Investment and Market Development in Carbon Capture and Storage

Role of the Energy Charter Treaty
Acknowledgements

The study was undertaken at the request of the Investment Group meeting on 20 October 2008 and the draft report was approved at the meeting on 29 May 2009.

The study was led by the Energy Efficiency Investment Division of the Energy Charter Secretariat with an extensive support from the Legal Affairs and Trade and Transit Divisions.

The study was prepared by Stanislav Stefanov, Zafar Samadov, and Sedat Çal under the supervision and guidance of Dario Chello, Director for Energy Efficiency and Investment of the Energy Charter Secretariat. The study greatly benefited from discussions with delegates from the Energy Charter member governments in the Investment Group, Group on Energy Efficiency and Related Environmental Aspects and industry experts from the Industry Advisory Panel throughout 2008-2009.

Disclaimer

Information contained in this work has been obtained from sources believed to be reliable. However, neither the Energy Charter Secretariat nor its authors guarantee the accuracy or completeness of any information published herein, and neither the Energy Charter Secretariat nor its authors shall be responsible for any losses or damages arising from the use of this information or from any errors or omissions therein. This work is published with the understanding that the Energy Charter Secretariat and its authors are supplying the information, but are not attempting to render legal or other professional services.

© Energy Charter Secretariat, 2009

Boulevard de la Woluwe, 56

B-1200 Brussels, Belgium

ISBN: 978-905948-085-8 (English PDF)

Reproduction of this work, save where otherwise stated, is authorised, provided the source is acknowledged. All rights otherwise reserved.
The Energy Charter Treaty

The Energy Charter Treaty is a unique legally-binding multilateral instrument covering investment protection, liberalisation of trade, freedom of transit, dispute settlement and environmental aspects in the energy sector. It is designed to promote energy security through the operation of more open and competitive energy markets, while respecting the principles of sustainable development and sovereignty over energy resources. The Treaty is the only agreement of its kind dealing with intergovernmental cooperation in the energy sector, covering the whole energy value chain (from exploration to end use) and all energy products and energy-related equipment.

Based on the Energy Charter of 1991, which was a political declaration signalling the intent to strengthen international energy ties, the Energy Charter Treaty was signed in December 1994 and entered into force in April 1998. To date, the Treaty’s membership covers fifty-one states plus the European Communities, which together represent nearly 40% of global GDP. There are also twenty-three observers, as well as ten international organisations with observer status.

Members of the Energy Charter Treaty:
Albania, Armenia, Austria, Australia, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, European Communities, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Kazakhstan, Kyrgyzstan, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Moldova, Mongolia, the Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tajikistan, the former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Ukraine, United Kingdom, Uzbekistan

Observers:
Afghanistan, Algeria, Bahrain, Canada, China, Egypt, Indonesia, Iran, Jordan, Korea, Kuwait, Morocco, Nigeria, Oman, Pakistan, Palestinian National Authority, Qatar, Saudi Arabia, Serbia, Tunisia, United Arab Emirates, United States of America, Venezuela
(vertical stripes denote the countries of ASEAN)

International Organisations with Observer Status:
ASEAN, BASREC, BSEC, CIS Electric Power Council, EBRD, IEA, OECD, UN-ECE, World Bank, WTO
FOREWORD

Worldwide economic stability and development require energy but the vast majority of the world’s current energy sources emit carbon. Solving the challenge of climate change will require, therefore, not only breakthroughs in alternative sources of energy but also new technologies that allow continued use of fossil fuels in an environmentally friendly way. Currently, 60% of electricity generation is from fossil fuels. This level is expected to persist for several decades. If energy production is to be moved onto a sustainable path, carbon dioxide emissions from fossil fuel combustion must be reduced.

One option for large-scale CO₂ mitigation is the use of Carbon Capture and Storage (CCS). Since the 1990s, advanced economies have put considerable resources toward research, development and deployment of CCS technologies around the world. Attention is currently shifting from the technical feasibility of this technology to launching large scale demonstration projects. At the same time, efforts are underway to address the market and regulatory challenges involved in CCS. This includes the issues of cost, the development of legal and regulatory frameworks, and promoting public acceptance of the new technology.

Given that approximately 35% of global natural gas reserves and 42% of coal reserves are located within the ECT region, the issue of CCS will be a vital issue of Energy Charter member states. A key principle of the Energy Charter is the pursuit of sustainable development on the basis of the international environmental agreements to which Charter Contracting Parties adhere. The Energy Charter Treaty provides its member states with a unique legal framework for cooperation through its comprehensive provisions on investment protection and technology transfer, which could further facilitate the uptake of large international CCS projects.

This report provides the first analysis of the applicability of the Energy Charter Treaty to the development of CCS. The Report offers a broad overview of CCS. The available regulatory options for CCS as a potential tool for mitigating the effects of carbon dioxide emissions from fixed sources, particularly power generation plants, are evaluated. Key issues affecting the long term deployment of CCS and the barriers and incentives that currently exist to this deployment are examined.

An issue that receives particular attention in the report is the transportation of CO₂. The deployment of CCS at the scale required to mitigate global warming will require transporting substantial quantities of CO₂ from capture to storage sites. This will, potentially, raise questions about cross-border transit; an area where the Energy Charter Treaty could play an important role.

This report is made publicly available under my authority as Secretary General of the Energy Charter Secretariat and without prejudice to the positions of Contracting Parties or to their rights or obligations under the Energy Charter Treaty or the WTO agreements.

André Mernier
Secretary General
Brussels, October 2009
Table of Contents

1. Executive Summary........................................................................................................... 8
2. Main Findings................................................................................................................... 10
3. Introduction ...................................................................................................................... 11
   3.1. Climate Change and Nature of CO₂ Emissions ......................................................... 11
   3.2. Maturity of Different CCS Technologies ................................................................. 14
4. Regulation of CCS........................................................................................................... 15
   4.1. Definition of CO₂ ..................................................................................................... 15
   4.2. Storage Design ........................................................................................................ 16
   4.3. Access and Property Rights...................................................................................... 16
   4.4. Intellectual Property Rights .................................................................................... 17
   4.5. Monitoring and Verification of Stored CO₂ .............................................................. 17
   4.6. Liability .................................................................................................................... 18
   4.7. Interests of Different Stakeholders ......................................................................... 19
   4.8. Drivers and Barriers for CCS Regulation ................................................................. 20
   4.9. National Legislation on CCS .................................................................................. 22
   4.10. Current Issues ....................................................................................................... 25
   4.11. Outlook ................................................................................................................... 26
5. Role of the ECT in CCS .................................................................................................. 27
   5.1. Geographic Coverage of the ECT .......................................................................... 27
   5.2. Regulation of CCS under the ECT ......................................................................... 27
   5.3. Investment ............................................................................................................... 29
   5.4. The Principle of Non-Discrimination ..................................................................... 30
   5.5. Individual Investment Contracts ............................................................................. 30
   5.6. Expropriation ........................................................................................................... 31
   5.7. Dispute Settlement .................................................................................................. 31
   5.8. Transfer of Technology ......................................................................................... 31
   5.9. An Analytical Look at the CO₂ under the ECT ....................................................... 31
   5.10. The ECT in Relation to Other International Treaties .............................................. 34
6. CCS in the Energy Charter Geographic Coverage: Case Studies ....................................... 36
   6.1. Sleipner Project ....................................................................................................... 36
   6.2. Gorgon Project ....................................................................................................... 37
   6.3. Nagaoka Project ..................................................................................................... 38
7. Main International Legal Documents Regulating CCS

7.1. Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)


7.4. UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol

7.5. EU Directive on Geological Storage

8. Conclusions and Recommendations

Annex A. CCS Technologies

CO₂ Capture Techniques
Options for CCS Power Station Design
CO₂ Transport
Types of CO₂ Storage
Ocean Storage
Mineral Storage – Industrial Fixation of CO₂ into Inorganic Carbonates
Terrestrial (Biological) Sequestration

Annex B. Financing & Economic Models for CCS

Economic Models of CCS: Costs and Benefits (Including a Comparison with Other Options)
CCS Model of the National Energy Technology Laboratory (NETL)
Model of Intergovernmental Panel on Climate Change (IPCC)
IEA Model
Model of RITE (Japan)

Annex C. Definition of Gases

Annex D. References
List of Figures

Figure 1 Profile of Worldwide Large Stationary CO₂ Sources (Emissions > 0.1 Million Tonnes of CO₂ per Year) .................................................. 12
Figure 2 Geological Storage Potential .................................................................................................................................................. 13
Figure 3 Maturity of Various CCS Technologies ................................................................................................................................. 14
Figure 4 The Energy Charter Constituency (as of May 2009) .................................................................................................................. 27
Figure 5 Major Current and Planned CCS Projects ............................................................................................................................... 36
Figure 6 The Sleipner Project ..................................................................................................................................................................... 37
Figure 7 The Gorgon Project ..................................................................................................................................................................... 38
Figure 8 The Nagaoka Project ..................................................................................................................................................................... 39
Figure 9 Geographic Coverage of the OSPAR Convention .................................................................................................................. 41
Figure 10 Geographic Coverage of the London Convention ................................................................................................................ 42
Figure 11 Geographic Coverage of UNCLOS ......................................................................................................................................... 42
Figure 12 Geographic Coverage of UNFCCC ........................................................................................................................................... 43
Figure 13 Geographic Coverage of the European Economic Area (EEA) ............................................................................................. 44
Figure 14 Post-combustion Capture of CO₂ ........................................................................................................................................... 47
Figure 15 Pre-combustion Capture of CO₂ ................................................................................................................................................ 48
Figure 16 Oxy-fuelling Capture of CO₂ .................................................................................................................................................... 48
Figure 17 Geological Storage of CO₂ ..................................................................................................................................................... 51
Figure 18 Geographic Distribution of Geological Storage Opportunities ................................................................................................ 52
Figure 19 Ocean Storage of CO₂.................................................................................................................................................................. 53

List of Tables

Table 1 Large Stationary CO₂ Sources .................................................................................................................................................... 12
Table 2 Drivers for CCS Regulation .......................................................................................................................................................... 20
Table 3 Barriers for CCS Regulation ..................................................................................................................................................... 21
Table 4 CCS Cost Estimates Based on the NETL Model ...................................................................................................................... 57
Table 5 CCS Cost Breakdown Based on the IPCC Model .................................................................................................................... 57
Table 6 Characteristics of Power Plants with CO₂ Capture .................................................................................................................. 58
Table 7 CCS Cost Comparison between the Models of RITE and IPCC ............................................................................................... 58
1. Executive Summary

This study focuses on different aspects of Carbon Capture and Storage (CCS) as a potentially credible climate change mitigation option. The development and demonstration of a reliable, affordable and safe technology for capturing, transporting and injecting carbon dioxide (CO₂) into suitable geological formations are of crucial importance for assuring a broader public acceptance and a faster commercial uptake of the CCS technology.

From a technical point of view it appears that the post-combustion technology is the most promising of the three capture mechanisms to address the issue of existing power plants, but it should also be noted that it is as well the most expensive one. However, CCS can fit easily to those plants that have been specifically designed to accommodate a “retrofit” CCS capacity. Older plants present more of a challenge because of the cost aspect in adapting them to the post-combustion technology, but nonetheless it is feasible to re-engineer these plants to this specification.

The existing legal and regulatory frameworks including Energy Charter Treaty as well as the recent amendments to key international legally binding instruments related to CCS, for example the Convention for the protection of the marine environment of the North-East Atlantic (OSPAR Convention) and the London Convention on the prevention of marine pollution by dumping wastes and other matters (London Convention/London Protocol), are among the major documents considered.

It seems that for the time being there is no universally acknowledged framework for regulating CCS. However, the Energy Charter Treaty (ECT) could no doubt be used as a valuable legal basis for addressing some CO₂-related issues. The ECT has four pillars regulating the energy activities, namely investment, dispute settlement, trade and transit, and the place of CO₂ under the ECT in this respect may be summarised as follows:

- Investment related aspects of the Treaty are applicable to CO₂ related activities within the energy sector, since CO₂ may be taken within the coverage of the term “energy related activity” especially in the light of the Understanding which relates to Art. 1(5) to the treaty regarding activities illustrative of Economic Activities in the Energy Sector, i.e. “removal and disposal of wastes from energy related facilities such as power stations…” Furthermore, definition of “energy cycle” in Art 19 also supports, inter alia, the argument that CCS may be taken as a waste storage and thus part of the energy chain activity under the ECT, all leading to an outcome that as an energy sector activity CO₂ might be construed so as to be covered by the investment regulation of the ECT under Part III.

- Furthermore, the ECT may also apply to CCS-related transfer of technology. Art. 8(1) of the Treaty makes a reference to “Investment” in relation to promoting access to and transfer of energy technology on a commercial and non-discriminatory basis, and thus arguably allowing CCS technology to be, in a legal and reliable manner, transferred from a Contracting Party to another under the provisions of the Energy Charter Treaty.

- Transit related provisions seem to be not applicable to CO₂, given that the transit related provisions only apply to energy materials and products, which are defined in an exhaustive manner under Annex EM to the ECT, and this Annex does not refer to CO₂.

- Trade related provisions also seem to be not applicable to the CO₂, since Art. 3 of the ECT refers to “promote access to international markets on commercial terms, and generally to develop an open and competitive market, for Energy Materials and Products” which do not include CO₂ as described above. Furthermore, the Trade Amendment of the ECT which governs trading of energy related equipment seems not to cover CO₂ among the list of various items in a broad range of 70 categories.
As a result, CO₂ is arguably not regulated by the trade related provisions of the ECT. It seems that WTO provisions also do not cover CO₂ in the international trade system.

Finally, as outlined above in relation to the possibility of CO₂ to be included within the scope of the term “Investment”, dispute settlement procedures outlined in the Treaty might also be viewed as having relevance to CCS-related activities, and this is especially true with respect to investor-state arbitration provided under Art. 26 of the ECT, allowing for enforcement of the Part III protections provided for in the Treaty.

On another account, it is important to clarify the hierarchy, potency and geographical scope of the ECT vis-à-vis other international treaties and national legislative frameworks in order to help provide a reasonable and efficient vehicle for the deployment of CCS technology worldwide. It should be emphasised that the ECT is self implementing and that no direct legislative and regulative initiatives concerning CCS were pursued through this study.
2. Main Findings

Some of the main findings in this paper are related to the following:

- Carbon capture and storage is a promising option for the mitigation of climate change over the next few decades.

- A well working carbon market could give the right economic signals to the stakeholders by providing a carbon price needed to make the CCS projects more viable, so to address the higher price of the “CCS choice”. In addition, strong government support is needed during research, development and implementation of large scale demonstration projects.

- There seems to be no incompatibility between the ECT and other international treaties in regulating various parts of CCS projects. The ECT could be a useful legal instrument for the regulation of some aspects of CCS projects, in particular ensuring investment protection and reducing to a minimum the non-commercial risks associated with CCS sector investments.

- Investment decisions concerning CCS will not be taken without clear perspectives on an adequate intellectual property rights (IPR) regime applicable to new CO₂ capture technologies plus long-term guarantees for stability of storage site regulation and long-term liability and its transfer from the private to the public sector.

- So far, despite the efforts, the CCS issues are treated on a case by case basis and the most advanced technologies are the ones that also provide at least partial return that offsets the cost, for example, enhanced oil recovery (EOR). For this reason, it is not surprising that the largest parts of existing regulation are dealing with these processes.
3. Introduction

Economic development and today’s high quality lifestyle have been for a long time based on technological improvement and greater consumption of energy. Forecasts of energy demand indicate that over the next decades it will significantly increase; accordingly, greater supply will be needed to meet the demand and avoid unaffordable prices and a negative impact on economic growth and employment. Fossil fuels, and especially coal, are abundant energy resources that dominate the world energy supply and demand mix nowadays. The need to supply more electricity in the future means that additional quantities of coal are likely to be burned to generate it.

However, in using more energy, the world economy and the public are now facing challenges of both economic and environmental nature. A growing consensus is emerging about the necessity to establish a clear, broadly acceptable framework for sustainability, involving a safer, cleaner, and less harming environment, by mitigating the negative effects of energy production and consumption.

One of the technically possible and potentially economically viable options is the “smarter” use of coal as a primary energy source for electricity generation, supported by the carbon capture and storage (CCS) method. CCS is an approach to mitigating climate change via the process of capturing CO₂ emissions from large point sources such as power plants, compressing it into a dense fluid, transporting it (usually by pipeline) and storing it securely in geological formations, on land or under the seabed. However, the implementation of CCS is directly related to a range of issues pertaining to the energy sector, the environment, and the use of natural resources at national, regional and global levels. There are specific aspects of CCS that could easily lead to difficulties in its implementation, for example, due to uncertainties regarding the legal basis on which the CCS technology is expected to be developed and deployed.

Taking into account the divergent CCS-related regulatory provisions currently in place around the globe, the importance of defining and assessing the best options for promoting the CCS technology and improving its public acceptance becomes evident. The Energy Charter, which has a specific mandate to deal with waste generated in the energy sector, is a multilateral platform which seems to be well poised to deal with some matters related to CCS from the viewpoint of promoting investment in CCS, cross-border trade and transfer of technology.

3.1. Climate Change and Nature of CO₂ Emissions

As one of the “hottest” issues, global warming is nowadays on the agenda of almost every meeting dealing with energy all over the world.

International negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol (KP) aim to reach a new global climate change regime for the post-2012 period in Copenhagen in December 2009. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) demonstrates that, up to 2050, substantial global emission reductions of at least 50% below 1990 levels are needed. This leads to a need for emissions to be stabilised and then reduced in the relatively short-term. Beyond 2050, additional global emission reductions are required to move to a zero or near-zero carbon economy.

---

1 Countries like, USA, Germany, China, India rely strongly on coal.
Around 75% of global greenhouse gas emissions are from energy-related activities; CO₂ is the major contributor. There are two types of energy-related CO₂ emission sources: stationary and non-stationary sources. Stationary source emissions come from a particular, identifiable, localised source, for instance a power plant. Non-stationary source emissions include CO₂ emissions mainly from the transportation sector. Figure 1 provides an illustration of the geographic distribution of stationary CO₂ sources worldwide.

**Figure 1 Profile of Worldwide Large Stationary CO₂ Sources**  
(Emissions > 0.1 Million Tonnes of CO₂ per Year)

![Figure 1 Profile of Worldwide Large Stationary CO₂ Sources](source: IPCC)

<table>
<thead>
<tr>
<th>Process</th>
<th>Number of sources</th>
<th>Emissions in millions of tonnes CO₂ per year (MtCO₂/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>4 942</td>
<td>10 539</td>
</tr>
<tr>
<td>Cement production</td>
<td>1 175</td>
<td>932</td>
</tr>
<tr>
<td>Refineries</td>
<td>638</td>
<td>798</td>
</tr>
<tr>
<td>Iron and steel industry</td>
<td>269</td>
<td>646</td>
</tr>
<tr>
<td>Petrochemical industry</td>
<td>470</td>
<td>379</td>
</tr>
<tr>
<td>Oil and gas processing</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Other sources</td>
<td>90</td>
<td>33</td>
</tr>
<tr>
<td>Biomass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioethanol and bioenergy</td>
<td>303</td>
<td>91</td>
</tr>
<tr>
<td>Total</td>
<td>7 887</td>
<td>13 466</td>
</tr>
</tbody>
</table>

*Source: IPCC Special Report on Carbon Dioxide Capture and Storage*

In almost all countries, major sources of industrial stationary CO₂ are power plants, integrated steel plants, refineries, petrochemical complexes and cement works. Probably the only exception is Norway, which relies almost entirely on hydropower for its electricity production. In Norway, many
of the major sources of CO₂ are offshore oil and gas fields.³ As indicated in Table 1, power generation is by far the single largest stationary source of CO₂ emissions both in number of sites (almost 2/3 of all sites) and in volume of CO₂ released in the atmosphere (almost 80% of emissions). For instance, a 1,000 MW black coal-based power plant would typically produce some 6 million tons of CO₂ per year.

In many countries, a relatively small number of industrial sources account for a significant proportion of total CO₂ emissions. Bearing this fact in mind, it could be assumed that an important reduction in total volume of CO₂ emissions could be achieved by implementing a suitable CCS technology on a limited number of sites.

Apart from being the most promising storage option from a technical point of view, one should keep in mind the fact that the volume of CO₂ which could be removed by geological sequestration is potentially very large, as can be seen on Figure 2.

![Figure 2 Geological Storage Potential](source: Carbon Sequestration R&D overview, NETL, 2008)

It is clear that – apart from CCS – there are many climate change mitigation options, such as improvement of energy efficiency, greater use of renewable energy sources (RES), massive switch to nuclear power, yet CCS is often seen as one of the most promising technologies in the nearest future, both from economic and technological point of view. The reasons for that are related to both the availability of the technology and the abundance of coal. Nevertheless, the effect of the CCS technology should be evaluated by taking into account many factors, for example not just the eventual reduction of CO₂ emissions, but also the inevitable decrease of the overall efficiency of the facility (power plant) due to the increase of energy consumption in processes related to CO₂ capture, transport and injection. According to the IPCC, the available technologies nowadays could offer 85-95% of CO₂ capture, adding at the same time from 10% to 40% to the energy used for own needs at the plant.

Carbon dioxide (CO₂) capture and storage (CCS) is a process consisting of the separation of CO₂ from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere. CCS is considered as an option in the portfolio of mitigation actions for stabilisation of atmospheric greenhouse gas concentrations.

(Source: IPCC Special report on Carbon Dioxide capture and storage)

In general, CCS could be described as a technological process that first separates the carbon dioxide from the flue gases or fossil fuels, then compresses CO\(_2\) and transports it to a location where it can be stored, for instance by injecting CO\(_2\) into suitable geological formations.

### 3.2. Maturity of Different CCS Technologies

One of the most debated issues of CCS is related to the maturity of CCS technology. While different options exist today for capture and storage of CO\(_2\) and some of them have been successfully used for decades, it is also true that large-scale demonstration of CCS at a big stationary CO\(_2\) emitter (e.g. a power plant) has yet to be provided. To some extent, this is probably due to the fact that some elements of the technology are still immature, but maybe the substantive cause of the “delay” is a complex mix of regulatory and economic factors, rather than the immature status of the technology. As can be seen on Figure 3, the most advanced technologies are the ones that also provide at least partial return which offsets the cost, for example EOR. For this reason, it is not surprising that it is these processes that are also the most regulated.

![Figure 3 Maturity of Various CCS Technologies](image)

*Source: IPCC Special report on carbon dioxide capture and storage*

Detailed description of various CO\(_2\) capture techniques are presented in Annex A.
4. Regulation of CCS

The regulation of CCS could be a more difficult task than expected because of some apparently simple but extremely important issues that have to be addressed:

- What is CO₂ – waste or an industrial commodity?
- How to address concrete issues related to: (1) access and property rights to all facilities in the CCS chain; (2) intellectual property rights for technology deployment; (3) standards and criteria for storage choice; (4) monitoring and verification during injection and over the post injection phase; (5) long term liability and stewardship in order to guarantee the safety requirements of the reservoir?
- Under what type of legislation should CCS projects belong to – environmental, energy, geological or a mix of these?
- Are new CCS-specific legal and regulatory frameworks needed or are the existing legislation and regulations sufficient to deal with CO₂ storage issues?
- Is a global model for the regulation of CCS the best option or are regional or individual (case by case) approaches more appropriate to regulating these projects?

The regulation of CO₂ storage should be based on proper definition of carbon dioxide in order to find the right jurisdiction that covers it and on reasonable and trusted rules for development of standards and well /facilities design.

4.1. Definition of CO₂

There is no uniform or broadly accepted definition of CO₂. From a technical point of view, it is generally assumed be a relatively pure stream of the substance along with lesser quantities of other substances, but for the purposes of regulation there is no clear consensus whether this stream should be classified as simple waste or as an industrial commodity. The difficulty in this hypothesis is the fact that the generally accepted classifications under various international treaties related to waste or industrial commodities are conceived without taking into account CCS as a possible climate change mitigation option.

In the case of use of CO₂ for the purpose of enhanced resource recovery (oil or coalbed methane) it is apparently clear and generally accepted that the injected carbon dioxide is a special industrial commodity and there is no reason for the process to be treated as a simple disposal of waste. However, when the project of CO₂ storage does not involve some kind of enhanced resource recovery, it is generally assumed that the carbon dioxide stream could be considered as a waste and should fall under the environmental legislation related to waste management. Nevertheless, it is again not clear whether CO₂ is a waste or not. Presuming that in practice the waste is simply some unwanted or undesired material or substance, the focus of CO₂ definition could be moved slightly. In practice, if for instance a price of CO₂ and new business opportunities related to its capture, transport and storage exist, then CO₂ is not any more “unwanted”. Of course, this does not change the negative environmental impact of CO₂, but the entire process of CCS is not anymore a simple disposal of waste, but rather part of a “profitable economic activity”, which could become a “necessary additional element” for some industrial projects to become viable. For instance, if the price of CO₂ were to reach a certain level, then electricity generation with CCS from fossil fuels, ceteris paribus, could be justified.

---

4 For instance as a specific product being part of some industrial process.
There are international treaties, for example the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention), the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter” (London Convention/London Protocol) and the United Nations Convention on the Law of the Sea” (UNCLOS), that regulate certain aspects of the CCS process. One of the main weaknesses of these documents is related to the fact that the treaties were not conceived for the purposes of CCS. While some recent amendments could lead to an expansion of the scope and the detail of the regulation of CO₂, the major downside remains: the geographical coverage of the existing legislation. The proposed solutions in the field of CCS will be applicable only to a limited number of countries. This could create unnecessary barriers, especially to multinational CCS projects including countries that are not covered by a concrete legislative framework.

Nevertheless, in evaluating various existing international legally binding documents that could have bearing on the regulation of CCS, it seems that the Energy Charter Treaty (ECT) could provide a broad geographical scope for regulating CO₂. However, setting aside the issue of geographic coverage, one substantial issue is the classification of CO₂ and the lack of a clear definition or the lack of appropriate addressing of CO₂ under the current treaties, including the ECT. Besides, in many countries the national law regulates some aspects of CCS projects, for example waste disposal or groundwater use and protection. In this instance, too, the regulations have not been conceived with the CCS option in mind, which could make it largely irrelevant to today’s or tomorrow’s CCS projects.

4.2. Storage Design

Storage design is probably the most controversial element in the entire CCS chain for the moment. At the same time, the bulk of attention in every CCS project should be precisely on the evaluation of the storage vehicle itself, by using a set of appropriate predefined criteria. A cursory list of such criteria could include, for example, adequate depth (>800 m); minimum level of tectonics; favourable pressure conditions; adequate porosity and permeability, etc. The importance of developing the “right” set of criteria and procedures for the choice of the storage site and medium, as well as the design and the operation of the relevant facilities (wells, etc.) is revealed when one takes into consideration the fact that these criteria and procedures are the main warranty for the future safe and permanent trapping of carbon dioxide.

In many instances, considerable technical expertise is already in place. The initial reservoir potential evaluation, characterisation and simulation are particularly well developed for oil and gas fields, and the extensive experience of the oil and gas business can be put to good use. It does not come as a surprise that oil and gas companies are realising the first big CO₂ storage projects (Sleipner, Weyburn, In Salah and Snohvit). The petroleum business has the necessary geological data, analytical and engineering tools, and the ability to create realistic models of reservoirs in order to evaluate the possible behaviour of the injected CO₂ and the reservoir itself. So far however, this valuable experience has found rather limited application, mainly in North America and the North Sea. With the establishment of appropriate legal and regulatory framework, especially concerning technology transfer and intellectual property rights, a faster pace of spreading worldwide could be achieved.

In evaluating the storage design, some concrete parameters of injection should be taken into account to assess the viability of the project.

4.3. Access and Property Rights

The access and property rights related to the different stages of a CCS project have to be properly resolved on time in order the project to be realised. Investment decisions will not be taken without clear perspectives on long-term guarantees for stability of storage site regulation and liabilities. The main areas of property rights are surface (injection of the CO₂), sub-surface (reservoir) and the CO₂
A factor of crucial importance is the fact that the existing legislation and regulatory frameworks concerning land property and the use of underground resources vary widely worldwide. In addition, special attention should be paid to the transport of CO₂, as the public acceptance of the construction of any new energy (or similar) facilities can be pretty difficult nowadays.

An extremely important issue is the issue of long-term liability and its transfer from the private to the public sector. The way the issue is dealt with is dependent on the initial definition of property rights. It should be clear from the very start of the project who, what, where and when would have an obligation to transfer to whom. The issue is even more complicated in a setting where a project crosses one or several national borders. Nevertheless, the apparently insufficient legal basis has not deterred the development of some projects on purely contractual terms, even without a clear definition of the responsibilities of the parties in case of eventual future leakage. For this reason, it will probably be very helpful to establish a minimum set of standards for the regulation and the assigning of liability to each CCS project stakeholder.

4.4. Intellectual Property Rights

The development and the uptake of a new technology are related to intellectual property rights (IPR). The issue could become extremely aggravated, especially in countries that lack adequate IPR legislation and do not apply it properly. CCS is based on new technologies and, given the relative scarcity of international regulation in the field of CCS, may entail a high potential for IPR-related disputes. Adding to that the huge costs of CCS projects during the initial/demonstration phase, the importance of an adequate IPR regime applicable to CCS becomes evident. Without strong warranties in the IPR field, investors would be reluctant to spend significant amount of resources in many countries where – according to forecasts – the need for CCS would be the greatest. With this in mind, and taking into account the fact that the ECT contains strong provisions on energy technology transfer, it may be assumed that the ECT could provide an initial basis for the promotion of CCS in the Energy Charter constituency.

4.5. Monitoring and Verification of Stored CO₂

Once injected in the underground geological formation, the CO₂ stream is not anymore under the direct control of the operator. For this reason, it is of critical importance to put in place some mechanism of indirect control. Different techniques for measurement, monitoring and verification (MMV) have been used by the oil and gas companies for many years in order to monitor the behaviour of the underground fluids. In fact, CO₂ is not a “different object” of monitoring when compared to other substances originally (naturally) existing in the reservoir, such as methane. In addition, according to some studies, the corrosive characteristics of natural gas are stronger than those of CO₂, and thus the risk of corrosion as a factor leading to eventual future leakage is smaller in the case of CO₂.

The existing methods seem to be quite sufficient to guarantee the secure monitoring of a project during and after the injection of CO₂ in reservoirs used by the petroleum industry. However, to assure the acceptance of CCS as a viable climate change mitigation option, and to certify the volumes of CO₂ that are not emitted into the atmosphere so that they could be recognised under a certain trading mechanism, it is mandatory to adopt a set of de minimus standards for the measurement, monitoring and verification of CCS. Such a coherent set of standards would help improve the public acceptance of CCS projects, especially if the set is part of a bigger legislative and regulatory framework which would also define the responsibilities of the monitoring institutions and the liability of the CCS project stakeholders.

---

From a technical point of view, the monitoring of CO₂ is focused on the possible lateral migration or eventual vertical leakage outside the storage area. MMV is quite important because of its close relation to liability issues in the case of an eventual future leakage of CO₂. The main difficulty is caused by the need to deploy a long-run monitoring process of considerable cost. So far, it is not clear who and how will cover these costs, which could be incurred for 100 or more years. It is obvious that such a financial burden is highly unacceptable and difficult to be covered under the existing practices. In addition, the financial and insurance institutions have no significant experience in similar projects and are quite reluctant to participate in them without a strong regulatory framework already in place. The importance of proper MMV is also related to the fact that – in case of potential leakage of CO₂ – the assigned amounts units (AAUs) of emissions not released into the atmosphere should be corrected.

4.6. Liability

The liability associated with new, uncertain and often unprecedented long-term projects is maybe the most difficult issue to overcome in order to arrive at CCS deployment. Who, when, for what and how will be responsible in a given CCS project? So far, the existing projects are few, small-scale and at an initial development phase, and are thus not yet facing serious problems with liability. It is obvious that in the short run all responsibilities rest with the project developers and operators, who are typically very clearly defined under the granted permits for the project development in a certain environmental legislation and/or concession regime. The liability related to development of a CCS project in the short run, or the so called “operational liability”, is not at all different from that associated with oil and gas projects, and obviously has to cover environmental, health and safety risks associated with the entire chain of CCS – capture, transport, storage (injection) of the carbon dioxide stream. Business seems to be pretty adept at dealing with this kind of problems.

However, the unclear and extremely difficult issue appears especially once the injection process is over. The issue of liability is so acute in SSC because, unlike most other industries, the liability for leakage could arise centuries after the cessation of storage when the operator has ceased to exist and the storage sites are no longer in use and have been decommissioned, with any profit made by the operator possibly having been distributed long before the leakage occurs and thus making it impossible to seek compensation from the beneficiaries. Also, when and under which conditions should the liability be transferred from the private to the public sector – if transferable at all? Of course, such a transfer is not obligatory, but it is likely that many commercial entities would not exist 100, 200 or more years after the implementation of a CCS project. Taking this into account, the only practical way to deal with long-term liability is through its assignment to the government, which would assume the responsibility for the CCS project at some future moment. States usually exist much longer than other “liable persons”.

This perception is also shared by Eurelectric, which suggests that the long-term monitoring and liability for stored CO₂ should be transferred to the relevant Member State after completion of the CO₂ injection phase. Nevertheless, the question under what conditions the liability would be “accepted” by the public sector remains. On the other hand, the MMV process is of crucial importance for the evaluation of the storage site and of the behaviour of the injected CO₂.

Three types of long-term liability could be defined regarding the CCS projects, namely environmental, “in situ”, and trans-border liability. The environmental liability is generally related

---

7 Ibid.
8 Newberry, op. cit., p. 160.
to the possible global climate harm and one could presume serious difficulties in proving it. The “in situ” and trans-border liabilities are of a more “concrete location” which makes public perceptions far more sensitive. The fear of possible sub-surface leakage of CO₂ that could damage fields or soils is quite widespread. However, if the appropriate initial evaluation of geological data has been done and the “right” storage site has been chosen, and the subsequent MMV has shown no unusual behaviour of the CO₂ plume, then the risk of future leakage becomes quite insignificant. In reality, if the CO₂ leakage appears on the territory of the same country where the injection has been carried out, the liability would be easier to define compared to a situation where CO₂ has been crossed one or several national borders. The trans-border liability could be addressed only by some strong and legally binding international treaties or agreements. This assumption without doubt supports the view that it is necessary to arrive at a widely accepted cross-border CCS legal framework, supported by appropriate financial mechanisms or funds to cover the costs of eventual leakages. Nevertheless, it is not clear how the appropriate level of these funds would be evaluated in order to cover the costs (or at least a significant part of costs) in case of CO₂ leakage.

The extremely complex case of long-term liability associated with CCS projects raises another important issue that should for sure be clarified at the onset of every project. Which government would have to carry the long-term liability in case the project is developed for instance by a multinational company, or consortium¹¹ in a third country? The government where the multinational company headquarters are located or the government hosting the CO₂ storage, or in case that AAUs have been transferred to another company/government, then the latter would also be liable to the degree of its share of AAUs? These questions in essence boil down to whether or not the liability should remain territorial or should be attached to the “benefits” of CCS, namely the AAUs.

4.7. Interests of Different Stakeholders

A comprehensive gas storage (GS) regulatory framework must balance the competing needs and interests of all actors through the project cycle. This includes public at local, national and international levels, CO₂ producers, GS project developers, financial and insurance institutions supporting the project, government agencies setting safety and environmental requirements, and national and international agencies managing climate regimes [Rubin et al. 2007].

**The public.** Public priorities will vary by context. The global public’s interest in GS is to avoid dangerous climate change. The public at the national and state levels will be concerned with economic competitiveness, including the cost of electricity, and with cost and effectiveness of regulatory agencies. The local public will focus on health, safety and environmental concerns, as well as property rights issues.

**CO₂ producers.** CO₂ producers will need secure repositories for CO₂ coupled to a reliable pipeline system linking sources to sinks. Clear definition of CO₂ ownership through the industrial process from capture to injection will be important, as will a stable climate regime to make CCS economically viable.

**GS project developers.** Project developers need GS to be legal and profitable [Wright 2007]. They must satisfy the rules established by the four key bodies that will govern GS: government agencies setting safety and environmental regulations, national or international agencies administering climate regimes, insurance institutions participating in liability coverage, and financial institutions supporting the project. Therefore, project developers will want to see the maximum coordination between the actors governing their operations, as well as stability and predictability in regulatory frameworks.

---

¹¹ *De facto*, in today’s globalised world, due to the high cost levels and complicity of the CCS projects this has been a common practice so far.
**Local and national regulators.** Protection of human health and the environment is the primary objective of local and national regulators. They will also strive to minimise the cost of regulation to both the public and industry, and equitably balance the risks of GS between public and private actors [Rubin et al. 2007].

**Climate regime administrators.** A climate regime will need to accurately measure CO₂ emissions avoided. Development of harmonised GHG accounting procedures, as well as minimum international GS site operating procedures (site selection, injection, and monitoring) will be necessary to enable international carbon trading and ensure that the value of emissions allowances is not eroded by leakage from GS sites.

**Insurance companies.** The needs of insurers and reinsurers will depend on which activities they are asked to cover, and the limits on liability (if any) provided under national law.

**Financial underwriting companies.** GS projects will not be possible without financing. Financial institutions will require that GS is profitable i.e. the revenue stream to the GS operator must be dependable and exceed the annual obligation of repayment of principal and return on capital to investors. This calls, first of all, for creation of incentive structures to render CCS economically viable. It will also likely entail long-term contracts with CO₂ producers. Regulatory stability is crucial for financial investors, so adaptive regulatory processes should be structured in a way that balances risk-based management with regulatory predictability. Finally, no investment can occur before legal operation is assured. Onshore and offshore regulation and guidance must explicitly address CO₂ and associated substances, to remove legal uncertainty, and clarify ownership rights of subsurface pore space and mineral rights affected by CO₂ storage.

### 4.8. Drivers and Barriers for CCS Regulation

An international workshop organised by International Risk Governance Council (IRGC) identified following drivers for CCS Regulation:

<table>
<thead>
<tr>
<th>Type of Regulation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>Permitting and siting, operation and maintenance, MV, remediation</td>
</tr>
<tr>
<td>Property rights</td>
<td>Transport, trade practices, storage rights, third-party access, mineral rights</td>
</tr>
<tr>
<td>Competition</td>
<td>Natural monopoly concerns with pipeline transport</td>
</tr>
<tr>
<td>Health, safety and</td>
<td>Industrial safety, protection of populations, groundwater, and ecosystems</td>
</tr>
<tr>
<td>environmental</td>
<td>near storage sites</td>
</tr>
<tr>
<td>GHG emissions standards</td>
<td>Links to climate regimes</td>
</tr>
<tr>
<td>Financial responsibility</td>
<td>Required for injection permit, designed to cover operational liabilities and</td>
</tr>
<tr>
<td></td>
<td>fund long-term stewardship</td>
</tr>
<tr>
<td>Long-term responsibility</td>
<td>Establish entity to assume long-term responsibility and liability, including</td>
</tr>
<tr>
<td>and liability</td>
<td>funding mechanism</td>
</tr>
<tr>
<td>Electricity price/rate review</td>
<td>For regulated utilities</td>
</tr>
<tr>
<td>Tax and subsidies</td>
<td>Links to national incentive structures</td>
</tr>
<tr>
<td>International treaties</td>
<td>Govern off-shore and cross-border storage process</td>
</tr>
</tbody>
</table>

*Source: International Risk Governance Council (IRGC)*
IRGC also identified following uncertainties that represent barriers for GS regulation:

### Table 3 Barriers for CCS Regulation

<table>
<thead>
<tr>
<th>Unknown</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Capture reliability, cost, energy penalty</td>
<td>Rate regulators and public need to know incremental cost increase of electricity; and Utilities and financial backers need to know cost of projects.</td>
</tr>
<tr>
<td>2. Geologic performance (leakage risk profiles) in a variety of geological settings and reservoir types</td>
<td>Local public needs to understand leakage risk and in situ behaviour to permit siting and acquisition of storage rights; Global/national public needs assurance that CCS is an effective mitigation technique; Health and safety regulators need to design monitoring and remediation requirements; Insurers need to know risk levels to price liability coverage; Climate regime administrators need to assure integrity of emissions reductions; and Financial backers need to assess project viability.</td>
</tr>
<tr>
<td>3. Basin-scale impacts (fluid displacement, induced seismicity)</td>
<td>Public acceptance rests on accurate portrayal of “the big picture”; Regulators and project operators need to design monitoring to detect basin-scale effects; and Insurers and financial backers need to assess potential for basin-scale impacts to price liability coverage and gauge financial viability.</td>
</tr>
<tr>
<td>4. Adequacy of models to predict reservoir performance at scale</td>
<td>Permitting and acquisition of storage rights rests on accurate projections of storage capacity, plume size and behaviour; and Financial assurance requirements, monitoring requirements and site closure requirements will all be based on comparing model projections with actual site performance.</td>
</tr>
<tr>
<td>5. Monitoring methodology, detection limits</td>
<td>Local public, and health and safety regulators need to know potential leakage can be detected; Detection limits are a factor in setting acceptable leakage rates; and Project operators, regulators need to select appropriate monitoring methods.</td>
</tr>
<tr>
<td>6. Remediation techniques, costs</td>
<td>Local public, and health and safety regulators need to know potential leakage can be remediated if necessary; Remediation costs would affect financial responsibility and assurance requirements; Insurers would weigh remediation’s potential to mitigate risk; and Remediability would improve financial viability.</td>
</tr>
<tr>
<td>7. Effects of varying purity of CO₂ streams</td>
<td>Pipeline system design would vary to accommodate mixed streams; Project costs will vary if co-disposal is possible, or alternatively, if high purity is required; Reservoir response may vary; and Risk profiles will vary; affecting public acceptance, health and safety regulations, liability requirements, and financial viability.</td>
</tr>
<tr>
<td>8. Industrial organisation</td>
<td>Difficult to design regulations for an industry that does not yet exist; Ownership of CO₂ from generation through transport to storage will influence liability coverage; and CCS project developers need to understand commercial connections between CO₂ generator, pipeline operator and GS storage site operator.</td>
</tr>
<tr>
<td>9. Public acceptance</td>
<td>Necessary to obtain public financial support for early projects; Necessary for launching large-scale commercial projects; and Necessary for resolution of long-term stewardship issues.</td>
</tr>
<tr>
<td>10. Climate regime/incentive structures</td>
<td>CCS projects (except EOR) are not viable without a climate regime; The specifics of the climate regime rules will influence industrial organisation; and Climate regime stringency will determine climate related liabilities.</td>
</tr>
</tbody>
</table>

*Source: International Risk Governance Council (IRGC)*
4.9. National Legislation on CCS

There are a number of important goals guiding the establishment of legal and regulatory frameworks governing CO₂ storage. Governments are interested in promoting CO₂ storage as a climate change strategy while at the same time ensuring the protection of public health and the environment. The following are some examples that could be taken into consideration:

North America

Certain North American jurisdictions (e.g. Alberta, Texas) have already put in place a regulatory framework for CO₂ transportation and injection, either for enhanced hydrocarbon recovery or for disposal. The framework can be adapted and/or adopted “as is” for the operational phase of CCS beyond the CO₂ source.¹²

Australia

The Australian Ministerial Council on Mineral and Petroleum Resources has created Regulatory Guiding Principles for CCS projects. The Guiding Principles were released in November 2005 and intended to establish consistent regulations for CCS across state and federal jurisdictions, addressing all stages of a project. The following describes some of the important regulatory definitions established in the guidelines, including:¹³

1. Separation of CCS process into four distinct stages, including capture, transport, injection, and post-closure, with recommendations for regulatory steps for each distinct stage.

2. Clear delineation between the injection and post-closure stages, with post-injection fitting into the “injection” category and de-commissioning and site rehabilitation falling under “post-closure.” This distinction will be useful for determining the potential transition point between private and public liability.

3. Pre-project assessment and demonstration of site stability are both categorised under the “injection” stage. A project cannot move to the “post-closure” phase until it has demonstrated site stability. This distinction is useful because it provides some flexibility in terms of defining the length of time that the project may use to move through each stage, yet provides a clear indicator for when the project could be covered by any potential “long-term” liability rules.

4. Requirement that monitoring and verification must be undertaken during the injection stage to demonstrate site stability before the project can move to the post-closure stage. The monitoring and verification process must address a number of pre-specified issues, including level of accuracy, the quantity, composition and location of gas captured, transported, injected and stored, the net abatement of emissions, and an identification and accounting for potential leakage.

Apart of the Regulatory Guiding Principles for CCS projects, a special legal document (The Barrow Island Act 2003)” specific to the Gorgon project has been adopted and thus allows the re-injection of CO₂ into the saline aquifer on Barrow Island.

A more practical step, worth of $500 million over 8 years, is the National Low Emissions Coal Initiative (NLECI), that has been set up by the Australian Government to accelerate the development and deployment of technologies that will reduce emissions from coal use.¹⁴

---

On April 16 2009 Prime Minister Kevin Rudd launched the Global Carbon Capture and Storage Institute (GCCSI) which aiming to accelerate carbon projects through facilitating demonstration projects and identifying and supporting necessary research – including regulatory settings and regulatory frameworks.\textsuperscript{15} The Australian government agreed to contribute up to $100 million per annum towards operation of GCCSI. Located in Canberra, membership includes government and industry stakeholders, researchers, and non-government organisations from around the world. GCCSI will support commercial scale CCS projects, with the aim of reducing carbon pollution.

The Offshore Petroleum and Greenhouse Gas Storage Act 2006, which came into force on 21 November 2008, provides for a system of access and property rights for the geological storage of greenhouse gas in offshore waters under Commonwealth jurisdiction. As the first step in the process of providing these access and property rights, the Minister for Resources and Energy of Australia, the Hon Martin Ferguson AM MP, announced on 27 March 2009 the release of ten offshore areas for the exploration of greenhouse gas storage areas.

In May 2009, the Government of Australia has also announced the Clean Energy Initiative (CEI) which will complement the Carbon Pollution Reduction Scheme and Renewable Energy Target, by supporting the research, development and demonstration of low-emission energy technologies, including industrial scale carbon capture and storage (CCS) and solar energy.

\textbf{Japan}

The Marine Pollution Prevention Law has been amended in accordance with the recent amendments of international treaties like The London Protocol and the OSPAR Convention, regulating the CCS offshore aspects.\textsuperscript{16} The following amendments merit to be widely evaluated as one of the best practices in the regulation of CCS projects:

1. Prohibition of the disposal of oil, hazardous liquid substances, and wastes under the seabed:
   - “No one shall dispose oil, hazardous liquid substances, and wastes under the seabed, except for CO\textsubscript{2} stream storage under the seabed with permit from Minister of the Environment” (Article 18.7);

2. Provisions for the permit for CO\textsubscript{2} stream storage under the seabed:
   - “Anyone intending to dispose CO\textsubscript{2} stream under the seabed must obtain a permit from Minister of the Environment” (Article 18.8)
   - “The Minister of the Environment shall not issue a permit for the CO\textsubscript{2} stream storage under the seabed unless it meets all conditions required such as “the storage site under the seabed and the method taken for the storage will not harm marine environmental protection at the storage site” and “there is no other appropriate disposal is available other than storage under the seabed”. (Article 18.9)
   - “A person holding a permit for CO\textsubscript{2} stream storage under the seabed must monitor status of the pollution at the storage site and report monitoring results to Minister of the Environment” (Article 18.12)

3. Designation of a registered area:
   - “The Minister of the Environment designates a CO\textsubscript{2} storage site under the seabed as a registered area, in order to prevent potential impact on marine environment from CO\textsubscript{2} leakage by altering the seabed and the sub-seabed features” (Article 18.15; details are provided by Cabinet Order);

\textsuperscript{15} http://minister.net.gov.au/TheHonMartinFergusonMP/Pages/GLOBALCARBONCAPTUREANDSTORAGEINITIATIVE.aspx.
\textsuperscript{16} Source: “CCS regulatory development in Japan”; D. Maeda; Ministry of Environment, Japan, 2008.
4. Validation

- “The Minister of the Environment has competence to order submission of a report on CO₂ storage under the seabed and conduct inspection for the purpose of implementation of the Law” (Article 48).

5. Exemption and Purity Standards

- Exemptions (Cabinet Order Article 11.4)
  - CO₂ from offshore operation
  - EOR/EGR operation

- Purity Standards (Cabinet Order Article 11.5)
  - The CO₂ stream should consist overwhelmingly of CO₂ and meet the standards set by Cabinet Order. CO₂ purity must be ≥99% (vol). It could be 98% (vol) for the stream captured from hydrogen production process at petroleum refinery.

6. Period of Permit: Re-permitting is required every 5 years [Announcement of the MOE 2-2-(1)].

Apart to this, site selection criteria and a precise monitoring plan evaluating possible leakage situations and determining the further adequate measures have also been prepared through the secondary national legislation.

Europe

The following may be noted among the discussed incentive mechanisms in EU designed to encourage the implementation of large-scale CCS demonstration projects:¹⁷

- Creating a network of flagship demonstration projects as a support action under the EU’s seventh Research Framework Programme (FP7);
- Facilitation of state aid clearance for demonstration projects;
- Commitment to address the higher operating costs (Community measures to improve “bankability” of projects).

Furthermore, based on the proposals contained in the January 2008 climate and energy package, it is possible that CCS in Europe could be linked to the EU ETS. In the framework of the SET Plan, the European Commission proposed to launch a European Industrial Initiative on CCS as a base for coordination, transparency and visibility of demonstration projects.

On 10 November 2008, the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ETP-ZEP) presented its proposal for an EU demonstration project to bring forward the large-scale deployment of carbon capture and storage (CCS) by ten years.¹⁸ The plan foresees the setting-up of a total of 10 to 12 demonstration projects, using a variety of technologies, by 2015 to “de-risk” CCS and make it commercially available by 2020. In addition, on 17 December 2008, the EU Parliament voted overwhelmingly in favour of the EU’s energy and climate change package, which includes a directive providing a legal framework for CCS technology. The legislation ensured that 300 million ETS allowances will be awarded to fund large scale CCS projects in the EU. Under the deal, the allowances would be taken from a special pool of CO₂ emission rights reserved for

¹⁷ “Providing incentives for CCS demonstration and deployment”, D. Taylor, EC.
companies entering the ETS, the so-called ‘New Entrants Reserve’. However, the level of funding available under this scheme may vary according to the level of CO\textsubscript{2} prices on the EU's nascent carbon market. Given the level of carbon prices at the time of the summit deal, it was foreseen that the agreement would secure around 6-7 billion euros for CCS demonstration projects. But a subsequent drop in carbon prices could reduce this amount to much less.

Another “working” way of enhancing CO\textsubscript{2} reduction was introduced in Norway in 1991. This is the so-called “CO\textsubscript{2} offshore tax” designed to stimulate the reduction of CO\textsubscript{2} emissions. The tax now is around 50 $/ton.

4.10. Current Issues

As illustrated by the plethora of studies and initiatives undertaken in the field of CCS across the globe, the expectations of the international community vis-à-vis the CCS technology have been on the rise. At the same time, the first CCS projects are facing rather strong head-winds, notably very high costs and low levels of public support and acceptance.

**CCS Cost and CCS Project Financing Options**

CCS projects face the challenge of substantial up-front investment costs, large not just in absolute terms, but also relative to conventional plants. On top of that, the estimated operating costs will also inevitably be higher as compared to conventional plants. The industry estimates that, between now and year 2020, up to €1 billion will be needed for CCS-related R&D.

In addition, the demonstration of the CCS technology on a large-scale basis will be costly. A newly built power plant with a CCS facility would entail incremental costs requiring an additional up-front capital in the range of €1,100-€1,700 per kW of installed capacity.\(^\text{19}\) This equates to extra €860-1,360 million for a demonstration power plant of around 800 MW compared to similar power plants without CCS.

A cost of this magnitude is not likely to be carried only by industry and would have to be supported by some public funding. For this reason, it should be clear how much money are needed and what would be the share borne by each stakeholder. However - for instance - in EU the mechanisms of such a partnership are not yet clear. Discussions are focused on the possible provision of state aid to CCS projects by the Member States and the inclusion of the CCS projects in EU ETS. Furthermore, CCS projects, or parts of them, could be identified as projects of European interest, for instance by including the CO\textsubscript{2} transport facilities in the Trans-European Energy Networks (TEN-E).

**Public Acceptance of CCS**

Public acceptance, or rather the lack of it, may be one of the greatest barriers for the development of CCS projects. *Not in my back yard* (NIMBY) attitudes are popular regarding many energy related projects in EU. The consternations are mainly rooted in ignorance and lack of reliable information, but dominate the public opinion about these projects. The majority of studies of the issue show that the negative attitude towards CCS is shared by people who are confronted with the idea for the first time.\(^\text{20}\) In a situation where more is known about the context (global warming and its causes and consequences, possible climate change mitigation options etc.) and the technology (e.g. CCS) the attitude of the public becomes more moderate, even neutral or positive.

\(^{19}\) “Providing incentives for CCS demonstration and deployment”, D. Taylor, EC.

\(^{20}\) “Carbon dioxide capture and storage: public perception, policy and regulatory issues in the Nederlands” H. Coninck and N. Huijts.
4.11. Outlook

Above listed uncertainties require to create a knowledge base upon which a comprehensive GS regulatory framework can be built. A number of projects are being executed around the world but a need for a large scale comprehensive programme is required to generate answers to barriers hindering development of an appropriate regulation for CCS market. In this regard a European “Flagship Programme” of CCS demonstration plants that is being discussed will help to bridge the uncertainty gap.

GS regulation will need to evolve as scientific and technical knowledge expands. An evolutionary regulatory process is needed because full-scale GS projects are urgently needed (and must be regulated), but key uncertainties prevent design of a comprehensive regulatory framework at this time. The first stage, essentially underway, will consist of several dozen full-scale GS projects worldwide, operated under existing regulations modified to account for specific features of GS. At this demonstration project stage, we should not lock in rigid regulatory instruments that cannot be adapted to incorporate new knowledge. The second stage will use data and experience from these early projects to design and update general GS regulations to cover widespread commercial deployment. The transition from early to mature regulatory framework could be accomplished through continuous improvement within existing regulatory bodies, but might require creation of institutional mechanisms to coordinate and integrate emerging knowledge and establish the long-term regulatory and legal framework.
5. Role of the ECT in CCS

5.1. Geographic Coverage of the ECT

The ECT could be one of the most useful legal cross-border instruments in CCS deployment because of its broad geographic coverage and well-articulated provisions. To date, the total number of members of the ECT is 53 (51 states, the European Community and Euratom), and there are over 30 observers (10 of which are international organisations with observer status). While countries like the US, Canada and China are only observers to the ECT and thus not legally bound by the Treaty provisions, the EU member states, the Russian Federation and many of the neighbouring countries are members.

![Figure 4 The Energy Charter Constituency (as of May 2009)](http://www.encharter.org/index.php?id=61)

According to its Article 2, the ECT aims to establish a legal framework in order to promote long-term cooperation in the energy field, based on complementarities and mutual benefits, in accordance with the objectives and principles of the Energy Charter. The basic elements of the ECT include promotion and protection of foreign direct investment, trade in energy, freedom of energy transit, improvement of energy efficiency, and a dispute settlement mechanism. While the ECT covers all energy sub-sectors (oil, gas, coal, electricity), this chapter focuses on the role of the Treaty in relation to CCS.

5.2. Regulation of CCS under the ECT

In order to identify scope of legal regulation of the ECT in relation to CCS, an evaluation is required within the context of “Economic Activity in the Energy Sector”, which is defined by Article 1(5) as follows:

(5) “Economic Activity in the Energy Sector” means an economic activity concerning the exploration, extraction, refining, production, storage, land transport, transmission, distribution, trade, marketing, or sale of Energy Materials and Products except those included in Annex N, or concerning the distribution of heat to multiple premises.”

---

21 Countries marked in green are signatories to the Energy Charter Treaty, and members of the Energy Charter Conference. Countries marked in blue are observers (blue vertical stripes denote the countries of ASEAN).
This definition is in turn based on the defined term “Energy Materials and Products”, defined at Article 1(4):

(4) “Energy Materials and Products”, based on the Harmonised System of the Customs Cooperation Council and the Combined Nomenclature of the European Communities, means the items included in Annex EM.

Annex EM contains, under the category “Coal, Natural Gas, Petroleum and Petroleum Products, Electrical Energy”, the following items:

27.05 Coal gas, water gas, producer gas and similar gases, other than petroleum gases and other gaseous hydrocarbons.

In order to have more clarity on listed gases a review of definitions (source is Sci-Tech Encyclopedia) is given in Annex D. The review shows that above listed gases such as coal gas, water gas, producer gas are all combustible gases while CO₂ is not a combustible gas.

“27.11 Liquified petroleum gases and other gaseous hydrocarbons
- natural gas
- propane
- butanes
- ethylene, propylene, butylene and butadiene (27.11.14)
- other

In gaseous state:
- natural gas
- other”

With high degree of probability a conclusion can be drawn from the above that CO₂ gas is not covered by Annex EM. Nevertheless, it is also relevant to refer to Understanding 2 with respect to Article 1(5). This provides:

(a) It is understood that the Treaty confers no rights to engage in economic activities other than Economic Activity in the Energy Sector.

(b) The following activities are illustrative of Economic Activity in the Energy Sector:
- (ii) construction and operation of power generation facilities, including those powered by wind and other renewable energy sources;
- (iv) removal and disposal of wastes from energy related facilities such as power stations, including radioactive wastes from nuclear power stations;

Understanding (b) (ii) and (iv) allows of the interpretation that CCS can be attributed to Economic Activity in the Energy Sector as an integral part of power generation facilities and as a removal of waste from energy related facilities.

In addition, under the Art. 19 (1) and (3), it may be argued that CO₂ storage is a part of the entire energy production chain, which means that it could be understood not as simple disposal of carbon dioxide but rather as part of an industrial process, which de facto is the production of energy in a clean and sustainable way.
Art. 19 (1) of the ECT further stipulates that,

“In pursuit of sustainable development and taking into account its obligations under those international agreements concerning the environment to which it is party, each Contracting Party shall strive to minimise in an economically efficient manner harmful Environmental Impacts occurring either within or outside its Area from all operations within the Energy Cycle in its Area, taking proper account of safety...”

Also, Art. 19 (3) (a) clearly explains that the

“Energy Cycle – means the entire energy chain, including activities related to prospecting for, exploration, production, conversion, storage, transport, distribution and consumption of the various forms of energy, and the treatment and disposal of wastes, as well as the decommissioning, cessation or closure of these activities, minimising harmful Environmental Impacts.”

The important argument is that the CO₂ storage is part of the entire “energy cycle” which is regulated under the ECT, especially regarding the minimisation of harmful environmental impacts stemming from energy related activities. This would imply the application to CCS-related activities of Art. 19 under Part IV.

It is clear that the ECT was conceived without taking into account CCS as a possible climate change mitigation option. Review of definitions and relevant articles of the ECT does not allow a clear consensus whether CO₂ should be classified as a simple waste or as an industrial commodity. With a high degree of probability it can be stated that CO₂ does not fall under category of “Energy Materials and Products”. Therefore, Art. 7 on transit, which specifically refers to “Energy Material and Products”, seems clearly not to be applicable to CCS.

5.3. Investment

According to Article 1(6), ““Investment” means every kind of asset, owned or controlled directly or indirectly by an investor”.

The ECT thus contains a broad, non-exhaustive, asset-based definition of an “investment”. It covers, inter alia, greenfield investments, acquisitions and mergers. It appears that these would be the standard forms in which investments in CCS infrastructure are made.

Since the Treaty is a sectoral agreement, only such investments are covered that relate to an economic activity in the energy sector. It is discussed above that the Understandings to Article 1 (5) of the ECT and Art. 19 (3) (a) allow us to define CCS as an integral activities of energy cycle and relevance to definition of “economic activities” CO₂ capture equipment, its transportation by pipelines and storage facilities fall within the scope of this provision. Possible future pipelines across the ECT member countries could likewise be covered.

Under normal circumstances, the owner of a power plant with CO₂ capture facilities, transportation pipelines and storage facilities will likewise be the operator of all this system. One could, however, also imagine that ownership and operation or management are separated between several companies. In this case, one could question whether the operator of the certain part of CCS infrastructure could be considered as an “investor”. According to the ECT, it is sufficient to effectively control the investment in order to qualify as an investor. It therefore seems that the operator is protected under the ECT if he exercises control over any facility, including the assumption of entrepreneurial risks in connection with the project.
Another important treaty provision under investment promotion and protection is about exchange of
information. Article 10 (8): “The modalities of application of paragraph (7) in relation to
programmes under which a Contracting Party provides grants or other financial assistance, or enters
into contracts, for energy technology research and development, shall be reserved for the
supplementary treaty described in paragraph (4). Each Contracting Party shall through the
Secretariat keep the Charter Conference informed of the modalities it applies to the programmes
described in this paragraph.”

The Article 10 (8) serves an important function to ensure timely exchange of information among
treaty members. A reference can be made to a recent decision of EU leaders that agreed to provide
300 million allowances from the EU’s emissions trading scheme to subsidise the construction of the
10-12 demonstration plants with CCS technologies. Under the deal, the allowances would be taken
from a special pool of CO₂ emission rights reserved for companies entering the ETS, the so-called
'New Entrants Reserve'. Given the level of carbon prices at the time of the summit deal, it was
foreseen that the agreement would secure around 6-7 billion euros for CCS demonstration projects.
Taking into amount a large size of this EU CCS energy technology development programme the
Charter Conference shall be informed about modalities of the programme.

5.4. The Principle of Non-Discrimination

Pursuant to Article 10 (7), “each Contracting Party shall accord to Investments in its Area of
Investors of other Contracting Parties, and their related activities including management,
maintenance, use, enjoyment or disposal, treatment no less favourable than that which it accords to
Investments of its own Investors or any other Contracting Party or any third state”.

Protection against discrimination is one of the most important components in creating a favourable
investment climate. The legally binding obligation to grant non-discriminatory treatment (which
includes national treatment and most-favoured nation treatment) applies once an investment has
been made (so-called “post-investment phase”). Foreign owners of power plants with CCS
infrastructure are therefore protected against the risk they could face in that they may have to
operate under more burdensome legal conditions than their domestic counterparts, provided that
they are in like circumstances. This includes, for instance, non-discriminatory treatment with regard
to certain performance requirements, if those are not already prohibited otherwise.

5.5. Individual Investment Contracts

According to Article 10(1), last sentence, “each Contracting Party shall observe any obligations it
has entered into with an Investor or an Investment of an Investor of any other Contracting Party”.

This provision, nicknamed the “umbrella clause”, enshrines the principle of “pacta sund servanda”,
as applied between investor and state. Respect for this standard is of particular relevance in the
energy sector where most major investments are made on the basis of an individual contract
between the investor and the state. This includes the construction of power plants, pipelines and
storage facilities for CO₂.

Article 10(1), last sentence, has arguably the important effect that a breach of an individual
investment contract by the host country becomes a violation of the ECT. As a result, the foreign
investor or his home country has the right to sue the host country before an international arbitration
tribunal. Thus, if the host country contractually guarantees to the foreign owner of a CCS
infrastructure that he can run the facility for a certain period, a premature termination of the licence
or concession by the host country would be illegal under the ECT. This is a very important aspect
taking into account that regulatory framework for CCS is evolving thus creating a high risks on
investments associated with CCS projects. Nevertheless, even without a contractual obligation in
favour of investors, a mere license unilaterally granted by the host (member) states to investors may well suffice to enable allegations to be taken before international arbitral tribunals under the ECT.

5.6. Expropriation

Pursuant to Art. 13(1), “Investments of Investors of a Contracting Party in the Area of any other Contracting Party shall not be nationalised, expropriated or subjected to a measure or measures having effect equivalent to nationalisation or expropriation except where such expropriation is for a purpose which is in the public interest, not discriminatory, carried out under due process of law, and accompanied by the payment of prompt, adequate and effective compensation”.

Protection of foreign investors in case of an expropriation is a core element of international investment agreements. The ECT protects foreign owners of CCS infrastructure against formal expropriations. With regard to CCS infrastructure, one example would be the host country adopting new legislation imposing excessively onerous burdens on companies dealing in CCS-related activities. These new regulations may lead to bankruptcy, possibly allowing the finding of a disguised expropriation.

5.7. Dispute Settlement

The ECT contains a full-fledged system of international dispute resolution, comprising investor-to-state arbitration (Article 26), and state-to-state arbitration (Article 27). Foreign owners of CCS infrastructure therefore have the right to sue their host country before an international arbitration tribunal in case of an alleged violation of the latter’s obligations under the Treaty.

The ECT does not establish its own investment tribunal. With regard to investor-state arbitration, the Treaty refers to already existing international fora or procedures, such as the International Centre for the Settlement of Investment Disputes (“ICSID”), the Rules of the Arbitration Institute of the Stockholm Chamber of Commerce, or the UNCITRAL arbitration rules. As far as state-to-state arbitration is concerned, the Treaty provides for *ad hoc* procedures, which should, in principle, be held at the International Court of Justice in The Hague. This is an important provision because there is lack of comprehensive international legislation covering the CCS market. National legislations on CCS are also different among ECT member countries.

5.8. Transfer of Technology

CCS technology could, in a legal and reliable manner, be transferred from a Contracting Party to another under the provisions of Art. 8(1) of the Energy Charter Treaty, which stipulates “(…) Contracting Parties agree to promote access to and transfer of energy technology on a commercial and non-discriminatory basis to assist effective trade in Energy Materials and Products and Investment and to implement the objectives of the Charter subject to their laws and regulations, and to the protection of Intellectual Property rights.” Such a legal basis would without doubt make the commercial uptake of CCS technology faster and easier compared to prevailing regional approaches, as the current practice shows.

5.9. An Analytical Look at the CO₂ under the ECT

As it currently stands, the ECT provides no specific definition of CCS. Furthermore, the *travaux préparatoires* contain no reference to CCS or the place carbon capture might hold within the energy cycle. Therefore, a detailed analysis is required in order to see how the ECT bears on the issue of CCS. The ECT does not clearly stipulate whether CO₂ is to be taken as “waste” or “energy material”, yet a discussion thereby would help determine if the CCS would be covered by the investment or trade and transit related provisions of the ECT.
Regardless of the question whether CO₂ is to be classified as a waste or a product, it can be underlined that the ECT refers to the “waste” in its “Preamble” such that the Treaty “… recognises the increasingly urgent need for measures to protect the environment… including… waste disposal.”

Another reference to the issue of CO₂ might be drawn from the Treaty’s first regular review conclusions adopted by the Energy Charter Conference at its 15th meeting on 14 December 2004, whereby the member states underline the “common objectives to strengthen international energy cooperation, to enhance security of energy supply and access to energy markets, to maximise the efficiency production and consumption, and to minimise their environmental impact.”

Putting all these determinations aside, we may dwell upon the substantive issues hereunder. Firstly, to identify which project phases of CCS process are covered by the ECT, there needs to be a careful evaluation of the definition of “Economic Activity in the Energy Sector”, which arguably includes CCS-related activities (see definition in the preceding section). This definition has a reference to the defined term “Energy Materials and Products” (Art. 1(4)) which does not cite CO₂ among the exhaustive list of items enumerated in Annex EM.

Therefore, with high degree of probability a conclusion can be driven that CO₂ gas is not listed in the Annex EM. Thus, it may be deduced that CO₂ is not covered under the definition of “Energy Materials and Products”. This may easily lead to the understanding that CO₂ would not be covered under the provisions of the ECT regulating the transit of Energy Products and Materials.

Nevertheless, it is also relevant to refer to Understanding 2 with respect to Article 1(5), which refers to “removal and disposal of wastes from energy related facilities such as power stations, including radioactive wastes from nuclear power stations” (see wider reference to the text of this Art. in the preceding section). Therefore, from the foregoing, it is arguable that CO₂ might be considered as within the sphere of “economic activities in the energy sector”.

It should be noted that the enumerated activities are merely meant as “illustrative of Economic Activity in the Energy Sector”, thus part of a non-exhaustive list. An argument might be able to be made that, in light of the ECT’s objectives, CCS-related activities should be categorised as “Economic Activity in the Energy Sector”, regardless of whether it is classified to be within the context of “removal or disposal of waste” activities. The interpretation given at this level to CCS activities would notably have as a consequence the application of investment protection provisions to CCS-related investments, since the application of ECT Part III is contingent on the finding of an investment related to an “Economic Activity in the Energy Sector” (Art. 1(6)(f). Furthermore, the objective of “long-term cooperation in the energy field” is best promoted by attributing the widest possible coverage to the ECT investment protection provisions. Indeed, arbitral tribunals’ approach has also embraced this view, as evidenced by an arbitral tribunal in the Petrobart v Kyrgyzstan case.

Should CCS activities be covered under the Investment related provisions of the ECT, this would support the argument that ECT Art. 8 about transfer of technology would also be applicable to the CCS, since this article regulates issues also relating to Investment.

Under the Art. 19(1) and (3), it may be argued that CO₂ storage is a part of the entire energy production chain, which means that it could be understood not as simple disposal of CO₂ but rather as part of an industrial process, which de facto is the production of energy in a clean and sustainable way.

Art. 19 (1) of the ECT stipulates that:

“In pursuit of sustainable development and taking into account its obligations under those international agreements concerning the environment to which it is party, each Contracting Party shall strive to minimise in an economically efficient manner harmful
Environmental Impacts occurring either within or outside its Area from all operations within the Energy Cycle in its Area, taking proper account of safety…”

In addition, a definition in Art. 19 (3) (a) clearly explains that the

“Energy Cycle – means the entire energy chain, including activities related to prospecting for, exploration, production, conversion, storage, transport, distribution and consumption of the various forms of energy, and the treatment and disposal of wastes, as well as the decommissioning, cessation or closure of these activities, minimising harmful Environmental Impacts.”

These provisions cover the two important aspects of the legal treatment of CCS and especially the difficult issue of defining CO2. Under the given articles, it is difficult to define what is CO2, a waste or an industrial commodity? The important argument is that the CO2 storage is part of the entire “energy cycle” which is regulated under the ECT, especially regarding the minimisation of harmful environmental impacts stemming from energy related activities. It should also be remembered hereunder that this is a “soft-law” obligation under the ECT, and therefore the legally binding nature of it is arguably rather questionable.

Another parallel way of thinking may be drawn vis-à-vis the LNG activities. According to a study by the Secretariat,22 LNG liquefaction and re-gasification facilities are to be within the coverage of the Charter provisions. Although the shipping part of the LNG is outside the boundary of the ECT since maritime trade is not covered, other parts of the LNG chain might be subject to ECT. However, LNG would be subjected to the trade provisions of the ECT only if LNG would fall under the “Energy Materials and Products” definition. Under normal circumstances, LNG falls under this definition, since natural gas and liquefied gas are mentioned by name in Annex EM of the Treaty. This is in line with the constructing hypothesis that these materials would be used as an energy source material or product.

As regards the term “product” or “produce”, an interesting analysis has been done in the LNG study of the Secretariat. It refers to the issue of LNG production and whether liquefaction is covered by the term ‘production’ or not. It is suggested in the said paper that the term “product” should not be taken with its regular energy-industry-specific meaning (which might exclude conversion of natural gas into LNG and vice versa) but a more general meaning (which would a priori appear to include these processes).

What if, then, the LNG is used for chemical purposes, such as in fertiliser plants? Would such a use be covered under the general spirit of the ECT? How should ECT provisions be understood in terms of taking a product as within the energy cycle, towards a prospective use of it in the energy form, or towards a backward look at the cycle in promoting the production of energy? And where should we draw the line in successive chain of activities?

As regards with energy trade provisions, the amended trade regime24 of the ECT has been extended to cover more than 70 categories of items of energy related equipment, such as tubes and pipes, etc., which would normally not be under the coverage of the investment provisions of the ECT regarding the production of those items mentioned in the list. Therefore, so long as materials are used within the energy cycle, they are covered under the trade provisions, though not covered under the transit related

---

23 Ibid., p. 96.
24 This amendment is still not on its face in force, awaiting further ratification by one more signatory to the amendment, yet it is still applicable since it envisages the provisional application of the amendment except for those signatories who made a declaration that they would not be applying the amendment provisionally.
provisions of the Treaty as they fall outside the scope of the list of items under Annex EM. Would the CO₂ be covered under the same analogy since it also relates to the energy cycle not in terms of leading to energy production or transportation & trade, but in allowing further energy production at the beginning of the phase of this cycle? These questions obviously merit further discussions.

The answers to the questions raised above might have some implications regarding CCS-related activities. Given the high probability of CO₂ being classified as waste but not as an energy product especially when CO₂ is not used for EOR, it would much less likely to be covered under the trade and transit provisions of the ECT. If LNG would be not used as an energy material but for different purposes, would it then be on the similar stance compared to the CO₂? Also, what if the re-gasification plants are of dual use, i.e. some gas used for a nearby fertiliser plant and some for use in a power plant?

One further probable way of thinking goes as follows: If CO₂ were to be covered under the trade and transit provisions of the ECT with an understanding that the downstream part (i.e. the CO₂) of the whole cycle in the coal-fired power plant electricity production business would promote the “upstream part”, i.e. the realisation of power plants, and thus would arguably be in line with the promotion and protection of energy investments and energy security, etc., or in sum, with the overall spirit of the ECT. Similar to the dual use of the LNG mentioned above, what if the CO₂ is partly used for OER and partly as storage? Any authoritative statement on the possibility of such a reasoning to be employed, however, similarly as with the other provisions of the ECT, would be subject to the interpretations by prospective cases that might come up before arbitral tribunals in the future.

Furthermore, one may also come up with the following argument. Transit provisions of the ECT apply only to Energy Products and Materials as listed in Annex EM of the Treaty, which clearly involves natural gas and excludes CO₂. By this regulation, it may be induced that the intention for allowing certain coverage under the ECT as regards with the transit was only intended to cover the energy products and materials but not any other energy related equipment or product. This may inevitably lead to the hypothesis that, transportation in a grid of gas or other energy materials would be subject to the transit regime of the Treaty regardless of the use of such product at the other end of the network, such as transportation of natural gas through a pipeline would be under the coverage of the transit provisions albeit the use of such gas might have well been exclusively devoted for a non-energy related purpose such as producing fertilisers. On the other hand, the same transportation grid to be used for CO₂ would not be covered under the transit provisions with a possible understanding that it is not an energy material or product, though it may be used for OER purposes and therefore helps towards producing an energy material. There seems to be a clear contradiction in this picture.

Let us assume that in the above-scenario the pipeline transportation of CO₂ would not be used towards EOR purposes but simply as underground storage. Even in this case, one idea might be well placed that the CO₂ storage would further facilitate energy production by enabling more coal-fired thermal power plants which would otherwise not be in place due to environmental concerns. The argument may continue, therefore, that it is to the benefit of the overarching aim of the ECT to ensure that CO₂ transportation would be better taken under the coverage of the facilitating provisions of the transit regime of the ECT. Yet in the light of the clear wording of the transit related provisions of the ECT, there seems to be no ground to endorse or embrace such a hypothetical reasoning.

5.10. The ECT in Relation to Other International Treaties

From a legal point of view, there seems to be no incompatibility between the ECT and other international treaties in regulating various parts of CCS projects. In this respect, the ECT could be a useful legal instrument for the regulation of some aspects of cross-border CCS projects, especially in cases where not all the parties participate in regional unions. In addition, taking into account
customary international law, and in particular the rule of *lex specialis* establishing the principle that more specific provisions will supersede general ones, it is probable that reaching a clearer understanding regarding the position of the ECT on CCS projects would be advantageous.

Another important issue is the hierarchy of different treaties regulating various aspects of CCS. An opinion has been voiced that – although the Charter of the United Nations is often referred to as the constitution of the international community – there is no hierarchy between different international treaties. Conflicts amongst different treaty regimes may be addressed in the treaties themselves but can be subject to often contentious questions of application and interpretation.\(^{25}\)

Furthermore, there is one international treaty regulating certain relationships among the treaties themselves, the Vienna Convention on the Law of Treaties (VCLT), which provides for certain rules, principles and interpretations regarding international treaties. For example, Art. 30 stipulates that the latter treaty provisions conflicting with the earlier one shall prevail, unless the latter treaty provisions specify to the contrary. Another important provision of the VCLT is Art. 53 which states that a peremptory norm of international law ("*jus cogens*") would at any time invalidate any existing treaty provisions, including any *jus cogens* emerging in the future (Art. 64).

In line with the international customary law and the VCLT (which indeed is viewed as a codification of international customary law),\(^{26}\) and as well as in accordance with various domestic jurisdictions, the generally accepted practice related to international treaties is based on the presumption that in cases “where obligations are inconsistent, later treaties will supersede earlier ones …” and “… *lex specialis* where provisions on specific subject will supersede general ones.”\(^{27}\)

So far, we have not been able to identify any incompatibility of application between the ECT and the other international treaties regulating the CCS. Besides, the ECT is a flexible tool covering both the offshore and the onshore. In this sense, the Energy Charter Treaty could be called upon to play an important role regarding CCS-related activities.

---

\(^{25}\) “Marine protected areas on the high seas?”; FIELD, 2008.


6. CCS in the Energy Charter Geographic Coverage: Case Studies

While the number of different CCS projects in the world increases constantly, it is evident that the pace will not allow CCS to become a real climate change mitigation option within the next 10 years. It is obvious that the existing legal, regulatory and financial barriers are among the main burdens hindering the uptake of CCS technology. Nevertheless, some large-scale28 (more than 1 Mt of CO2 stored per year) projects are operating today, mainly as part of enhanced resource recovery projects. Figure 5 below illustrates the locations of CCS projects. As can be seen, some of the major CCS projects are in the ECT area and could be regarded as “case study projects”. Among them are the Sleipner project (Norway), the Gorgon project (Australia), the Nagaoka project (Japan) (note that Norway and Australia have signed the ECT, yet neither ratified it nor apply the Treaty provisionally).

6.1. Sleipner Project29

In 1990 the Statoil-operated gas/condensate field Sleipner Vest in the North Sea was in its planning phase. The natural gas at Sleipner contains naturally around 9% CO2. This was too much with respect to the customer requirements. The CO2 needed to be removed first.

In 1991 the Norwegian authorities introduced a CO2 offshore tax with the aim of reducing CO2 emissions. At the moment this tax is around 50 USD/tonne. Motivated by this tax, Statoil proposed to remove the CO2 offshore and inject it into a deep geological layer below the Sleipner platform and above the producing reservoir (the outlay of the project is illustrated in Figure 6).

In this geological layer the CO2 will be stored for a long time, probably thousands of years. This layer contains porous sand rock filled with salt water, and is called the Utsira formation.

Figure 5 Major Current and Planned CCS Projects

Source: IPCC

---

28 This evaluation is based on today’s standards – in future the threshold will be higher for sure.

29 Source: Statoil Hydro.
The CO₂ is prevented from seeping into the atmosphere by an 800 meter thick gastight cap rock above this layer. The Sleipner license partners supported this idea. Its implementation meant a reduction in CO₂ emissions of nearly one million tonnes per year, which was roughly 3% of the Norwegian CO₂ emissions in 1990.

The field became operative in October 1996. This meant that the world’s first offshore CO₂ capture plant was running, together with the world’s first CO₂ storage project in a geological layer 1,000 meters below the sea floor.

CO₂ capture is done at Sleipner with a conventional amine process. The extra equipment cost for the CO₂ compression and the drilling of the CO₂ injection well was roughly 100 million USD.

Until now 8 million tonnes of CO₂ have been stored from around 20 million tonnes planned. The spreading of the CO₂ underground has been mapped in various research projects, which were partly financed by the European Union (EU).

6.2. Gorgon Project

The Gorgon Project plans to develop the Greater Gorgon gas fields, located between 130 km and 200 km off the north-west coast of Western Australia. The Greater Gorgon gas fields contain resources of about 40 trillion cubic feet of gas, Australia's largest-known gas resource. One of the substantial parts of the whole project is related to greenhouse gas management via injection of carbon dioxide into deep formations beneath Barrow Island (see Figure 7).

The Gorgon project is expected to be the first project in Australia permitting to significantly reduce emissions by the underground injection of carbon dioxide, because project emissions are expected to be reduced by approximately 40%. Like the other CCS projects, this one is also expensive and evidence for this is the fact that more than $100 million are spent on investigation and development to date. However, per tonne costs remain less expensive that alternate abatement options.

An extremely important feature of the Gorgon project is that especially for the purposes of this project is elaborated the first geo-sequestration legislation – “The Barrow Island Act 2003”, which allows the re-injection of CO2 into the saline aquifer on Barrow Island. Furthermore, according to previsions, this will be also the first project to undergo detailed environmental impact assessment (including public review and comment). The start of injection of CO2 is planned for year 2011 and thus the Gorgon project would become the largest-scale CCS project in the world with expected injection rate of 10,000 tons of CO2 per day or approximately 2.7 million tons per year over 40 years.31

6.3. Nagaoka Project32

The purpose of the Nagaoka CCS project was to inject CO2 into an aquifer at the Minami-Nagaoka gas field in Japan and to collect data on CO2 behaviour during and after the injection. The selected reservoir is a predominantly sandstone area with a thickness of approximately 60 m at a depth of about 1,100 m (see Figure 8).

Injection began on July 7th, 2003 at a rate of 20 t/day during 2003 and 40 t/day during 2004. Injection was completed in January 2005 with the final cumulative injection totaling 10,405 tons, without experiencing any serious problems. Furthermore, there was no registered CO2 leakage caused by the Niigata Chuetsu earthquake.

Various kinds of monitoring technology were applied for identifying CO2 migration and distribution and long-term CO2 behaviour in 1,000 years was clarified with the help of a newly developed simulator based on the observation results.

32 Source: Research Institute of Innovative technology for the Earth.
The achievements of the projects are:

1. The feasibility of CO₂ geological storage was demonstrated via the successful injection of CO₂ into the aquifer which has a relatively low permeability;

2. The understanding of CO₂ geological storage was significantly advanced by the surveys and tests designed for ascertaining reservoir behaviour, as well as by the monitoring and simulation study during and after CO₂ injection;

3. The applicability of existing field technologies such as natural resources engineering was demonstrated through a range of processes including drilling of wells, design and construction of an injection facility, injection, monitoring, and simulation studies.

**Figure 8 The Nagaoka Project**

*Source: RITE*
7. Main International Legal Documents Regulating CCS

Where CO₂ storage occurs completely within territorial land and waters, national and sub national laws apply. However, if project activities take place offshore in international waters, a variety of international marine environment protection instruments may apply, as there are potential risks to the marine environment associated with CO₂ leakage during CO₂ injection and long-term storage. To address issues related to offshore CO₂ storage, Contracting Parties to international marine environment protection instruments have proactively worked to develop appropriate amendments to the London Protocol and the OSPAR Convention to allow for regulation of sub-seabed CO₂ storage. In this respect, in June 2007 the contracting parties amended the OSPAR Convention by adopting amendments to the Annexes to allow the storage of CO₂ in geological formations under the seabed. The parties have also undertaken to develop guidance on transport and storage of CO₂ and also in relation to monitoring of storage sites.³³

Current international conventions that have implications for CCS include: the United Nations Convention on the Law of the Seas (UNCLOS), the London Convention, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the London Protocol, the UN Framework Convention on Climate Change (UNFCCC), and the Kyoto Protocol. Together, these conventions set some existing limits on how CCS might be regulated in the absence of an independent regulatory framework. The London Protocol (being a revision of the London Convention) has a broader scope and extends to the storage of wastes in the subsoil. Regulation under this Convention could be circumvented only if CO₂ were not classified as an industrial waste but instead as some other form of non-hazardous discharge (if classified as a “hazardous waste”, however, then the application of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal would need to be considered).³⁴ Nonetheless, there is no indication that CO₂ will be defined as a hazardous waste under the Convention except in relation to the presence of impurities such as heavy metals and some organic compounds that may be entrained during the capture of CO₂, and accordingly this Convention does not appear to directly impose any restriction on the transportation of CO₂.³⁵ Similarly, the UNFCCC and the Kyoto Protocol have implications for nearly all storage projects with links to CO₂ markets or emissions trading programmes, as there will have to be international agreements on how to credit CO₂ arising from CCS.

7.1. Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)

The OSPAR Convention was concluded in 1992 (entered into force in 1998) by 15 Northern European States and the European Community. Coverage is illustrated in Figure 9.

The Convention is a regional agreement and it applies to the waters of the Contracting Parties in the geographical maritime area around the North Sea and parts of the Atlantic and Artic oceans.³⁶ Initially CO₂ storage in maritime area seems not to have been covered directly by the Convention. However, the Convention allows or prohibits certain activities depending on the source of the material (land-based, from a vessel, or from offshore activities) and the nature of the placement (scientific experiment, facilitating oil or gas production, or other mere disposal, which includes placement for the purpose of mitigating the climate change).³⁷ There is no distinction between storage in the water column (ocean storage) and off-shore geological storage.

---

³³ Newberry, op. cit., p. 158.
³⁴ Ibid., p. 156.
In view of the need for decisive action towards reducing the negative effects of climate change, the OSPAR Commission adopted in 2007 amendments to the Annexes to the Convention to allow the storage of carbon dioxide in geological formations under the seabed. The Commission has also adopted a Decision to legally rule out placement of CO₂ into the water column of the sea and on the seabed, because of the potential negative effects.38


The London Convention framework consists of the London Convention and the London Protocol and aims to protect the marine environment from human activities. The London Convention was concluded in 1972 and entered into force in 1975. The London Protocol was signed in 1996 and entered into force in 2006 with the purpose to modernise (or eventually replace) the London Convention).39 The contracting parties ratified the London Convention are 81, but those ratified the London Protocol are only 29. Figure 10 illustrates the coverage of the instruments.

Under the London Protocol provisions, the dumping of any wastes is prohibited except of that being mentioned in a special “reverse” list. The CO₂ is not explicitly included in that list but nevertheless falls within the scope of the agreement because the Protocol applies to the introduction in the marine environment of wastes or other matter.40

However, the storage of carbon dioxide under the seabed is allowed now under the London Protocol as of 10 February 2007. The contracting parties adopted amendments in Annex 1, listing the allowed substances for dumping and added as point (8) to the list “CO₂ streams from CO₂ capture

---

40 Ibid.
processes”. The parties also agreed that guidance on the means by which sub-seabed geological sequestration of carbon dioxide can be conducted should be developed as soon as possible.\footnote{IMO press release, 2007.}

**Figure 10 Geographic Coverage of the London Convention**

![Image](image10.png)

*Source: Wikipedia*

### 7.3. The United Nations Convention on the Law of the Sea (UNCLOS)

The United Nations Convention on the Law of the Sea (UNCLOS), also called the Law of the Sea Convention or the Law of the Sea Treaty, is the international agreement that resulted from the third United Nations Conference on the Law of the Sea (UNCLOS III), which took place from 1973 through 1982. The Law of the Sea Convention defines the rights and responsibilities of nations in their use of the world’s oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources.

While UNCLOS does not explicitly regulate nor prohibit CO$_2$ storage, it does require States to prevent, reduce and control pollution of the marine environment and to protect and preserve the marine environment from human activities that might adversely affect it.

**Figure 11 Geographic Coverage of UNCLOS**

![Image](image11.png)

*Dark green – ratified; light green – signed, but not yet ratified; grey – did not sign*

*Source: Wikipedia*
7.4. UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol

The United Nations Framework Convention on Climate Change (UNFCCC or FCCC) is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro from 3 to 14 June 1992. The treaty is aimed at stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The treaty as originally framed set no mandatory limits on greenhouse gas emissions for individual nations and contained no enforcement provisions; it is therefore considered legally non-binding. Rather, the treaty included provisions for updates (called “protocols”) that would set mandatory emission limits. The principal update is the Kyoto Protocol, which has become much better known than the UNFCCC itself.

Figure 12 Geographic Coverage of UNFCCC

Green – UNFCCC Member; peach – UNFCCC Observer; grey – not party to UNFCCC

7.5. EU Directive on Geological Storage

Directive 2009/31/EC of the European parliament and of the Council of 23 April 2009 applies to the geological storage of CO₂ within the territory of the Member States, in their exclusive economic zones and on their continental shelves. The Directive does not apply to projects with a total intended storage below 100 kilotons, undertaken for research, development or testing of new products and processes. The directive states that the storage of CO₂ in storage complexes extending beyond the territorial scope of this Directive and the storage of CO₂ in the water column should not be permitted. The adoption of this Directive was aimed at ensuring a high level of protection of the environment and human health from the risks posed by the geological storage of CO₂.

The adopted directive covered following aspects of CCS: selection of storage site, system of permits, monitoring, closure obligations, and transfer of responsibility, financing mechanisms, third party access, cross-border cooperation and dispute settlement. The coverage of the proposed instrument is illustrated by Figure 13.

Chapter 7 of the Directives 2009/31/EC introduced a number of amendments to previously issued directives dealing with CCS. Among them is amendment of Directive 85/337/EEC allows pipelines with a diameter of more than 800 mm and a length of more than 40 km for the transport of gas, oil,
chemicals, and, for the transport of carbon dioxide (CO₂) streams for the purposes of geological storage, including associated booster stations. Amendment of Directive 2000/60/EC allows injection of carbon dioxide streams for storage purposes into geological formations which for natural reasons are permanently unsuitable for other purposes.

**Figure 13 Geographic Coverage of the European Economic Area (EEA)**

*Source: Answers.com*
8. Conclusions and Recommendations

- Carbon capture and storage is not a panacea but is a promising option for the mitigation of climate change over the next few decades. However, the price of the “CCS choice” expressed in higher costs and lower efficiency compared to other options could be a heavy burden to carry. Therefore, there is a strong need for continued support provided by bilateral and multilateral institutions to development partners.

- The timing of CCS technology deployment is of a paramount importance. It would be a challenge to keep CO2 emissions from growing to at least the year 2030. To achieve the desired climate goals, a stable decreasing trend should be maintained thereafter. Taking into account the different climate change mitigation options, large-scale deployment of CCS should begin to take place within the next 10-12 years. The deployment would be possible only if the demonstration phase of CCS begins now, so that the full commercialisation of the technology could occur around 2020.

- The most important point regarding international conventions is that large-scale CCS will require some type of international oversight or, at the very least, multilateral regulations. Where these issues become most complex is when regulations (amended or new) require approval and ratification from a specified majority of parties and then apply only to parties that have ratified any proposed changes. Given these constraints on establishing uniform standards, ensuring widespread regulatory acceptance will likely involve a combination of amending existing regulations and implementing new standards.

- The ECT is an existing, widely accepted legally binding instrument which could promote investment in CCS projects. The ECT could be a useful tool for the regulation of some aspects of CCS projects, in particular ensuring investment protection and reducing to a minimum the non-commercial risks associated with CCS sector investments. The ECT could help to transfer CCS technology and experience gained so far in some projects. The technology transfer should be accomplished on a commercial basis in compliance to the best technological practices and the broadly accepted legal provisions related to intellectual property rights.

- Taking into account the existing technology, the recent amendments to international legislation relevant to CCS, and the degree of public acceptance of CCS, the most advanced and viable permanent storage of CO2 seems to be its injection into suitable geological formations, particularly depleted oil and gas fields and saline aquifers.

- The construction of CO2 “highway” pipeline systems (similar to these in the USA and Canada) in other parts of the world needs to be endorsed by an appropriate legislative and regulatory framework. The experience of the petroleum industry could be an important element in the CCS deployment process. Without suitable CO2 transport network the uptake of CCS technology would be slower and more difficult to realise because of the remoteness of many possible CCS sites. In that case, the distance between even the largest single CO2 emitters and the storage site becomes a physical barrier, as to be efficient – the CO2 carrying pipeline would have to be large to tap into economies of scale, but the volume of CO2 from a single source would not be sufficient to assure high load factors. An additional argument in favour of “highway” CO2 pipeline systems is related to the nature of their technical operation and the associated liabilities.

- The establishment of a working carbon market could give the right economic signals to the stakeholders by providing a carbon price needed to make the CCS projects more viable. In addition, strong government support is needed during research, development and implementation of large scale demonstration projects.
There are signs that public opposition to CCS technology exists in some developed countries. On the other hand, CCS will be needed in developing countries relying mainly on carbon to cover their current and future energy needs. In the absence of examples for the developed world it may be difficult to “convince” other countries to implement CCS technology. This would be a disaster, bearing in mind the increasing reliance of these countries on coal as a relatively cheap and abundant energy resource and the pace of construction of new coal-fired power generation capacities.

The approach to promoting CCS in various leading developed regions is divergent. Initially, this divergence could be beneficial because the relative effectiveness of various methods would be demonstrated, but eventually there would be a need to arrive at some knowledge about best practices in the matter of CCS. Having used CO₂ for EOR in their petroleum industry for more than three decades now, the US and Canada seem to lean to the promotion of the “technological” aspect of CCS while relying on existing legislation and regulation of the oil and gas industries, which is believed to be easily adaptable to CCS. The European Union, where industrial experience is of lesser scale, is “investing” firstly in the relevant legal and regulatory framework in order to establish a suitable investment environment for CCS. An issue related to this approach may be the lack of adequate information about the suitable geological potential for CO₂ storage in the region. From another point of view, promoting regulation and introducing different incentive mechanisms could be the more effective approach in the short run, since the desired effect could be achieved faster. However, relying mainly on incentive mechanisms could hinder the development of the “right” technologies because businesses may prefer to pay fines instead of developing an alternative that is more costly now, even though it may become more efficient in the long run.

The existing legislation seems to treat similar projects, for instance the injection of CO₂, in a different manner depending on the purpose of the project, for example EOR or CO₂ storage. However, the technologies for the evaluation, development, construction, injection and monitoring of the facilities for EOR and CCS in depleted oil and gas fields are almost identical and have been used for decades by the petroleum business in routine operations. For this reason, it seems unjustified to have a different treatment for similar projects. It would be better to have common standards for the implementation and the monitoring of CCS projects, simply because as long as CO₂ is trapped in the geological formation it is not important for what purpose it has been injected – commercial or environmental, but how it behaves and what the eventual consequences would be.

Right now, CCS is without doubt an expensive mitigation option, so the right incentive and promotion mechanisms at national, regional and global levels of crucial importance for making its commercial uptake possible. Nevertheless, CCS is not the only option in tackling with issue of the emissions reduction. Therefore, the discussion inevitably boils down to the critical issue of costs and different characteristics of such other options like the nuclear or renewable energy. In the light of severe criticism about the technological as well as legal uncertainties coupled with the costs associated with CCS, there is also the possibility of not being able to realise a commercially viable CCS at industrial scale coming on stage in the near future.

---

It is important to be understood that the ecological aspect is also subject of perception, because if a legal regulation, related to some financial incentives or constraints regarding the release of CO₂ in atmosphere, is in place it could be that the ecological motivation becomes purely commercial.
Annex A. CCS Technologies

**CO₂ Capture Techniques**

Due to economies of scale and specific technology features, CO₂ capture is a reasonable option only when applied to large single point sources emitting huge volumes of carbon dioxide. At present, three different techniques for capturing of CO₂ exist, depending on the phases and the conditions under which capturing is carried out: post-combustion, pre-combustion, and oxyfuel combustion:

- In the post-combustion option, as the name suggests, CO₂ is captured from flue gases after the combustion of fossil fuels. This technology, being well-known and taking into account the design of existing conventional power plants, is likely to be the easiest to apply in technical terms (see Figure 14).

- The pre-combustion technique consists of initial partial oxidisation of the fossil fuel, resulting in formation of syngas, which is subsequently re-processed into CO₂ and hydrogen (H₂). The syngas gas contains between 3% and 4% CO₂ by volume in a gas-fired plant and around 15% in a coal-fired plant. The key point in this technology, being also one of its main advantages, is that the captured CO₂ is in a highly pure stream and the resulting H₂ could be used as a CO₂-free fuel (see Figure 15).

- The main feature of oxy-fuel combustion is in the fact that the fuel is burned in pure oxygen instead of air. The process produces about 75% less flue gas by volume than air-fueled combustion and the exhaust consists of between 80 and 90% CO₂. The remaining gas is water vapor (condensed through cooling), which simplifies the CO₂ separation step. The result is almost pure CO₂ stream that can be transported to the sequestration site and stored. Power plant processes based on oxyfuel combustion are sometimes referred to as "almost zero emission" cycles, because the CO₂ stored is not a fraction of its total volume removed from the flue gas stream (as in the cases of pre- and post-combustion capture) but the flue gas stream itself. From environmental and technological point of view this technique is quite promising, but the difficulty to overcome here is related to the need to introduce an initial oxygen-from-air separation cycle that is extremely energy demanding, which in practice means that an air separation plant is required to produce pure oxygen for the process from air (see Figure 16).

![Figure 14 Post-combustion Capture of CO₂](source: CO₂ Capture Project)

---

43 World Energy Outlook 2007, IEA.

44 Source: CRC for greenhouse gas technologies.
Another method, which is currently under development, is the so-called chemical looping combustion (CLC). Chemical looping uses metal oxide as a solid oxygen carrier. Metal oxide particles react with a solid, liquid or gaseous fuel in a fluidised bed combustor, producing solid metal particles and a mixture of carbon dioxide and water vapour. The water vapour is condensed, leaving pure carbon dioxide which can be sequestered. The solid metal particles are circulated to another fluidised bed where they react with air, producing heat and regenerating metal oxide particles that are re-circulated to the fluidised bed combustor.

From a practical point of view it has to be noted that there is not a single capture type or technology that may be the best solution for every industrial setting. Post-combustion has a wider applicability.

than other approaches, since it is in principle always usable for retrofitting existing units.\textsuperscript{46} The associated cost may however be higher than with pre-combustion or oxy-firing.

According to Mitsubishi Heavy Industries\textsuperscript{47} the main advantages of post combustion technology could be summarised in the following:

1. Is applicable for the current, global PC fleet.
2. Offers high degree of flexibility – is adaptable and cost competitive with other technologies.
3. Operation at atmospheric pressure – safe and does not require exotic materials.
4. Produces highly purified CO\textsubscript{2} – important environmental consideration for transport and disposal.
5. Easy to transfer post combustion technology to developing countries – simple process and configuration.
6. Allows for future zero emission use of coal.

\textit{Options for CCS Power Station Design}

One of the attractive features of CCS projects is the possible implementation of a carbon capture module at every newly built fossil fuel power plant in the near future. So far, carbon capture technology has not yet been demonstrated on a large commercial scale, for example at an operational power plant, but trends in adopting related legislation may suggest that carbon capture modules most likely would become mandatory in the medium term. Such an assumption presumes that future power plants, constructed over the next years, should be at least “carbon capture ready”.

While it has not yet been firmly specified what exactly such “readiness” could represent, it is evident that a larger land area would be needed for the “integration” of the carbon capture module in the plant. The module could include CO\textsubscript{2} capture equipment like scrubbers, CO\textsubscript{2} compressors, oxygen production plant, etc., plus additional infrastructure such as cooling water and electrical systems, safety barrier zones, piping and tie-ins to existing equipment.\textsuperscript{48}

\begin{quote}
\textbf{According to CO\textsubscript{2} capture project’s definition - CCS-ready indicates a plant or industrial facility has been fitted with the necessary CO\textsubscript{2} processing structure and physical space to easily add a post-combustion CCS facility at some point in the future. Making new build CCS-ready is one of the most important steps to ensuring that the widest range of CO\textsubscript{2}-emitting sources can be quickly adapted to CCS.}
\end{quote}

Likewise, more space would be needed because retrofitting CO\textsubscript{2} capture to existing plant would reduce the net power output, for example by about 20-25% for current post-combustion capture technology at a coal fired plant. If the net power output from the site has to be maintained, additional space would also have to be provided for the construction of an additional power generation plant.\textsuperscript{49}

Apart from the need to provide a bigger power plant site, it would be necessary to modify the design of the plant because the components would no longer be laid in the typical (linear) manner. “The ‘non linear’ nature of capture - and capture-ready plant suggests another suitable layout, whereby - in very general terms - the main power block units of the boiler, turbine and emissions

\textsuperscript{46} Source: “CO\textsubscript{2} Capture Project”.
\textsuperscript{47} Source: “MHI's Commercial Post Combustion CO\textsubscript{2} Capture Experiences in a Carbon Constrained World” 2008.
\textsuperscript{48} “CO\textsubscript{2} capture ready power plants”, IEA, 2007.
\textsuperscript{49} Ibid.
control systems would be arranged in a ‘n’ shape in the case of capture-ready plant and an ‘o’ shape for a plant built for carbon dioxide capture from the outset. The closing of the ‘o’ shape is formed by the carbon dioxide capture plant which has interfaces both to the emissions control equipment and the turbine hall. This is to allow the majority of systems to have better tie-ins to all other systems for easier process integration.”

Another factor to consider is the availability of a suitable CO\(_2\) sink (i.e. a favourable geological formation) in close proximity to the new facility. Although not directly related to the design of the CCS power plant, the availability of an adjacent or not too distant “sink” is without doubt a critically important precondition for the eventual future construction of such power generation capacities.

**CO\(_2\) Transport**

Once captured, the CO\(_2\) must be transported by pipelines or by ships to suitable permanent storage site(s). Similar to oil and gas transportation, the choice of transportation for CO\(_2\) depends on the volume and the distance. In general, a pipeline is a better option from an economic point of view, but only if a few million tons of CO\(_2\) have to be transported annually; if the distance between the source and the storage points is greater than 1,000 km over a sea, it is probable that transportation by a vessel (liquid CO\(_2\) tanker) would be more economically efficient.

Onshore, CO\(_2\) is already routinely transported by pipeline. For example, in the United States there are approximately 5,800 km of CO\(_2\) pipelines used to carry the gas to oil fields where the CO\(_2\) is injected in the reservoir for the purpose of EOR.

**Types of CO\(_2\) Storage**

Permanent CO\(_2\) storage could be implemented in various ways, including storage in deep geological formations, ocean, mineral and terrestrial (biological) sequestration. The estimated storage capacity worldwide is sufficient for storing today’s global CO\(_2\) emissions for thousands of years.

**Geological Storage (Known Also as Geological Sequestration)**

In the search for suitable places for long-term storage of significant volumes of CO\(_2\), attention is now focused mainly on depleted oil and gas fields, saline aquifer formations and non-minable coal seams, overlaid by physical (e.g. highly impermeable caprock) and/or geochemical trapping structures and mechanisms that would prevent the CO\(_2\) to escape to the surface. As a disadvantage, one could note the geographic distribution of oil and gas fields, which are generally not located in the immediate vicinity of large CO\(_2\) emitting sources.

Geological storage of CO\(_2\) is based on a well-known and routinely practiced technique for injection of carbon dioxide, generally in supercritical state, directly into underground geological formations. Figure 17 illustrates various geological storage options.

For more than three decades now, oil companies have been successfully using relatively small volumes of compressed carbon dioxide as injection fluid for the purposes of EOR. The attractiveness of this option is enhanced by the fact that it is possible to generate additional revenue by selling the extra quantities of oil produced from the reservoir in which CO\(_2\) is injected, thus partially or entirely offsetting storage costs, especially if oil prices are high.

---

50 Source: http://www.priorartdatabase.com/IPCOM/000144132/.
There are four main mechanisms which trap CO\textsubscript{2} in suitable geological formations.\textsuperscript{51} The first is “structural trapping”. In this instance, impermeable cap-rock prevents CO\textsubscript{2} from escaping from the reservoir. The second mechanism is known as “residual CO\textsubscript{2} trapping”; in this case, CO\textsubscript{2} is trapped by capillary forces in the inter-matrix space of the rock formation, which develops about 10 years after injection. The third mechanism is “solubility trapping”, where the CO\textsubscript{2} dissolves in the water found in the geological formation and sinks, because the water in which CO\textsubscript{2} is dissolved is heavier than normal water. This becomes important some 10-100 years after injection. Finally, “mineral trapping” happens when dissolved CO\textsubscript{2} chemically reacts with the formation rock to produce minerals.

### Figure 17 Geological Storage of CO\textsubscript{2}

Non-minable coal seams could potentially be CO\textsubscript{2} storage formations, as carbon dioxide is adsorbed onto coal. During the adsorption process previously adsorbed methane is released, becoming free to be recovered, i.e. the process de facto represents enhanced coal bed methane recovery (ECBM). From a technical point of view, the outcome is highly dependent on the permeability of the coal bed. The economics of the operation has to be evaluated bearing in mind the potential revenues from future sale of the extracted methane, but also taking into account the direct or indirect costs associated with the mine safety.

Saline aquifer formations contain highly mineralised brines, and have been so far considered of no significant use to humans. However, the potential of saline aquifers – a reliable, large, and commonly occurring geological feature – for CO\textsubscript{2} storage is considerable. The geology of saline formations and the potential behaviour of CO\textsubscript{2} in them are less well understood compared to oil fields, which could be a drawback for a certain period of time, until better data and knowledge become available. Unlike geological storage in oil and gas fields or coal beds, the economics of CCS in the case of saline aquifers cannot be improved through the recovery of a by-product that would offset at least partially the cost of storage.

It is clear that deep saline formations could become the most widely used CO\textsubscript{2} storage reservoirs. Meanwhile, bearing in mind that in this case there is no offset option that could improve the

\textsuperscript{51} Source: “Questions and answers on the proposal for a directive on geological storage of carbon dioxide”, Memo/08/36, 2008.
economics of the storage process, it is important to look for and implement other sustainable mechanisms. In the future, one might consider also the introduction of a carbon trading scheme designed in such a way as to encourage the evaluation and the use of the aquifer storage option, which is so far generally less known.

For well selected, designed and managed geological storage sites, IPCC estimates that CO₂ could be trapped for millions of years, and the sites are likely to retain over 99% of the injected CO₂ for more than 1,000 years. An idea of the distribution of sedimentary basins suitable for storing CO₂ worldwide may be obtained from the map (see Figure 18).

**Figure 18 Geographic Distribution of Geological Storage Opportunities**

![Geographic Distribution of Geological Storage Opportunities](source: IPCC Special report on Carbon Dioxide capture and storage)

While evaluating storage potential in general on a global or regional level is important as it provides a measure of the total volume available for storing CO₂, in order to obtain a realistic idea about the actual “operational” storage potential one has to also take into account the “delivery” capacity, i.e. the maximum sustainable daily rate of CO₂ injection. This parameter is of crucial importance as it limits the scale of CCS projects related to a concrete geological reservoir.

**Ocean Storage**

Apart from geological sequestration, another proposed option for storing CO₂ is to place it in oceans through various – largely unproven – techniques. “Ocean storage” is the direct release of CO₂ into the water or onto the deep seafloor. The techniques of this type that have been most widely discussed and may have some real potential are the following:

1. Dissolution of CO₂, i.e. controlled injection of CO₂ from a ship or a pipeline into the water of the ocean at a depth of 1,000 m or more where the pressure is believed to be sufficient to keep the CO₂ in solution and the conditions are good for preventing future CO₂ dissolution.

2. Formation of a CO₂ “lake” – in this case, CO₂ is directly discharged onto the seabed at depths exceeding 3,000 m, where temperature and pressure are such as to make the CO₂ denser than water and consequently the formation of a “CO₂ lake” is to be expected. The dissolution of CO₂ into the environment is estimated to be slow and occur over hundreds or thousands of years (see Figure 19).
The key concern in ocean storage is the long-term safety and reliability of the process. The general perception about the environmental effects of ocean storage is negative, because according to many assessments this type of storage could assure permanent sequestration and limit the future release of CO₂ into the atmosphere. In addition, the reaction of CO₂ with water generates carbonic acid, which would increase the acidity of the ocean waters. Current international marine legislation has raised legal barriers to ocean storage of CO₂.

An interesting option with a huge potential for CO₂ storage is the sequestration of carbon dioxide into deep-sea basalt formations. According to David Goldberg, a geophysicist at Columbia University’s Lamont-Doherty Earth observatory, basalt reservoirs are immense, accessible and well sealed formations of hardened lava and represent the basic stuff of the ocean floors. Upon injecting liquid CO₂ into them, a chemical reaction is likely to occur between the fluid and the basalt resulting in the formation of solid nontoxic mineral, which is essentially chalk. From a safety point of view, carbon dioxide could be well buried into these basalt formations, usually under some 3,000 meters of water and some hundred meters of fine-grained sediment.

This option is quite interesting because it could provide a large reservoir for decades of safe and secure injection of CO₂. Basalt formations are widespread, which would help attain reasonable cost of CO₂ transportation and storage, either by pipelines or by ships.

An important factor for the future development of this storage option is the fact that the recent amendments of Annex 1 to the London Protocol permit the storage of carbon dioxide into sub-seabed geologic formations.

Mineral Storage – Industrial Fixation of CO₂ into Inorganic Carbonates

Mineral storage is the production of stable carbonates under a chemical process, essentially an exothermal reaction of CO₂ with abundantly available oxides. This phenomenon is well known and

---

52 Source: Columbia University.

has been observed to take place naturally over many years, being responsible for the occurrence of much of the surface limestone.

From a technical point of view, the chemical reaction could be accelerated by either increasing temperature or pressure, or both. However, such “catalisation” requires significant quantities of additional energy, which could hinder the economics of the storage option. The IPCC estimates that a power plant equipped with CCS using mineral storage will need 60-180% more energy input than a power plant without CCS.

**Terrestrial (Biological) Sequestration**

Terrestrial carbon sequestration is a process through which carbon dioxide from the atmosphere is absorbed by trees, plants and crops through photosynthesis, and stored as carbon in biomass and soils. There is no doubt that the forests and the soils have a large impact on the atmospheric levels of carbon dioxide and according to the IPCC Special Report on LULUCF the tropical deforestation is responsible for about 20% of the world's annual CO₂ emissions.

In practice, CO₂ can be reduced through avoiding additional emissions by keeping existing CO₂ already stored in trees and soils or increasing the carbon storage potential, for instance through tree planting. According to IPCC, it is possible to expect that about 100 billion metric tons of carbon could be stored over the next 50 years via terrestrial sequestration, which would offset 10-20% of the world's projected fossil fuel emissions. The option is probably viable from an economic point of view, but the drawback is that it is a temporary solution and does not provide long-term or permanent storage. Given the nature of this concept of storage, it falls beyond the scope of this study, and therefore provided as a summary only.

---

Annex B. Financing & Economic Models for CCS

In order to apply CCS technology, investors would have to prove that compliance to the regulations of an appropriate IPR regime would be assured. Such a requirement is especially necessary because of the high cost of developing CCS technology. To facilitate the commercial uptake of CCS technology and to mitigate – to a certain degree – the hindering impact of high cost, some financial institutions are preparing convenient tools oriented to CCS. For example, the European Investment Bank (EIB) is currently analysing the possibility of developing new products for financing CCS, in addition to already existing means under the “Risk Sharing Finance Facility” (RSFF), the latter being mainly focused on R&D projects.

Also, in this respect, the Asian Development Bank (ADB) stated that it is ready to provide financial support to the People's Republic of China (PRC) and India:

- Grant-financed technical assistance (TA) for carrying out a detailed feasibility study and institutional capacity building ($2 million TA committed to India)
- Tailored low-cost financing focused on:
  1. Buy-down higher cost: ADB provides up to 10% of the loan amount as a grant;
  2. Sub-LIBOR interest rates, long tenor, flexible repayment option;
  3. Up-front carbon finance, a Future Carbon Fund is also being set.
- Concessional loans – a fund is being set up for multilateral development banks (MDBs) to offer concessional loans to mitigate incremental cost of IGCC plants.

ADB’s proposed financing for an IGCC plant in PRC will bring down the cost of electricity by 25% compared to domestic financing. However, the key challenges in financing CCS in the instance are related to:

- In the current pre-demonstration phase, risks are too high for private investors, it will need support from Governments and MDBs;
- MDBs like ADB can play an important role by providing finances, and risk mitigation products and can also leverage private capital flows by absorbing political and policy risks to give greater certainty to investors;
- Policy makers need to send a clear signal about their commitment and vision for low carbon technologies.

Economic Models of CCS: Costs and Benefits (Including a Comparison with Other Options)

The cost of CCS involves partly the cost of the capital investment on equipment to capture, transport and store CO₂, and partly the cost of operating this equipment to store the CO₂ in practice, i.e. the amount of energy required to capture, transport and inject the CO₂, etc. At current technology prices, up-front investment costs are about 30 to 70% (i.e. several hundred million Euro per plant) greater than for standard plants and operating costs are currently 25 to 75% greater than in non-CCS coal-fired plants. These costs are expected to substantially decrease as the technology is proven on a commercial scale. It is clear, on the other hand, that CCS will only be deployed if the cost per tonne of CO₂ avoided is lower than the eventual carbon price.

Today, the average power plant efficiency is estimated at level of 33%-40%, so the expected decrease of overall output by around one third, as a consequence of CCS implementation, could become an overwhelming obstacle to retrofit the existing fleet of power plants.

The high costs of CCS may be mitigated via two avenues through:

- Intensifying R&D to speed up the commercial uptake of the CCS facilities and to find ways to diminish their costs;
- Involving CCS in wider policy-making strategies related to creating value for CO₂.

**CCS Model of the National Energy Technology Laboratory (NETL)**

According to NETL, the expected increase in capital costs on applying CCS as compared to conventional technological solutions is estimated between 35%-110% (35% for IGCC, 87% for PC and 110% for NGCC), while the increase of electricity costs is between 32%-83% (32% for IGCC, 83% for PC and 43% for NGCC).

More detailed information, based on absolute values, could be found on the table below, where the following notation is used:

- SCPC stands for Supercritical Pulverised Coal (state-of-the-art);
- IGCC stands for Integrated Gasification Combined Cycle (state-of-the-art, GE 7FA-type gas turbine);
- Advanced IGCC configuration that incorporates a dry feed pump, warm gas sulfur removal, membrane-based oxygen supply, and a GE 7FB-type gas turbine. Balance of plant is state-of-the-art;
- IGFC stands for Atmospheric Pressure Integrated Gasification Fuel Cell;
- Pressurised IGFC.

It is evident that the initially less expensive technology, namely SCPC, becomes the most costly one after adding a CCS module. Furthermore, its efficiency is the lowest. It does not come as a surprise that the costly options based on IGCC or fuel cell technology provide better overall efficiency which results in lower costs per ton of captured CO₂.

**Model of Intergovernmental Panel on Climate Change (IPCC)**

There are two main ways of expressing costs related to CCS implementation. The first one consists of evaluating additional electricity costs and is supported by the energy policymaking community in some countries. The second one assumes CO₂ avoidance costs measurement and is supported respectively by the climate policymaking community in some countries. In the first case, according to the IPCC model, the additional costs are estimated at 0.01-0.05 US$/kWh, while in the second case the avoided CO₂ emissions are evaluated in the range of 20$⁵⁷⁻²⁷⁰ US$/t CO₂ (in the case of EOR, zero to 240 US$/t CO₂ avoided). Table 5 shows the breakdown of different costs of CO₂ avoidance.

Similar calculations⁵⁹ show that in the case of deploying NGCC with CCS, the increase of energy needs varies between 11% and 22%, while the expected increase of capital expenditure (capex) is between 64% and 100%. The cumulative effect is a net cost per ton of captured CO₂ from $37 to $75. In a pulverised coal power plant fitted with a CCS module, additionally needed energy is within the range of 24% to 40% over the base case and the increase of capex varies between 44%

---

⁵⁷ Source: IPCC.
⁵⁸ Low-end: capture-ready, low transport cost, revenues from storage: 360 MtCO₂/yr.
Investment and Market Development in Carbon Capture and Storage: Role of the ECT

and 74%. The cost of captured ton of CO₂ is at $29-$51 per ton of CO₂. The promising IGCC technology will need some 14-25% more energy, but capex goes up “only” by some 19-66% - all of which results in a cost of captured CO₂ that varies between $13-$37 per ton.

Table 4 CCS Cost Estimates Based on the NETL Model

<table>
<thead>
<tr>
<th>Operating source</th>
<th>Baseline power systems (no CO₂ capture)</th>
<th>Systems with CO₂ capture, compression, and storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capacity (GW)</td>
<td>Efficiency</td>
</tr>
<tr>
<td></td>
<td>SCPC</td>
<td>EGE (IGCC)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>39.1%</td>
<td>38.2%</td>
</tr>
<tr>
<td></td>
<td>85%</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>0.00</td>
<td>0.9%</td>
</tr>
<tr>
<td></td>
<td>0.83</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>11.5%</td>
<td>5.7%</td>
</tr>
</tbody>
</table>


Table 5 CCS Cost Breakdown Based on the IPCC Model

<table>
<thead>
<tr>
<th>CCS component</th>
<th>Cost range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture from a power plant</td>
<td>$15-$75 per ton of CO₂ net captured</td>
</tr>
<tr>
<td>Capture from gas processing or ammonia production</td>
<td>$5-$55 per ton of CO₂ net captured</td>
</tr>
<tr>
<td>Capture from other industrial sources</td>
<td>$25-$115 per ton of CO₂ net captured</td>
</tr>
<tr>
<td>Transportation</td>
<td>$1-$8 per ton CO₂ transported per 250 km</td>
</tr>
<tr>
<td>Geological storage</td>
<td>$0.5-$8 per ton CO₂ injected</td>
</tr>
<tr>
<td>Ocean storage</td>
<td>$5-$30 per ton CO₂ injected</td>
</tr>
<tr>
<td>Mineral carbonation</td>
<td>$50-$100 per ton CO₂ net mineralised</td>
</tr>
</tbody>
</table>

Source: IPCC
IEA Model

Table 6 Characteristics of Power Plants with CO₂ Capture

<table>
<thead>
<tr>
<th>Fuel &amp; Technology</th>
<th>Starting Year</th>
<th>Investment cost (USD/kW)</th>
<th>Efficiency (%)</th>
<th>Efficiency loss (%)</th>
<th>Additional fuel (%)</th>
<th>Capture efficiency (%)</th>
<th>Capture cost (USD/t CO₂)</th>
<th>Electricity cost (US cents/kWh)</th>
<th>Electricity cost reference plant (US cents/kWh)</th>
<th>Additional electricity costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal, steam cycle, CA</td>
<td>2010</td>
<td>1 850</td>
<td>31</td>
<td>-12</td>
<td>39</td>
<td>85</td>
<td>33</td>
<td>6.79</td>
<td>3.75</td>
<td>3.04</td>
</tr>
<tr>
<td>Coal, steam cycle, membranes + CA</td>
<td>2030</td>
<td>1 720</td>
<td>36</td>
<td>-8</td>
<td>22</td>
<td>85</td>
<td>29</td>
<td>6.10</td>
<td>3.75</td>
<td>2.35</td>
</tr>
<tr>
<td>Coal, USC steam cycle, membranes + CA</td>
<td>2030</td>
<td>1 675</td>
<td>42</td>
<td>-8</td>
<td>19</td>
<td>95</td>
<td>25</td>
<td>5.70</td>
<td>3.75</td>
<td>1.95</td>
</tr>
<tr>
<td>Coal, IGCC, Selexol</td>
<td>2010</td>
<td>2 100</td>
<td>38</td>
<td>-8</td>
<td>21</td>
<td>85</td>
<td>39</td>
<td>6.73</td>
<td>3.75</td>
<td>2.98</td>
</tr>
<tr>
<td>Coal, IGCC, Selexol</td>
<td>2020</td>
<td>1 635</td>
<td>40</td>
<td>-6</td>
<td>15</td>
<td>85</td>
<td>26</td>
<td>5.71</td>
<td>3.75</td>
<td>1.96</td>
</tr>
<tr>
<td>Gas, CC, CA</td>
<td>2010</td>
<td>800</td>
<td>47</td>
<td>-9</td>
<td>19</td>
<td>85</td>
<td>54</td>
<td>5.73</td>
<td>3.75</td>
<td>1.98</td>
</tr>
<tr>
<td>Gas, CC, Oxyfueling</td>
<td>2020</td>
<td>800</td>
<td>51</td>
<td>-8</td>
<td>16</td>
<td>85</td>
<td>49</td>
<td>5.41</td>
<td>3.75</td>
<td>1.66</td>
</tr>
<tr>
<td>Black liquor, IGCC</td>
<td>2020</td>
<td>1 620</td>
<td>25</td>
<td>-3</td>
<td>12</td>
<td>85</td>
<td>15</td>
<td>3.35</td>
<td>2.35</td>
<td>1.00</td>
</tr>
<tr>
<td>Biomass, IGCC</td>
<td>2025</td>
<td>3 000</td>
<td>33</td>
<td>-7</td>
<td>21</td>
<td>85</td>
<td>32</td>
<td>10.06</td>
<td>7.46</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Technologies under development

<table>
<thead>
<tr>
<th>Fuel &amp; Technology</th>
<th>Starting Year</th>
<th>Investment cost (USD/kW)</th>
<th>Efficiency (%)</th>
<th>Efficiency loss (%)</th>
<th>Additional fuel (%)</th>
<th>Capture efficiency (%)</th>
<th>Capture cost (USD/t CO₂)</th>
<th>Electricity cost (US cents/kWh)</th>
<th>Electricity cost reference plant (US cents/kWh)</th>
<th>Additional electricity costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal, CFB, chemical looping</td>
<td>2020</td>
<td>1 400</td>
<td>39</td>
<td>-5</td>
<td>13</td>
<td>85</td>
<td>20</td>
<td>5.26</td>
<td>3.75</td>
<td>1.51</td>
</tr>
<tr>
<td>Gas, CC, chemical looping</td>
<td>2025</td>
<td>900</td>
<td>56</td>
<td>-4</td>
<td>7</td>
<td>85</td>
<td>54</td>
<td>5.39</td>
<td>3.75</td>
<td>1.64</td>
</tr>
<tr>
<td>Coal, IGCC &amp; SOFC</td>
<td>2035</td>
<td>2 100</td>
<td>56</td>
<td>-4</td>
<td>7</td>
<td>100</td>
<td>37</td>
<td>6.00</td>
<td>3.75</td>
<td>2.25</td>
</tr>
<tr>
<td>Gas, CC &amp; SOFC</td>
<td>2030</td>
<td>1 200</td>
<td>66</td>
<td>-4</td>
<td>6</td>
<td>100</td>
<td>54</td>
<td>5.39</td>
<td>3.75</td>
<td>1.64</td>
</tr>
</tbody>
</table>

Note: The above comparison is based on a 10% discount rate and a 30-year process lifespan. The investment costs exclude interest during the construction period and other owner costs, which could add 5-40% to overnight construction cost. This approach has been applied to all technologies that are compared. Coal price= USD 1.5/GJ; Natural gas price = USD 3/GJ. CO₂ product in a supercritical state at 100 bars. CO₂ transportation and storage is not included. Capture costs are compared to the same power plant without capture. CA= Chemical Absorption. CC*= Combined-cycle; CFB = Circulating fluidised bed; IGCC = Integrated Gasification Combined-cycle; SOFC = Solid Oxide Fuel Cell; USC = Ultra Supercritical.


Model of RITE (Japan)

Table 7 CCS Cost Comparison between the Models of RITE and IPCC

![Image of Table 7](image)

Source: Current Status of CCS in Japan, Akito Ito, RITE, 2008
It is obvious that the estimated CCS cost in Japan is higher than that projected by the IPCC model.

Similar results on the cost of CCS have been obtained by CO₂ CRC and other groups around the world, showing that the cost of capturing CO₂ from a stationary industrial source today would range between $30 and $35 per MWh for IGCC and between $35 and $45 per MWh for post-combustion technologies, depending on whether black or brown coal is used and where the geological storage location is sited.⁶⁰ If the base-case power generation costs of these different technologies are taken into consideration, the results show that CCS results in an overall increase of the cost of generation at a geo-sequestration-enabled power plant of $35-$45 per MWh. It is quite clear that the cost is quite high, and for this reason a major task-of-the-day is to bring down this cost increase to between $15 and $20 per MWh. It should also be born in mind that:

- Cost becomes high when storage reservoirs are located far from shore;
- Storage cost is heavily dependent on injection rates per well.

---

⁶⁰ Source: CRC for greenhouse gas technologies.
Annex C. Definition of Gases\textsuperscript{61}

- Coal gas, gas obtained in the destructive distillation of soft coal, as a by-product in the preparation of coke. Its composition varies, but in general it is made up largely of hydrogen and methane with small amounts of other hydrocarbons, carbon monoxide (a poisonous gas), carbon dioxide, and nitrogen. It is used as a fuel and illuminant.

- Producer gas, fuel gas consisting chiefly of carbon monoxide and nitrogen. It is prepared in a furnace or generator in which air is forced upward through a burning fuel of coal or coke. Although the fuel is introduced through the top, no air is admitted there. The carbon of the fuel is oxidised by the oxygen of the air from below to form the carbon monoxide. The nitrogen of the air, being inert, passes through the fire without change. When steam is introduced with the air, the final gaseous product contains hydrogen also. Producer gas has a low heating value because it is about 60% inert nitrogen. It is widely used in industry because it can be made with cheap fuel. When producer gas contains hydrogen, it is also a source material for the manufacture of synthetic ammonia.

- Water gas, colourless poisonous gas that burns with an intensely hot, bluish (nearly colourless) flame. The gas is a mixture of carbon monoxide and hydrogen with very small amounts of other gases, e.g., carbon dioxide, and is almost entirely combustible as a result. Water gas is so named because of the use of water (steam) in its preparation. This process involves treating white-hot hard coal or coke with a blast of steam; carbon monoxide and hydrogen are formed. The gas is manufactured in vast quantities for commercial use. It is of much importance in the preparation of hydrogen and as a fuel in the making of steel and in other industrial processes.

- Carbon dioxide, chemical compound, CO\textsubscript{2}, a colourless, odourless, tasteless gas that is about one and one-half times as dense as air under ordinary conditions of temperature and pressure. It does not burn, and under normal conditions it is stable, inert and nontoxic. It will however support combustion of magnesium to give magnesium oxide and carbon. Although it is not a poison, it can cause death by suffocation if inhaled in large amounts. It is a fairly stable compound but decomposes at very high temperatures into carbon and oxygen. It is fairly soluble in water, one volume of it dissolving in an equal volume of water at room temperature and pressure; the resultant weakly acidic aqueous solution is called carbonic acid.

\textsuperscript{61} Source: Sci-Tech Encyclopaedia.
Annex D. References

- Bachu, S., Overcoming Barriers to CCS Deployment -Legal and Regulatory Issues, (2007)
- Bachu, S., Overcoming barriers to CCS Deployment; CSLF workshop, (2007)
- Bradshaw, J., CSLF Workshop “Overcoming Barriers to Deployment” Overview of Technology Gap Analysis PIRT, (2007)
- CO₂SINK, CO₂ Storage by injection into a saline aquifer at Ketzin, (2005)
- Commission of the European communities, Communication from the Commission to the Council, the European parliament, the European economic and social committee and the committee of the regions, Limiting Global Climate Change to 2 degrees Celsius The way ahead for 2020 and beyond, (2007)
- Commission of the European communities, Communication from the Commission to the Council, the European parliament, Sustainable power generation from fossil fuels: aiming for near-zero emissions from coal after 2020, (2007)
• European Commission, DG Environment, Questions and answers on the proposal for a directive on geological storage of carbon dioxide, Memo/08/36, (2008)
• Goldberg, D. S., Carbon dioxide sequestration in deep-sea basalt, Lamont-Doherty Earth Observatory, (2008)
• GreenFacts, Facts on CO2 Capture and Storage – A Summary of a Special Report by the Intergovernmental Panel on Climate Change, (2007)
• IEA, CO2 capture ready plants, (2007)
• IEA, CO2 capture ready power plants, 2007
• IEA, Key world energy statistics, (2008)
• IEA, Legal aspects of storing CO2 – Update and recommendations, (2007)
• IEA, World energy outlook, 2007
• IPCC, Special report on carbon dioxide capture and storage, (2005)
• IPCC, The main findings of the IPCC Special Report on Carbon Dioxide Capture and Storage, (2005)
• IRGC, Workshop on Regulation of Carbon Capture and Storage, (2007)
• Kemp, A., Work undertaken on economics of CO₂ capture, transportation, EOR, and sequestration in UK/UKCS, University of Aberdeen, (2007)

• Ketzer, M., CO₂ Sequestration Technologies, Brazilian Carbon Storage Research Center, (2008)


• Maeda, D., CCS regulatory development in Japan, Ministry of Environment, Japan, (2008)


• Morrison, H., ZeroGen smarter, cleaner power, Presentation at Carbon Sequestration Leadership Forum (France) Overcoming Barriers to CCS Deployment, (2007)

• Newberry, M., “CCS and Clean Coal: Legal Barriers to Development”, in European Energy Law Report V, Intersentia, 2008,


• OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic, Press statement New Initiatives on CO₂ Capture and Storage and Marine Litter “OSPAR takes action on climate change and cleans up our beaches”, (2007)


• Rees, M., Butler, N., Carbon capture stations must not be delayed, (2008)


• Rogner, H-H, IPCC SRCCS Carbon Dioxide Sources and Capture, (2005)

• Scholes, C., Pre-combustion carbon capture technologies pilot plant trials on coal gasification, Cooperative Research Centre for Greenhouse Gas Technologies, The University of Melbourne, (2008)

• Schwarte, C., Siegele, L., Marine protected areas on the high seas?, FIELD, (2008)

• Swift, J., Carbon Sequestration R&D Overview, Workshop on Capture and Sequestration of CO₂ (CCS), (2008)


• The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), Strategic Research Agenda, (2007)


• Thomson, J., Legal issues relevant to deployment of CO₂ sequestration technologies, UK Department for Environment, Food and Rural Affairs, (2007)

• Thomson, J., Legal issues relevant to deployment of CO₂ sequestration technologies, UK Department for Environment, (2007)
• Wilson, E. J., Regulating the Geological Sequestration of CO₂, American Chemical Society, Environmental Science & Technology (2008)
• Winkler, H., Why does the world need carbon planning?, Energy Research Centre University of Cape Town, (2008)
• Wright, I., CO₂ Geological Storage: Lesson Learned from In Salah (Algeria), BP Group Technology, (2006)
• Young, W. S., Gorgon Project Briefing, Chevron Australia, (2008)
• http://ec.europa.eu/environment/climat/ccs/index_en.htm
• http://www.rite.or.jp/index_e.html
• www.co2captureproject.org/
• www.co2crc.com.au
• www.epa.gov/safewater/uic/wells_sequestration.html
• www.euroactiv.com
• www.gorgon.com.au
• www.imo.org/
• http://minister.ret.gov.au/TheHonMartinFergusonMP/Pages/GLOBALCARBONCAPTUREAN DSTORAGEINITIATIVE.aspx
• www.pnas.org/content/early/2008/07/11/0804397105.abstract
• www.priorartdatabase.com/IPCOM/000144132/
• www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2464617
• www.ret.gov.au/
• www.statoilhydro.com/en/Pages/default.aspx
• www.wikipedia.org