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# Comparing the development and deployment of carbon capture and storage technologies in Norway, the Netherlands, Australia, Canada and the United States– An innovation system perspective

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## Abstract

In order to take up the twin challenge of reducing CO<sub>2</sub>-emissions, while meeting a growing energy demand, the potential deployment of CCS is attracting a growing interest of policy makers around the world. In this study we evaluate and compare national approaches towards the development of CCS in the U.S.A, Canada, the Netherlands, Norway and Australia. The analysis is done by using the functions of innovation systems approach. This approach implicates that new technology is developed, demonstrated and deployed in the context of a technological innovation system. By the assessment made in this study the strengths and weaknesses of the innovation systems are identified, which is vital for the development of a coherent (long-term) policy strategy that enhance the successful implementation of CCS. The performance assessment and comparison of the CCS innovation systems shows that the extensive knowledge base and knowledge networks, which have been accumulated over the past years, has not yet been valorized by entrepreneurs to explore the market for integrated CCS concepts linked to power generation. This indicates that the build-up of the innovation system has entered a critical phase that is decisive for a further thriving development of CCS in Norway, the Netherlands, Canada, Australia and the USA. In order to move the CCS innovation systems through this present difficult episode and deploy more advanced CCS concepts at a larger scale; it is necessary to direct policy initiatives at the identified weak system functions, i.e. entrepreneurial activity, market formation and the mobilization of resources. Moreover, in some specific countries governmental guidance and the creation of legitimacy also needs more attention.

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Keywords: Functions of Innovation Systems; CCS RD&D; Innovation Policy; Energy Transition

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## 1. Introduction

In order to take up the twin challenge of reducing CO<sub>2</sub>-emissions, while meeting a growing energy demand, the potential deployment of CCS is attracting a growing interest of policy makers around the world. However to

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develop, deploy and commercialize low emission technologies, like CCS, one has to successfully traverse the transitional period between basic R&D and commercialization. A period also known as the ‘valley of death’: a graveyard of technologies that failed to negotiate the various market and institutional barriers that confronts new technologies. Innovation scholars have argued that technological change is a complex, non-linear development, which is constituted by feedback processes between R&D, production and market formation [Smits, 2002]. For governmental bodies that intend to promote and shape the development of CCS technology, understanding these processes is a phenomenal challenge. We analyzed this challenge by evaluating and comparing national approaches towards the development and deployment of CCS in the U.S.A, Canada, the Netherlands, Norway and Australia.

## 2. Theoretical Framework

The question of how a process of socio-technical change, also labeled as a technological transition, can be understood and influenced is receiving increasing attention in scientific literature [see e.g. Geels, 2002; Kemp et al., 2007]. One of the frameworks that has been successfully applied to several emergent trajectories of energy technologies is that of technological innovation systems (TIS) [see e.g. Foxon et al., 2005; Jacobsson and Bergek, 2004]. This framework is rooted in the field of innovation studies and is used to analyze the ‘network of actors interacting in a technological area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology’ [Carlsson and Stankiewicz, 1991].

Over the past years, progress is made in determining the most important processes that contribute to the growth and performance of an emerging TIS [see Edquist, 2004; Hekkert et al., 2007]. These processes are labeled as ‘functions of innovation systems’. In earlier empirical work these functions have been used effectively to deliver explanations for the success or failure of technological trajectories of sustainable energy technologies in various countries [for an overview see Hekkert and Negro 2008]. Furthermore, their fulfillment can be assessed to derive policy recommendations for supporting a specific technology [Bergek et al., 2008]. This research applies the recently developed list of system functions by Hekkert et al. [2007] to study the functioning and performance of the CCS innovation systems in the USA, Canada, Australia, the Netherlands and Norway (Table 1).

Table 1: Functions of Technological Innovation Systems [Hekkert et al., 2007]

<b>F1.</b> Entrepreneurial Activity	At the core of any innovation system are the entrepreneurs. These risk takers perform the innovative commercial experiments, seeing and exploiting business opportunities.
<b>F2.</b> Knowledge Development	Technology R&D are prerequisites for innovations, creating variety in technological options.
<b>F3.</b> Knowledge Diffusion	This is important in a strict R&D setting, but especially in a heterogeneous context where R&D meets government and market.
<b>F4.</b> Guidance of the Search	This function represents the selection process that is necessary to facilitate a convergence in technology development, involving policy targets and expectations about technological options.
<b>F5.</b> Market Formation	This function comprehends formation of new (niche) market by creating temporary competitive advantage through favorable tax regimes, consumption quotas, or other public policy activities.
<b>F6.</b> Resource Mobilisation	Financial and human resources are necessary inputs for all innovative activities, and can be enacted through e.g. investments by venture capitalists or through governmental support.
<b>F7.</b> Creation of legitimacy	The introduction of new technologies often leads to resistance from established parties, or society. Advocacy coalitions can counteract this inertia and lobby for compliance with current legislation.

## 3. Methods

In the analytical framework that is discussed below we have discerned three different sub-analysis.

*Part 1: TIS functioning* – The first part constitutes the core of the analysis, including the identification of the structural components (actors, institutions, networks) and their contribution to the fulfillment of the 7 innovation system functions. The data for this sub-analysis is collected by reviewing scientific as well as ‘grey literature’ (newspaper articles, professional journals and policy documents), and by interviewing the main actors involved in the development of CCS. Hereby we made use of a number of indicators or ‘evaluation questions’ that provide insight in the fulfillment of the functions [see van Alphen, 2008]. In total, more than 100 interviews have been conducted in the five countries under study. With the selection of interviewees a balanced representation of the

different actor groups in the TIS is pursued. Thereby a distinction is made between the following groups of actors: technology-developers and industry, research organizations, governmental parties and (environmental) NGOs.

*Part 2: TIS performance*– Now the fulfillment of the seven functions is mapped, a preliminary insight is created into the performance of the TIS. In order to specify this further, we let the main actors in the system reflect upon the ongoing activities in the system and rate their level of satisfaction with the fulfillment of a particular system function. The interviewees were asked to score the fulfillment of each system function on a 5 point Likert scale where 1 = very weak, 2 = weak, 3 sufficient, 4 = good and 5 = very good. In this way, our results are triangulated with critical evaluations from people who took part in shaping the technological trajectory for CCS.

*Part 3: Policy implications* – Based on the current functioning of the system and according to the judgment of key actors in the system, it is possible to specify key policy issues in terms of how the innovation system functions should develop in order to reach a higher performance. Therefore, the respondents also gave their view on what should be done to improve functions that are impeding a higher performance of the system. This provides the basis for advice on policy strategies to enhance the development of deployment of CCS.

#### 4. Results

This section describes the fulfillment of the seven system functions in the five countries under study and discusses the performance evaluation made by the 100 key-stakeholders that have participated in this study.

##### 4.1. Entrepreneurial Activities

Canada and Norway are hosting the two largest CCS projects in the world today. At the offshore Sleipner West gas field on the Norwegian continental shelf 1 MtCO<sub>2</sub> is separated and injected into the Utsira saline formation each year, since 1996. Norway's other major CCS project called Snøhvit, involves the production of LNG, whereby 0.7 MtCO<sub>2</sub> per year is separated and re-injected into a formation 2 600m below the seabed. In Canada 1–2 MtCO<sub>2</sub> is injected annually to enhance oil recovery from the Weyburn field. The CO<sub>2</sub> that is used in this project is a by-product from synthetic methane production at a coal gasification plant, located approximately 325 km south of Weyburn, in North Dakota (United States). Both projects stem from before the year 2000. Even though many smaller projects have been initiated after that<sup>2</sup>, CCS projects whereby over 1Mt of CO<sub>2</sub> is captured and stored currently only exist in project plans (Table 2).

Table 2: Major planned CCS projects in Norway, the Netherlands, United States, Canada and Australia, commencing before 2015.

Country	Name (location)	Source	CO <sub>2</sub> stored	Type	Start
Norway	Karstø	NGCC post-combustion	1.2 Mt	Saline	2012
	Mongstad	CHP post-combustion	1.5 Mt	Saline	2014
Netherlands	K12B	NG processing (separation)	± 0.5 Mt	EGR	2010
	Maasvlakte	PF coal post-combustion	± 0.5 Mt	Hydrocarbon	2014
US	Mount Simon	Ethanol production (separation)	1 Mt	Saline	2009
	Williston Basin	Lignite post combustion	4 Mt	EOR	2012
	Kimberlina	Coal oxy-combustion	1 Mt	Saline	2012
Canada	Boundary Dam	PF coal post-combustion	± 1Mt	EOR	2015
	Genesee	IGCC pre-combustion	± 1Mt	Saline	2015
Australia	Gorgon	LNG production (separation)	3-4 Mt	Hydrocarbon	2013
	Kwiana	H2 production (separation)	4 Mt	Saline	2012
	Monash	CTL (separation)	up to 10 Mt	Hydrocarbon	2015
	Zerogen	IGCC (pre-combustion)	0.4 Mt	Saline	2012
	Moomba	NG processing (separation)	1 Mt	EOR	2010

<sup>2</sup> For example, the CO2CRC Otway basin storage project and the Callide A oxyfuel project in Australia; the CANMET Oxyfuel pilot plant in Ottawa, Canada; the Frio Brine storage project in the US; the IGCC multifuel capture project at Buggenum, the Netherlands; and the Zero Emission Norwegian Gas project in Norway. For more information of CCS pilot projects, see for the Netherlands: [www.co2-cato.nl](http://www.co2-cato.nl); Australia: [www.co2crc.com.au](http://www.co2crc.com.au); USA: [fossil.energy.gov/sequestration](http://fossil.energy.gov/sequestration); Canada: [canmetenergy.nrcan.gc.ca](http://canmetenergy.nrcan.gc.ca); and Norway: [www.climit.no](http://www.climit.no).

*Evaluation of entrepreneurial activities:* The fact that so many projects have been planned in Australia and the relatively high amount of money that is available for demonstration projects is the reason that the Australian experts have evaluated the ‘entrepreneurial activities’ in their country higher than the others (Table 3). It should also be noted that the fulfillment of this function is evaluated higher in North America than in the two European countries. The latter can be explained by the uncertainty on the availability of public funding for large-scale CCS demonstration projects in Europe. On average this function scores relatively low compared to the other functions. In fact, in Norway and the Netherlands this is the lowest rated function. Despite the growing amount of industrial parties involved in the development of CCS, the number as well as the diversity of demonstration and commercial projects is too small according to the majority of stakeholders that participated in this study. The lack of commercial-scale integrated CCS projects is the most important impediment for a higher rating. At the same time it was noted by many experts that more efforts should be made to ‘pick the low hanging CO<sub>2</sub>’ and start up more low-cost CCS projects making use of CO<sub>2</sub> from relatively pure industrial CO<sub>2</sub> streams. In short, it is time to really start learning by doing, instead of ‘learning by planning’.

Table 3: Expert evaluation of ‘entrepreneurial activities’ on a scale of 1-5.

Netherlands	Norway	USA	Canada	Australia	Average
2.5	2.7	3	3.2	3.5	3

#### 4.2. Knowledge development and diffusion

While advocating the demonstration of several promising technologies, the respondents stress the importance to continue basic research. The current research programs carried out in the countries under study cover a wide variety of techniques for capture and storage. The US DOE’s Office of Fossil Energy manages the US Carbon Sequestration Regional Partnership Program, the implementation of which is managed by the National Energy Technology Laboratory (NETL). The seven regional partnerships together involve more than 350 organizations in 42 states and four Canadian provinces. Collectively they encompass 97% of coal-fired and industrial CO<sub>2</sub> emissions, and essentially all the geologic sequestration sites in the U.S. potentially available for CO<sub>2</sub> storage (Litynski, 2008). Within Canada similar CCS networks exist. Examples are: the Canadian-Alberta Taskforce, the federal Integrated CCS Network, and the Weyburn consortium, involved in the IEA GHG Weyburn-Midale monitoring and storage project. The Alberta Research Council has a lot of expertise and experience in ECBM technology and saline aquifer storage. In terms of capture there are two major Canadian test centers of which the International Test Centre (ITC) in Regina primarily focuses on post-combustion capture, while the CANMET Energy Technology Centre in Ottawa focuses mainly on oxyfuel combustion.

Norway’s first R&D project related to CCS was initiated by SINTEF in 1987. Since then, more than 40 R&D projects have been implemented. The number and size of these R&D projects increased considerably in the more recent years, but the focus has been mainly on natural gas separation, CO<sub>2</sub> capture related to gas power production and aquifer storage. Examples of the latter are the SACS and CO<sub>2</sub>Store programs, which are related to Statoil’s Sleipner project. In contrast to Norway, CCS R&D in Australia is more focused on coal. The R&D efforts in Australia center around the industry based COAL21 consortium and a number of Cooperative Research Centers (CRCs), including the CRC for Coal in Sustainable Development (CCSD) and the CRC for Greenhouse Gas Technologies (CO<sub>2</sub>CRC). The CO<sub>2</sub>CRC focuses on various capture and storage technologies, the implementation of pilot projects and regional CO<sub>2</sub> strategies. In the Netherlands, CCS R&D is also carried out within a heterogeneous national consortium. This CATO (CO<sub>2</sub> Capture, Transport and Storage) program runs between 2004-2008 and also includes systems analysis and public outreach. The CATO program will continue in the coming 5 years, with a focus on applied research to support CCS demonstration projects in the Netherlands. The Dutch CAPTECH R&D program (2006-2009) complements part of the capture research within CATO.

The national CCS consortia described above are strongly embedded in global CCS networks, like the IEA GHG program and the CSLF. Furthermore, there are many organizations participating in RD&D programs across the national border. For example, Dutch research institutes and companies are leading a number of European projects, including RECOPL and CO<sub>2</sub>REMOVE. And in the same way Norwegian organizations, like StatoilHydro, SINTEF and NTNU, joined various international research initiatives, such as: CCP; CASTOR; and CO<sub>2</sub>Sink. Despite their growing complexity, the national and international CCS networks are characterized as particularly

open and well connected. It is recognized that the increasing amount of (inter)national CCS platforms and conferences have contributed significantly to the optimization of CCS networks.

*Evaluation of knowledge development:* Field experts generally praise the quality, variety and amount CCS R&D, which has increased significantly over the past years. Therefore this function received the highest average rating of 3.8 (Table 4). It is hard to identify general impediments in the fulfillment of this function other than the need to move several preferred technologies further up the innovation chain and enhance learning by doing. Despite that, in some countries experts stress the need of diversifying research efforts. In Norway, for example, the possibility to diversify R&D efforts into capture technologies for coal-fired power plants was mentioned several times, as these technologies would have a larger world market potential. In the Netherlands, on the other hand, some experts ply for more focus on pre-combustion technologies, as the R&D budget is too small to be a front-runner in all CCS areas.

Table 4: Expert evaluation of 'knowledge development' on a scale of 1-5.

Netherlands	Norway	USA	Canada	Australia	Average
3.5	3.9	3.9	3.9	3.7	3.8

*Evaluation of knowledge diffusion:* Organizations in the field of CCS have two main reasons to establish partnerships and exchange knowledge. First, to share the relatively high costs (and investment risks) related to CCS development. Second, the technological challenges involved in the development of CCS, as well as the integration of different fields of expertise, entail to share knowledge and competences. The fact that CCS networks have increased significantly over the past years in terms of size and intensity is reflected in the relatively high average evaluation score of 3.6 (Table 5). However, it was noted by stakeholders in several countries that more should be done to develop a complementary set of CCS demonstration projects around the world, using different capture technologies and geologic settings for storage. Furthermore, CCS activities should be expanded in rapidly growing coal-using countries like China and India, as well as taking advantage of the important enhanced oil and gas recovery potential in North Africa and the Middle East. More intensive international cooperation is also considered as vital for the development of a supportive legal framework and a CO<sub>2</sub>-transportation system. Besides strengthening international ties, it was noted by the experts that commercial interest and the protection of intellectual property hinder an optimal flow of knowledge between the actors involved in CCS R&D.

Table 5: Expert evaluation of 'knowledge diffusion' on a scale of 1-5.

Netherlands	Norway	USA	Canada	Australia	Average
3.5	4	4	3.2	3.1	3.6

#### 4.3. Guidance

In all countries under study CCS is bound to play a key role in the low emission futures envisioned by the various governments (Table 6). The latter is formally illustrated in several white papers [e.g. Australian Government, 2004] and technology roadmaps [e.g. Environment Canada, 2008], but also in informal speeches like the new year speech of Norwegian Prime Minister Stoltenberg in 2007 wherein he calls the development of CCS technology for the Mongstad CHP plant "Norway's moon landing project".

Table 6: Most recent GHG emission reduction targets in the Netherlands, Norway, USA, Canada and Australia.

Country	Netherlands	Norway	USA	Canada	Australia
Target	30%	Carbon neutral	Voluntary	20%	60%
Target Year	2020	2030	-	2020	2050
Reference year	1990	-	-	2006	2000

Guidance in the technology development process is not only about setting ambitious targets and the creation of visions. It also involves the introduction of supportive legislation. In Australia, the Ministerial Council on Mineral and Petroleum Resources endorsed a set of Regulatory Guiding Principles for CCS [MCMMPR, 2005]. Designed to facilitate the development of consistent regulatory frameworks for CCS in all Australian jurisdictions, the principles address: assessment and approval processes; access and property rights; transportation issues; monitoring and verification; liability and post-closure responsibilities; and financial issues. Furthermore, the federal government released draft legislation, in May 2008, which amends the federal Offshore Petroleum Act 2006 to allow for CO<sub>2</sub>

injection and storage offshore. The draft legislation ensures the appropriate co-existence of petroleum and CO<sub>2</sub> injection activities and provides for safety management, including procedures for site selection and monitoring.

In 2008, the US EPA announced a regulation for commercial-scale CO<sub>2</sub> storage under the Underground Injection Control (UIC) program, with finalization targeted for early 2011. The regulation is expected to include site characterization, well construction and operation, monitoring, post-closure care and public participation. As in the United States and Australia, the regulation of CCS in Canada also involves a complex interaction between federal and state laws. Existing federal and provincial oil and gas legislation covers certain aspects of CCS, including CO<sub>2</sub> capture and transportation-related issues. It is anticipated that injection can be partly covered by existing legislation on CO<sub>2</sub> for EOR, natural gas storage and acid gas disposal. However, in most Canadian jurisdictions, issues around property rights and post-injection activities still remain to be addressed [Bachu, 2008]. Therefore, the federal government is funding several research projects that address these outstanding regulatory issues.

In Norway and Netherlands the government's work on a supportive legal framework, are approximating and complementing similar EU directives. Among other things, the CCS Directive seeks to ensure environmental security, address issues of liability, remove existing legislative barriers to deploying CCS and an enabling (rather than a mandatory) framework for CCS. It provides for the use of existing legislation where possible, in particular for capture and transport of CO<sub>2</sub>, but also proposes new legislation to address CO<sub>2</sub> storage. This new legislative framework for CCS sets criteria for site assessment and permitting; requirements for the CO<sub>2</sub> stream; specifications for a CO<sub>2</sub> storage monitoring system; liability measures, including the surrendering of EU Emission Trading Scheme (EU ETS) allowances for any leakage [IEA, 2008].

*Evaluation of the function guidance:* The interest in CCS by governments is greater than before and policy makers are working hard to enforce supportive legislation regarding CCS operations. However, it is argued by a majority of the 100 key stakeholders in all five countries under study that it remains uncertain in what way governmental bodies are going to support the commercial-scale demonstration CCS projects that are necessary to bring the technology down its learning curve. Therefore, the function guidance is rated moderately with a 3.0 (Table 7). The relatively high standard deviation of 1.2 indicates that there is little consensus on this rating among experts. This is mainly caused by the duality in strong generic guidance -i.e. CCS has an important role to play in the envisioned low-emissions future- and the lack of specific guidance -i.e. supportive financial instruments and short-term goals-, as CCS is not (yet) being adopted as a result of normal market forces.

Table 7: Expert evaluation of 'guidance' on a scale of 1-5.

Netherlands	Norway	USA	Canada	Australia	Average
3.3	3	3.2	2.6	3	3

#### 4.4. Market Formation

At present, CCS is hardly deployed on a commercial scale. Yet, CCS is considered crucial for achieving the ambitious GHG emissions reduction targets. All the countries under study are planning to create market incentives for CCS by introducing a CO<sub>2</sub> cap and trade system. The Canadian Government, for example, plans to transition from an emission-intensity based target system to a fixed emissions cap system in the 2020-2025 period. It has indicated that in determining the level of the cap, particular consideration will be given to climate change-related regulatory developments in the U.S. In the U.S., there are several emissions trading schemes (ETS) at state-level, and the EPA is working on federal legislation that will introduce a nation-wide cap-and-trade system. This legislative proposal -i.e. the Lieberman-Warner Climate Security Act- sets aside bonus allowances to reward CCS.

The Australian government also recognizes that if designed and implemented well, an ETS is a better approach to reduce its GHG emissions, than its current system of Mandatory Renewable Energy Targets. Australia's ETS will be established at the earliest in 2010. It is proposed that during the remainder of the Kyoto compliance period, to the end of 2012, permits should be sold at a fixed price. The sale of permits would generate substantial revenue, which could be allocated to support commercialization of CCS. A similar approach has been followed with the revenues from the carbon tax that has been introduced in Norway already in 1992. This carbon tax in itself proved to be an effective incentive to encourage CO<sub>2</sub> storage operations in the North Sea. Additionally, it triggered the development of capture solutions for initially offshore and later onshore gas-based power production. However, it appeared that until now the carbon tax of approximately €40/tCO<sub>2</sub> is not sufficient to initiate commercial CCS projects related to

power generation. Also, the introduction of a domestic GHG ETS, which could be linked to the EU ETS in later stage, is not likely to create enough incentive for private actors to engage in such projects on the short term.

A similar problem is encountered in the Netherlands, which mainly relies on the proposal of the European Commission to bring CCS into its ETS, as it comes to commercializing CCS. At present, a large gap exists between the CO<sub>2</sub> avoidance costs of CCS, which shows a range of 20–60 €/tCO<sub>2</sub>, and the carbon price, varying between 6 and 30 €/tCO<sub>2</sub>. This gap, in combination with the volatility of the carbon price, renders it likely that additional policies will be needed to ensure large-scale deployment of CCS [Groenenberg and de Coninck, 2008]. Therefore, the European Commission has outlined the possibility of a “CO<sub>2</sub> emissions fade out”, implicating the obligation of CCS for all new fossil-fuel-fired power stations from 2020 onwards. However, making CCS obligatory also implies financial support for demonstration of CCS to get the technology commercially viable. Therefore, the European Council’s plans to develop 10-12 CCS demonstration projects in commercial electricity generation by 2015.

*Evaluation of the formation of markets:* This function is rated with a 2.2 (Table 8); the lowest score of all functions. Despite the development of an ETS in all countries, the experts that participated in this study noted that additional market incentives and financial certainty are necessary to initiate multiple commercial-scale CCS projects in the coming 5-10 years. Hereby one could think of emission performance standards for power plants, or a guaranteed CO<sub>2</sub>-price provided by the government. The Norwegian experts seem to be a bit more optimistic about the development of their domestic market for CCS. The latter can be explained by the successful implementation of CCS projects related to natural gas handling due to the fixed carbon tax. Nevertheless, the financial difficulties that are encountered by the application of CCS linked to power production seem to be a bottleneck in Norway as well.

Table 8: Expert evaluation of ‘market formation’ on a scale of 1-5.

Netherlands	Norway	USA	Canada	Australia	Average
2	2.9	2.2	2	2.1	2.2

#### 4.5. Resources Mobilization

Over the past years CCS R&D budgets have increased significantly in all the countries under study. In Australia the CO<sub>2</sub>CRC plays an important role in CCS R&D with a budget of more than €100 million over seven years, to 2010. This comes close to the R&D budget within the Norwegian CLIMIT funding program of approximately €16 million per year. In the Netherlands the budget for CCS R&D within the CATO and CAPTECH programs is lower with €8.5 million per year, but this amount will be doubled in the coming five years when the focus switches to more applied research. In Canada the yearly budget for CCS lays around the 35 million euro, while in the U.S. 75 million euro was spent on CCS R&D over the last year. Thereby the US supplies the most financial resources in absolute terms, but it should be noted that Norway has the highest level of funding related to GDP.

Besides R&D budgets, Governments announced extra money for the demonstration projects. The majority of Australia’s €250 million Low Emissions Technology Demonstration Fund will be allocated for CCS deployment in public private partnerships. Furthermore, the €150 million COAL21 Fund established by the coal industry and the Queensland Future Growth Fund of €150 million will support the development of low emission coal technology. Last year, the US DOE awarded over €400 million to the regional partnerships for six large-scale field tests where over 1MtCO<sub>2</sub> will be injected into deep geologic formations. Furthermore, in Canada, Federal and Provincial governments made available €1.2 billion to leverage the billions of dollars of industry investment in the first integrated CCS projects. The amount of money that has been made available by the Norwegian government for the capture demonstration projects at Mongstad and Karstø are of the same order of magnitude. In that sense, the 92 million euro provided by the Dutch government for three small-scale capture pilot plants and two storage projects seem a bit low. However these projects will be implemented before 2013 and the Dutch government expressed its willingness to co-finance at least one of the European demonstration projects that are currently under consideration.

*Evaluation of mobilization of resources:* Despite increasing CCS R&D budgets and announcements for financial support for CCS demonstration projects, the availability of financial resources was rated relatively low with a 2.8 (Table 9). Insufficient funds (financial uncertainty) for large-scale projects were mentioned as the most important barrier for a higher rating; especially in the Netherlands. It was noted by many experts that public private partnerships are the way to go in establishing commercial-scale CCS demonstration projects and that government agencies should create financial certainty in providing a substantial part of the billions of Euros necessary to deploy

the first integrated CCS projects on a commercial scale. Next to a lack of financial resources, the respondents in all countries agree that the increasing scarcity of skilled (technical) personnel in CCS can cause problems as it comes to the development of a CCS industry. So more attention should be given to education and training in the field of CCS.

Table 9: Expert evaluation of ‘mobilization of resources’ on a scale of 1-5.

Netherlands	Norway	USA	Canada	Australia	Average
2.5	3.1	3.0	2.7	2.9	2.8

#### 4.6. Creation of Legitimacy

Over 500 stakeholders from across Europe participated in the ACCSEPT [2007] survey of opinion regarding the role of CCS in Europe’s energy futures. The study identified that respondents from the Netherlands and Norway are among the most enthusiastic about CCS and least concerned about the potential risks, of which Norway stands out as exceptionally optimistic. It was also found that there are distinctive ‘CCS communities’ in these countries, which appear to have come to a collective understanding on the importance of CCS within their own country. However, there are significant differences between Norway and the Netherlands, for example there are more favorable perceptions of public opinion to CCS in the former than in the latter. Even though the general public seems to be unfamiliar with CCS in all the countries under study, the public’s reaction on proposed CCS projects seems to differ. Important in the debate around the deployment CCS is the contribution of environmental groups, who have different views on CCS. For example, environmental NGOs: ‘Friends of the Earth (FoE)’ and Greenpeace are opposing CCS. They reason that continued production of electricity from fossil fuels with CCS lengthens the dependence on non-renewable resources, like coal. On the other hand, CCS is supported vigorously by the NGO Bellona, which followed a pragmatic approach towards the oil and gas industry and emphasized the economic potential of CCS in combination with EOR; thereby contributing to the acceptance of CCS by society (especially in Norway).

Equally important and characterizing all countries, is that CCS is favored by a powerful coalition of industrial peak organizations. For example the Norwegian Confederation of Trade Unions and Federation of Norwegian Industries are closely aligned with the regional electrochemical industries, being interested in using more natural gas in their production processes. Together with the national oil companies, these resources-based industrial interest groups occupy a privileged role in Norwegian politics and they perform a powerful lobby for its deployment in political arenas. Similar lobby activities can be found in Australia, where the coal industry is strongly in favor of deploying CCS technologies. Note that Canada, the US and the Netherlands also have strong petrochemical industries influencing the political game into favorable directions for CCS.

*Evaluation of the creation of legitimacy:* As a result of the lack of public support, field experts give the creation of legitimacy for CCS a moderate rating of 3.1. In order to increase public support, more should be done to engage the public and (environmental) NGO’s in CCS projects. In Norway, for example, the combined lobbying activities of various environmental and industrial interest organizations, as well as the increased public awareness of climate change have created more legitimacy for the technology, which have lead to a rating of 4.0 in this country. Furthermore, it was mentioned by several experts that CCS projects should be stimulated in a broader portfolio of climate change mitigation projects in order to gain credibility among the general public.

Table 10: Expert evaluation of ‘creation of legitimacy’ on a scale of 1-5.

Netherlands	Norway	USA	Canada	Australia	Average
3	4	2.9	2.9	2.8	3.1

## 5. Policy Implications and conclusions

The performance assessment and comparison of the CCS innovation systems shows that the extensive knowledge base and networks, accumulated over the past years, have not yet been valorized by entrepreneurs to explore the markets for integrated CCS concepts linked to power generation. This indicates that the build-up of the innovation system has entered a critical phase that is decisive for a further thriving development of CCS in Norway, the Netherlands, Canada, Australia and the U.S. In order to move the CCS innovation system through this present difficult phase and deploy more advanced CCS concepts at a larger scale; it is necessary to direct policy initiatives at

the identified weak system functions, i.e. entrepreneurial activity, market formation and mobilization of resources. Moreover, in some specific countries governmental guidance and the creation of legitimacy may also be improved.

In order to improve their guiding role, governments can foster the implementation of CCS technologies by stating short-term objectives in addition to the mid-term GHG emission reduction targets and long-term visions. Furthermore, it seems desirable to provide clarity on the set of policy instruments that will be used to reach these goals. The latter is important for the involvement of private parties in the development of CCS linked to power production. The industrial sectors that may apply CCS in their daily operations should be able to rely on a long-lasting change in the institutional structure of the innovation system that creates a clear market for CCS. Temporal subsidies, taxes, or gap- and trade systems that are applied at present do not seem to be strong enough to deal with the relatively high (investment) costs of CCS. Policies can foster market formation and entrepreneurial activity by financially supporting learning by doing, i.e. by establishing more demonstration projects in public private partnerships. In this way the technology is brought down its learning curve, which is necessary to bring about the required cost reductions and performance improvements for the technology to enter the market. The current Norwegian (carbon) tax system and the (proposed) Emission Trading Schemes, provide opportunities to create such financial incentives. This can be done by reallocating the tax revenues, or revenues from emission credit auctions, of the oil and gas industry to the implementation of full-scale CCS projects and the construction of a pipeline infrastructure for CO<sub>2</sub> transportation.

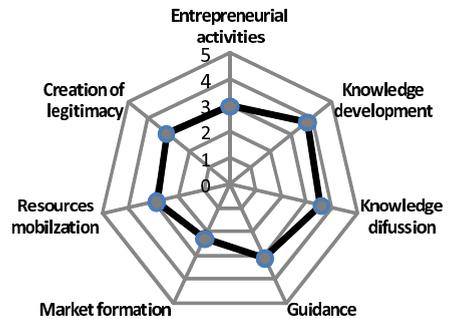


Figure 1: Overall score on the TIS functions by 100 experts in Norway, Netherlands, United States, Canada and Australia.

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