Services, 2001).

Annex 8.A1

List of interviews

Interviews

All interviews took place in January 2010. The interviews with the Carbon Trust were conducted at the Carbon Trust premises in London on 20 January 2010. The remaining interviews, apart from interviews with Mr. Arnold Black and Mr. Jonathan Essex, were conducted by telephone.

The Carbon Trust

David Vincent, Director, Projects (co-founder of the Carbon Trust)

Kofu Atuah, Technology Acceleration Manager, in charge of Micro-CHP Accelerator

Michael Coffey, Aquastrat LTD, contractor to the Carbon Trust, in charge of Off-Shore Wind Accelerator

UK government

Tim Lord, The Department of Energy and Climate Change (DECC)

Hugh McNeal, Director for Low Carbon Business Opportunities, The Department for Business, Innovation and Skills (currently appointed to sit on the CT Board)

Jeanie Cruickshank, Director of Energy and Innovation, Department for Business, Innovation and Skills (formerly on the CT Board)

Investors

Alex Hook, NESTA

NGOs and think tanks

Karen Lawrence, Policy Officer, Local Government Information Unit (LGIU)

Arnold Black, Deputy Director, KTN Environmental Sustainability

Jonathan Essex, Bioregional

Researchers and analysts

Florian Kern, Research Fellow, SPRU, Sussex University

Joe Ravetz, Co-Director, CURE, SED, University of Manchester

Matt Prescott, independent expert, formerly director of Carbon Limited at Royal Society for the Encouragement of Arts, Manufactures and Commerce

References

BERR, DEFRA, DIUS (2008), *UK Environmental Transformation Plan*.

Carbon Trust (2009a), *Annual Report 2008/09*, The Carbon Trust, London.

Carbon Trust (2009b), Delay T., Carbon Trust Chief Executive, "UK clean tech sector a hotbed of innovation, GBP 18m Investment Boost for UK Clean Tech Sector", press release, 19 October.

Environmental Data Services (2001), "The Carbon Trust: picking winners in the climate change game", *ENDS Report* 322, November, pp. 23-26.

Environmental Data Services (2009a), 'Carbon Trust emissions standard slow to take off', ENDS Report 415, August 2009, p 8.

Environmental Data Services (2009b), "Carbon Trust under fire from energy consultants", *ENDS Report* 410, March, pp. 6-8.

House of Commons (2008), Committee of Public Accounts, "The Carbon Trust: Accelerating the move to a low carbon economy", Twenty-first report of session 2007-2008, HC157, May.

Kern, F. (2008), "Fostering innovation for sustainable energy systems: Lessons from the Carbon Trust in the UK", Paper presented at the DIME International Conference, "Innovation, Sustainability and Policy", GREThA, University Montesquieu Bordeaux IV, France, 11-13 September.

Kern, F. (2009) "The Carbon Trust: A model for fostering low carbon innovation in the transition countries?", *Economic and Environmental Studies*, Vol. 7, No. 1, pp. 34-47.

MHB (Morgan Harris Burrows) (2007), "The Carbon Trust Innovation and Investment, A report to the National Audit Office".

National Audit Office (2007), "The Carbon Trust, Accelerating the move to a low carbon economy", Report by the Comptroller and the Auditor General, HC 7 Session 2007-2008, 22 November.

OECD (2008), *Public-Private Partnerships, In Pursuit of Risk Sharing and Value for Money*, OECD, Paris.

Policy Innovations (2009), E. O'Neil, Interview of Michael Rea and Scott Kaufman, "Green Business Boom for Carbon Trust, TRANSCRIPT", Carbon Trust, *www.policyinnovations.org/innovators/people/data/evan_oneil*.

Chapter 9

Sustainable Development Technology Canada: The public-private partnership potential

This case study examines Sustainable Development Technology Canada (SDTC) in terms of the potential role of public-private partnerships (PPPs) in promoting eco-innovation. It considers the relevance and efficiency of this instrument for supporting eco-innovation and compares PPPs with alternative instruments to stimulate eco-innovation.

Introduction

This case study examines the potential role of public-private partnerships (PPPs) in promoting eco-innovation on the basis of Sustainable Development Technology Canada (SDTC). Created by the Government of Canada in 2001, this foundation manages two investment funds with a total of over CAD 1 billion, one for sustainable development technologies and the other dedicated to biofuels. The case study considers the relevance and efficiency of this dedicated instrument for supporting eco-innovation. SDTC has been evaluated several times; the most recent report was published in 2009 and reviewed its investment strategy and the efficiency of its internal operations.

This is not a traditional *ex post* evaluation report. It considers the main economic and working assumptions of SDTC as a public policy instrument as they relate to the specific features of eco-innovation in order to discuss their potential relevance and efficiency. The analysis is based on four key questions, which are discussed in the following sections of the report:

- Why a specific fund for eco-innovation, with public investment?
- Is the scope of eco-innovation homogenous enough for a coherent investment strategy?
- How does a PPP compare with alternative instruments to support innovation?
- How does a public instrument dedicated to eco-innovation such as SDTC stand up to the criticisms regularly addressed to PPPs?

An instrument framed for the specific features of eco-innovation?

Following 16 tenders since 2002, SDTC has received 1 760 applications involving more than 5 000 participants. In December 2009, 183 projects had been selected for a total public investment amounting to CAD 464 million.

Eco-innovation exhibits a number of distinctive economic features. Fieldwork research and academic literature have identified the following key elements:

- Contrary to innovative products based on the creation of a new utility or quality improvement, there is no clear, undisputed, instantly valued and widely shared evaluation of superior utility for green products or services. Most have higher prices but do not offer superior performance, quality improvement or satisfaction of a

previously unmet need. They usually offer an alternative to existing solutions with improved environmental impact at a higher price.

- The economic evaluation of eco-innovative products requires a life-cycle analysis to take into account savings over a long period of time. Even direct customer benefits such as energy saving must be aggregated on a life-cycle basis to compensate for the purchase price premium. External effects such as pollution or climate change are even more difficult to value on an individual consumer basis.
- Some green technologies involve network externalities (knowledge spillovers or facilitating infrastructure networks).
- Eco-innovation combines traditional product innovation valid in a specific market or sector with horizontal enabling innovation, potentially valid for any sector.
- Very often, eco-innovation involves several independent technological trajectories (*i.e.* limited demand substitution or R&D economies of scope) and thus raises irreversibility issues for public support or firms' R&D effort.

These features call for specific public instruments to stimulate and support innovation. The question is then: how does a public-private partnership, and in particular public venture capital such as SDTC in Canada, meet the specific needs of eco-innovation? In practical terms, three issues should be examined: Does this instrument facilitate a better and comprehensive evaluation of the utility an eco-innovation offers the customer? Does it consider product as well as horizontal (cross-sector) innovations? Does it encourage the parallel development and exploration of alternative technical trajectories for a given eco-objective?

The key role of combining public funding with private investment was underlined in Europe by a Green Paper on PPPs published by the European Commission in 2004. Building on a series of domestic initiatives, it seeks to encourage PPPs as a way of raising investment through administrative and financial incentives. The core idea is that the private sector will play an increasingly important role in financing infrastructure and modernising public services. The rationale is that governments, constrained by their growing public deficits, debt and EU fiscal rules, cannot alone make the necessary investment in public services and guarantee their affordability and the best possible quality in the future. PPPs are proposed as an efficient and innovative enabling instrument to complement government efforts with private funding. Like Europe, Canada and the United States have promoted the idea of PPPs and encouraged their development.

While PPPs can be implemented for a wide variety of services, the focus of this case study is innovation, new technologies and the associated R&D investment. Economic theory has long established the legitimacy of public intervention in this area to cope with market failures associated with the high level of uncertainty, the presence of positive externalities, and the long-term horizon of profitable returns. However, in most cases, the resulting policy mainly focuses on the early stages of technology development, with instruments such as R&D grants and the provision of public research facilities (laboratories, testing platforms, patent office). The idea is that, once the fundamental, applied research and prototype stages have been successfully overcome, the investment in product design, demonstration and commercialisation should be borne by private companies, which will benefit from the associated economic profits. While this assumption is indisputably true in many cases (cars, consumer goods, services), the specific features of eco-innovation raise additional challenges in later stages of the technology life cycle.

Before moving to market commercialisation, it is essential to prove the effective customer value of the eco-innovation in full-scale, real-world test situations. Given the lower cost of existing non-green substitutes, many eco-innovations would otherwise face levels of uncertainty and risk that could compromise their successful commercialisation. The demonstration stage is vital, not only to prove the technical validity of the technology in the field, but also to demonstrate the economic utility to the consumer and to stimulate early demand. Another element should also be considered from a public welfare perspective: for a given environmental benefit and generic utility, several technological alternative trajectories often are in competition, with limited or no economies of scope in R&D between them. There is the example of renewable power, with wind, solar, biomass, hydro and geothermal as alternative and independent solutions; even within the solar field, there is competition between solar tower, polycrystalline modules and thin films. In such a technological environment, it may be important from a public interest perspective to encourage the parallel development of several trajectories, in order to avoid future lock-in or dependency on foreign innovations. This implies a larger and more costly development effort than concentrating all resources on a single trajectory, with an unavoidable level of duplication and inefficiency.

This explains why, at the firm and country level, the demonstration and development stage between research and commercialisation for an eco-innovation involves higher than usual uncertainty and larger investment intensity. There are technological, financial and market risks which no normal investors (private companies, business angels, venture capital, private equity, banks) will undertake alone. Even if venture capital

investment in "clean tech" has grown rapidly since 2005 (to CAD 5.4 billion in 2009 according to the Cleantech Group) and now leads investment in biotechnology and software, this is not yet sufficient to cover the financing gap for demonstration and development in the eco-innovation chain. This gap has two negative consequences in terms of welfare: *i)* barriers to market entry are too great for potentially viable entrepreneurs and innovators; and *ii)* it lowers the return on investment in fundamental and applied upstream research, as no revenue will be derived from the commercialisation of successfully developed products or processes. This market failure makes the case for a dedicated public instrument. SDTC's project is in line with this objective.

To close this gap, a SD Tech Fund was established by SDTC in 2001. It aims at supporting the late-stage development and pre-commercial demonstration of clean technology solutions. CAD 350 million were initially allocated to support climate change and clean air projects. An additional CAD 200 million were provided in 2005 for clean water and clean soil projects. The fund does not act like a traditional source of venture capital (VC), as it does not take an equity stake in the companies or ask for repayment of any kind for the financial contribution it provides. It does not claim ownership of the intellectual property. The rationale is that the fund works as a catalyst for a project with a grant that helps overcome the financial barrier in the demonstration and development stage and encourages private investment to leverage this public funding. Risk reduction therefore appears to be the main objective of this instrument. The target of public support is also limited to a given project or innovation, not a company as a whole as in the case of equity investors. Finally, most projects involve a consortium of several firms and/or academic institutions. This instrument can be justified from a welfare perspective by the economic spillovers from the successful commercialisation of eco-innovations. The 2010 corporate plan describes this public objective in the following terms: "to increase each project's chances of successfully getting to market and to help Canadian entrepreneurs carry out their innovation efforts within Canada. […] To improve the productivity and the global competitiveness of the Canadian industry." (SDTC, 2010)

Beyond the specificity of this funding mechanism, a public instrument such as SDTC also differs from private capital on several key points:

- it can accept longer time horizons, beyond the average 5-7 years of VC investment in a company;
- factors other than financial profitability can be considered in the investment decision, such as job creation, environmental benefit or local economic development;

- information, knowledge and results can be shared in a targeted community.

The second of these defines an important specificity of SDTC as a public instrument. The Tech Fund evaluation of applications (statements of interest) explicitly refers to the notion of "sustainability", which is not a financial criterion, but a mix of environmental, economic and social considerations. The issue of knowledge sharing and spillovers is discussed below.

Once the economic rationale of the instrument is defined (financing a gap in the innovation chain for technology demonstration and development) and justified, one must then consider how an organisation like SDTC deals with the horizontal nature of some eco-innovations and with cases of proliferating technological environments. The general investment criteria in SDTC's selection process do not rule out horizontal innovation or the financing of two or several alternative competing technologies for the same utility. But only a study of the 183 selected projects (as of December 2009) can show if this occurs in practice. The diversity of the sample can be judged along three dimensions: sector, technology and geography. Even if energy (production and utilisation) clearly appears as a priority, Table 9.1 shows that quite a wide range of sectors benefit from SDTC funding and Table 9.2 shows the environmental benefits achieved by the selected projects.

Table 9.1. Distribution of SDTC funding by sector

Sector	Number of projects	SDTC funding (CAD millions)	SDTC funding breakdown
Energy exploration and production	29	109	23%
Power generation	28	84	18%
Energy utilisation	52	98	21%
Transport	27	80	17%
Agriculture	12	36	8%
Forestry, wood and pulp & paper products	10	16	3%
Waste management	26	45	10%

Source: SDTC, December 2009 data.

Table 9.2. Environmental benefits of the projects funded by SDTC, by sector

Sector	Number of projects	Environmental benefits			
		Climate change	Clean air	Clean soil	Clean water
Energy exploration and production	29	26	27	6	6
Power generation	28	26	27	2	2
Energy utilisation	52	45	46	12	20
Transport	27	25	18	2	4
Agriculture	12	10	11	11	10
Forestry, wood, pulp & paper products	10	9	9	5	1
Waste management	26	18	19	18	22

Source: SDTC, December 2009 data.

In terms of technological coverage, the 183 funded projects cover a total of 106 technology areas. This indicates significant diversity but also leaves room for parallel exploration of competing alternative trajectories.

Finally, it is worth considering the geographical dimension to test for potential bias. Table 9.3 therefore compares the share of SDTC funding by province with the relative weight of the region's GDP in the Canadian economy. It indicates quite a fair geographical distribution of project funding (extreme values of the ratio between a province's GDP and SDTC funding correspond to small figures). When looking at the details of selected projects, it is clear that in the four main provinces in terms of SDTC funding (88% of the total), all seven sectors are covered with the sole exception of transport in Alberta.

All these elements lead to the conclusion that SDTC is a policy instrument that properly takes into account in its economic model and its practical implementation the specific features of eco-innovation.

Table 9.3. Relative SDTC funding and GDP by province

Province	GDP 2008 (CAD millions)	Share of 2008 GDP	SDTC funding	Share of SDTC funding	Ratio
Ontario	532 209	40.3%	182	38.7%	1.0
Quebec	269 665	20.4%	67	14.3%	0.7
Alberta	185 780	14.1%	53	11.3%	0.8
British Columbia	164 520	12.5%	111	23.6%	1.9
Manitoba	42 407	3.2%	11	2.3%	0.7
Saskatchewan	41 583	3.2%	26	5.5%	1.7
Nova Scotia	29 215	2.2%	8	1.7%	0.8
New Brunswick	23 351	1.8%	2	0.4%	0.2
Newfoundland and Labrador	19 953	1.5%	0.7	0.1%	0.1
Prince Edward Island	4 148	0.3%	9	1.9%	6.4

Source: SDTC, December 2009 data.

A coherent and articulated investment strategy for eco-innovation

The second issue to consider is whether and how a public institution such as SDTC should structure a coherent and articulated investment strategy for eco-innovation. Given the huge variety of technical projects and the on-going "greening" affecting every economic activity, there is a clear risk of dilution and dissipation of the necessarily limited financial resources available. This raises two distinct questions: Where should the boundaries be drawn? Do the many eco-innovation projects generate positive externalities that could be valued and capitalised by the funding institution?

To implement an efficient and generic selection process, SDTC has been mandated to allocate funds to four types of environmental benefits: climate change, air, water and soil. Every statement of interest for a technical project is rated along these four dimensions and the sustainability criteria defined above. This analytical framework is used to test the eligibility of a given project, without pre-defining a set of targeted sectors or technologies. Owing to the nature of eco-innovation, proposals can come from any sector of the economy and a diversity of technological backgrounds.

This allows the fund to monitor the balance of funding over time according to its initial political objectives. Of the SD Tech Fund's total endowment of CAD 550 million, CAD 350 million were earmarked for projects with an environmental benefit related primarily to climate change (80%) and clean air (20%). This initial orientation was implemented in practice in the fund's operations. In December 2008, 92% to 95% of the designated funds had been allocated to projects in these areas. Additional priorities for clean water and soil (introduced with a complementary CAD 200 million from the federal budget in 2004) have also been clearly taken into account in project selection. Of the total portfolio of 154 SDTC projects in December 2008, 91% have climate change benefits, 84% have clean air benefits and 38% have soil or water benefits.

As detailed above, the rating of the four environmental benefits does not preclude a significant diversity of sectors, technologies and products/services, and 88% of SDTC projects have more than one environmental benefit. Moreover, 11 of the 123 currently active projects financed in December 2008 by the SD Tech Fund combine the four environmental advantages, thereby demonstrating the clear horizontal character of the eco-innovation involved. Three projects cover only one of the four environmental dimensions considered. Among the 24 completed projects, three cover the four categories and four cover only one.

While cleaner air, soil and water are clear and restricted goals of technological eco-innovation projects, climate change has a much larger and more diverse objective. The different available solutions for climate change mitigation are reviewed in *Energy Technology Perspectives* (IEA, 2008) according to their potential contribution to the necessary reduction of greenhouse gas emissions between 2010 and 2050. Energy (fuel and electricity) efficiency (36% of the global reduction effort), renewables (21%), and carbon capture and storage (CCS, 19%) are the leading technological fields in terms of the potential volume of carbon abatement. However, CCS demonstration projects require levels of capital investment and support funding well beyond the financial capacity of the SD Tech Fund (the same is true for nuclear power generation). Nonetheless, some associated technologies or equipment development for CCS systems have been selected for the fund's portfolio. Most of the projects deal with efficiency of power generation, renewable power and to some extent end-use efficiency.

In summary, the "climate change" target and the selection criteria work as an effective framework for structuring a coherent and articulated investment strategy for the fund, while authorising a wide variety of technologies and applications.

The objective of the SD Tech Fund is not limited solely to the funding of demonstration and development technological projects. As a public instrument, it also aims at generating larger collective benefits for the Canadian economy, as detailed in the SDTC corporate plan. Its purpose is to:

- fund the development and demonstration of new sustainable development technologies related to climate change, clean air, clean water and clean soil in order to make progress towards sustainable development;
- foster and encourage innovative collaboration and partnering among diverse persons in the private sector and in academic and not-for-profit organisations to channel and strengthen the Canadian capacity to develop and demonstrate sustainable development technologies with respect to climate change, clean air, clean water and clean soil;
- ensure timely diffusion by funded recipients of new sustainable development technologies in relevant market sectors throughout Canada.

The second element clearly refers to the economic notion of "national system of innovation", here in the environmental field, and the emphasis is on the collective dimension and multiple interactions in the innovation process. The review of selected projects illustrates this concern as the consortia combine large corporations, start-ups, universities, laboratories and a few NGOs. SDTC also stresses that the timely relevance and market prospects of the proposed technical projects are to be explicitly assessed in the due diligence carried out by the fund's team (based on the model of venture capital firms).

Finally, a last issue should be considered. Beyond technical projects, SDTC also targets the community of Canada's clean-technology entrepreneurs. To do so, the SD Tech Fund needs to accumulate expertise in the financing, management and eco-technical evaluation of eco-innovation in order to train firms' managers and improve their skills and capacities. However, the organisation and practical implementation of the corresponding knowledge transfer and experience sharing is not clearly detailed. With nearly 200 projects supported, SDTC will certainly gain vast experience in the development and diffusion of eco-innovation. In particular, it should be able to identify common bottlenecks or skills requirements with a view to further dedicated action. Still, there is currently little information on the method and instruments SDTC intends to use to carry out this collective task (apart from individual support of managers in selected projects) and make the most of the positive externalities.

The SD Tech Fund portfolio does not at present include projects in services, such as generic services for supporting and facilitating eco-innovation in the firms and regulatory issues, scaling-up and industrialisation, and human resources. This is a complementary dimension of public intervention in favour of eco-innovation which could be addressed. In particular, the dissemination of SDTC results and the exploitation of the knowledge it has gained regarding eco-innovation could help define and shape a more relevant and efficient range of supporting services. The resulting competitiveness of business services would in turn strengthen the local technological and business network and improve the attractiveness of the country for eco-operations.

Public-private partnerships *versus* alternative instruments to stimulate and support eco-innovation

Even if the kind of operations carried out by SDTC cannot be strictly assimilated to a PPP mechanism, the relevance of a public grant for technology demonstration and development must be compared to alternative available forms of public intervention. This suggests considering the economic efficiency of the instrument. The central argument in the SDTC scheme is that a public grant will help overcome the very high barriers to effective demonstration of the technology's potential, but will also trigger large additional private investments, given the reduced level of uncertainty. To try to evaluate the extent of the financial leverage allowed by public funding, Table 9.4 summarises the main features of the leveraging by private companies of SDTC funding: minimum value, maximum, average, mean and standard deviation, based on the sample of 147 projects run by SDTC at the end of 2008.

Table 9.4. Leverage of SDTC funding

CAD millions

	SDTC funding	Leveraged funding	Ratio
Minimum	0.15	0.18	0.51
Maximum	13.90	36.39	5.96
Average	2.53	5.10	1.92
Mean	2.00	3.55	1.88
Standard deviation	2.14	5.62	0.83

Source: SDTC (2008), *Supplement to the 2008 Annual Report*, Ottawa.

These data show the ability of the public funding of the selected projects by SDTC to stimulate a real financial commitment from private firms. Only 14 projects (9.5% of the total) have a leverage ratio lower than one; and 57 (39%) have a leverage ratio higher than 2. The small value of the standard deviation means that 68% of the selected projects have a leverage ratio between 1.1 and 2.7.

This result offers a new perspective on the traditional assessment of PPPs as a policy instrument. It should first be recalled that the term still lacks an internationally agreed definition. It is used in practice to cover a wide variety of institutional arrangements between public authorities and the business world in some fields of public interests. It covers for practical purposes two distinct cases: first, financing a public-sector capital investment project with a private company or a consortium of private firms; and second, contracting for delivering services, usually operating the capital assets financed through the first scheme. This raises two central but rather different issues for public authorities: Is a PPP a better way of financing the necessary capital investment than existing alternatives? Is a PPP a better way of operating the service than alternatives? In the case of eco-innovation support, only the first issue has to be considered: the efficiency of public funding for technology demonstration and development of an eco-innovation.

The usual argument claims that the government can borrow money on international financial markets more cheaply than any private company (for a mix of reasons involving economic size, capacity to raise taxes if necessary, legitimate sovereignty). In this context, a PPP is at a disadvantage for financing capital expenditure compared with finance raised by government borrowing. There must therefore be significant efficiency gains from involving the private sector in order to offset the additional borrowing costs. This argument has however to be revisited in the light of the current worldwide economic and budgetary crisis and the specific features of eco-innovation. Public stimulus to sustain economic growth has raised the total public debt in many countries to levels that push interest rates sometimes above those faced by large private corporations. In addition, the high level of risk and uncertainty associated with most eco-innovations is not compatible with the usual market mechanisms. There is thus room for mutually profitable co-operation between the public and private sectors to amplify entrepreneurial initiatives and facilitate scientific breakthroughs in commercially viable environmental applications for the market.

How does SDTC cope with the usual criticisms addressed to PPPs?

Finally, one has to consider the usual criticisms of PPPs. A range of concerns have emerged about the use of PPPs based on considerations of the public interest: *i)* long-term liabilities and a concern that the PPP may transfer investment costs from present to future generations; *ii)* dangers of fragmenting and worsening working conditions for employees in public services; *iii)* transparency of the process of allocating funding for projects and potential risks of corruption; *iv)* potential future lock-in; and *v)* unbalanced negotiating positions owing to information asymmetries with private partners. SDTC, as a public mechanism which funds technological demonstration and development projects, is only affected by the first and the third arguments.

As far as long-term liabilities for future generations are concerned, the limited level of public assets allocated to the SD Tech Fund (CAD 550 million) clearly restricts the corresponding risk. This sum is divided among a great number a projects, for average support of CAD 2.5 million, which means that even with a high rate of failure, the final public cost is capped. Regarding transparency and corruption concerns, two safeguards should be underlined. First, an independent selection committee (with a minority representation from the federal government) has been established by SDTC and a clear framework based on due diligence procedures implemented for evaluating statements of interest by companies or consortia. Second, SDTC co-operates with companies through non-repayable grants and does not take any equity stake or intellectual property ownership of the demonstrated innovation. While this might be considered as too weak a signal in terms of financial commitment to the success of the project compared to venture capitalist operations, such an approach clearly forecloses any risk or temptation of corruption based on future financial benefits.

The review of the four fundamental questions raised by a public fund for eco-innovation demonstrates that SDTC plays a very positive role in enhancing Canada's competitive position in the environmental field. Though the services side is still not considered and the dissemination of accumulated experience is not formally organised, this original public instrument successfully passes the different tests examined here. Whether such an instrument will be made durable with sufficient public financing over time to effectively reach its objectives, and ultimately improve Canada's position in the world competition on environmental innovation, is still however an open question.

References

International Energy Agency (2008), *Energy Technology Perspectives*, IEA, Paris.

SDTC (2008), *Supplement to the 2008 Annual Report*, Ottawa.

SDTC (2010), "SDTC Corporate Plan – Executive Summary", *www.sdtc.ca/uploads/documents/en/Executive_Summary-2010.pdf*.

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