ASEAN CCS STRATEGIC CONSIDERATIONS

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GLOBAL CCS INSTITUTE

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FOREWORD

Reducing the worlds greenhouse gas emissions, while delivering energy and growth, is a challenge to be met by a portfolio of clean energy technologies. Carbon capture and storage (CCS) can play an important role in reducing emissions, alongside renewables and energy efficiency. The costs of reducing emissions and addressing climate change are likely to be substantially higher if CCS is excluded.

This CCS Strategic Considerations Paper has been prepared by the Global CCS Institute and the ASEAN Centre for Energy to facilitate a discussion on CCS by ASEAN policymakers. The ASEAN forum is particularly well suited to discuss regional considerations.

The paper provides a high-level overview of some of the key matters related to CCS, including: global status of CCS, costs, capture technology, storage, legal and regulatory developments and public engagement. Useful references are provided for those looking for more detail on a particular topic.

The paper also provides an overview of CCS in the ASEAN region, and suggests next steps to assist in creating the right conditions for the deployment of CCS in the region in the future.

The Global CCS Institute looks forward to continuing our collaboration with the ASEAN Centre for Energy and facilitating knowledge sharing on CCS.

Clare Penrose
General Manager – Asia Pacific, Global CCS Institute

Sustainable energy development that supports regional economic growth is required to achieve optimal sustainable development for Southeast Asia. With the launch of the ASEAN Economic Community (AEC) in 2015, the region's energy requirements are expected to increase with resulting economic expansion and integration. According to the 3rd ASEAN Energy Outlook under a business-as usual scenario, the region's primary energy consumption will grow at 4.5% per annum from 2007 to 2030, resulting in a corresponding 5.7% growth in CO_2 emissions. This is largely due to the escalation of carbon-intensive fossil fuels such as coal, as well as oil and natural gas consumption.

This increasing primary energy consumption and corresponding increase in CO_2 emissions needs to be curbed. It requires an increasing role for low-carbon and zero-carbon energy technologies to be embedded in the long-term national energy programs. CCS deployment in the ASEAN region offers great potential for reducing CO_2 emissions from large point source emitters, such as coal-fired power plants, coal gasification and liquefaction plants, and oil and gas processing plants, to achieve low carbon development path in ASEAN energy sectors.

The preparation of this report, ASEAN CCS Strategic Considerations, is the result of a directive to the ASEAN Centre for Energy (ACE) by the Senior Officials Meeting on Energy (SOME) and ASEAN Ministers of Energy Meeting (AMEM). The Meeting agreed that the ACE, in coordination with the ASEAN Forum on Coal (AFOC), will work with the Global CCS Institute (the Institute) to develop a strategic paper on ASEAN CCS Strategic Considerations.

As a result, the Institute and ACE jointly prepared this document with the objective to facilitate high policy level dialogues and discussions for CCS development & deployment in the ASEAN region at the levels of SOME and AMEM. Importantly, the document rationalises the need for CCS in the ASEAN region, describes ASEAN's long-term energy path, quantifies the CCS contribution to emission reductions in ASEAN. It also provides insights into the status of CCS activities in the ASEAN Member States. Substantially, the paper provides a high-level overview of some of the key associated issues from up-stream to down-stream such as cost of CCS, capture technologies, CO_2 transport, risks and environmental impacts, CO_2 utilization, storage issues, regulatory frameworks, as well as legal public engagement and supporting mechanisms including global CCS status. The strategic issues and next steps are clearly described and elaborated in this report.

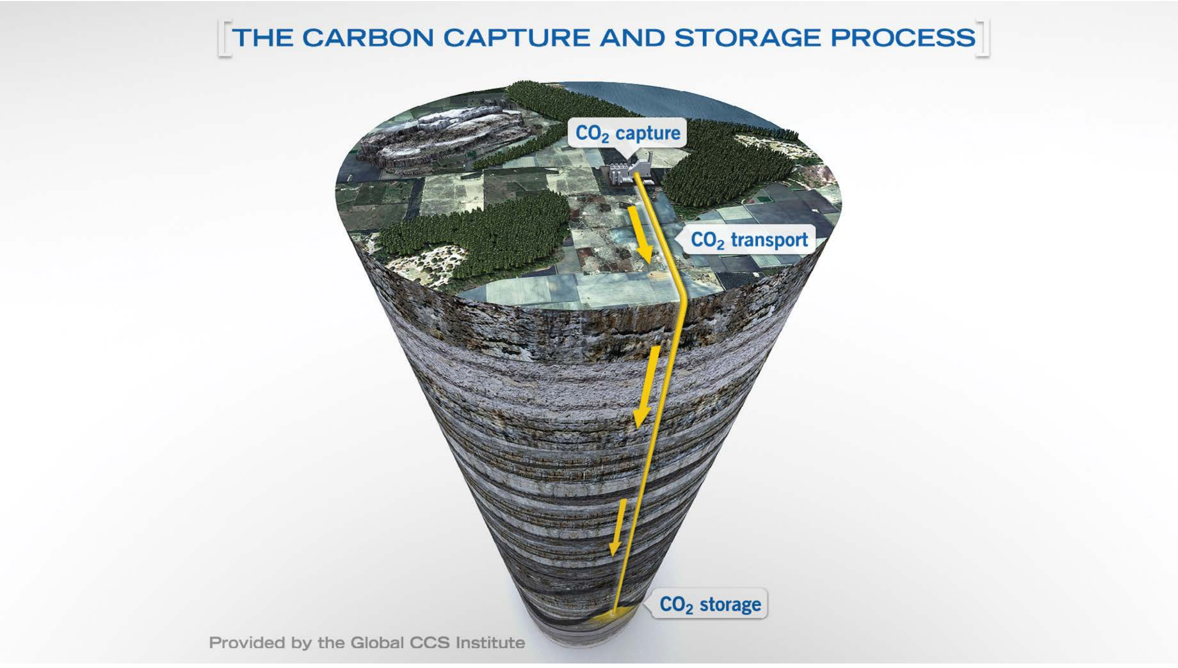
ACE hopes that this strategic paper will bring new insights, stimulate useful and productive discussions and to pave the way towards a unified action to develop and to deploy CCS in the ASEAN region for a low-carbon development path to achieving a sustainable energy system.

Dr. Hardiv Harris Situmeang
Executive Director
ASEAN Centre for Energy (ACE)

WHAT IS CCS?

Carbon capture and storage (CCS), sometimes called carbon capture and sequestration, prevents large amounts of carbon dioxide (CO_2) from being released into the atmosphere. The technology involves capturing CO_2 produced by large industrial and power plants, compressing it for transportation and then injecting it deep into a rock formation at a carefully selected and safe site, where it is permanently stored.

Figure 1: Carbon capture and storage



Because CCS can achieve significant CO_2 emission reductions, it is considered a key option within the portfolio of approaches required to reduce greenhouse gas emissions. CCS technology involves three major steps:

1. Capture: The separation of CO_2 from other gases produced at large industrial process facilities such as coal and natural gas power plants, oil and gas plants, steel mills and cement plants.
2. Transport: Once separated, the CO_2 is compressed and transported via pipelines, trucks, ships or other methods to a suitable site for geological storage.
3. Storage: CO_2 is injected into deep underground rock formations, at depths of one kilometre or more.

Why does the ASEAN region need CCS?

The world depends on energy, for which we rely predominantly on fossil fuels. Forecasts of global energy demand growth indicate that this reliance will grow for many decades to come with developing countries, many within the ASEAN region, consuming energy at increasing rates as their economies industrialise and standards of living continue to improve.

To avoid dangerous climate change, more than 100 countries have endorsed a goal for deep cuts in global emissions to hold the global average temperature rise at 2°C relative to pre-industrial times. To achieve this, we are dependent on a significant scale of CO_2 mitigation that could see CCS contribute between 15 and 55% of the required abatement to the year 2100 (IPCC, 2005).

Electricity sourced from fossil fuels accounts for more than 40% of the world's energy-related CO_2 emissions (IEA, 2011). Another 25% of emissions come from large-scale industrial processes such as iron and steel production, cement making, natural gas processing and petroleum refining. Demand for fossil fuels is increasing, especially in developing countries, where a significant percentage of the population has no access to electricity.

CCS is a viable option for reducing emissions from such large-scale sources. It has the potential to help reduce to almost zero the emissions released into the atmosphere from power plants and industrial plants.

CCS poses no greater environmental or safety risks than many aspects of the existing hydrocarbon industry; for instance natural gas storage in geological formations. However, the risks are not exactly the same, and they do have to be managed.

ASEAN'S LONG-TERM ENERGY PATH

Energy and sustainable development

The size and composition of the energy sector in ASEAN requires a carefully planned energy path to support sustainable development while at the same time meeting ASEAN's energy needs. Managing the energy system while ensuring sustainable development is one of the key roles of government. The energy sector plays a central role in supporting a country's social and economic development by maintaining a stable national energy supply. Other priorities include energy security and energy independence by utilising domestic energy sources and managing national reserves. To achieve a low-carbon development path in the energy sector, ASEAN countries are pursuing: expanding reliable energy infrastructure; decreasing dependence on fossil fuels (still the major source of energy in the region); promoting energy efficiency; promoting utilisation of renewable energy; and enhancing diffusion of low-carbon and zero-carbon energy technologies.

The preferred long-term national energy plan must be able to address the main challenges facing the energy sector in achieving sustainable development. Action is required to steer the national energy system towards a sustainable energy path while supporting national economic growth. The dual objectives of national energy security and reducing CO_2 emissions must be met. An integrated and optimal energy mix can be implemented using environmentally friendly technology. Due to emission constraints, fossil fuels cannot contiune to meet all of ASEAN's future energy needs, therefore technology improvements and knowledge transfer in the energy sector have become very important.

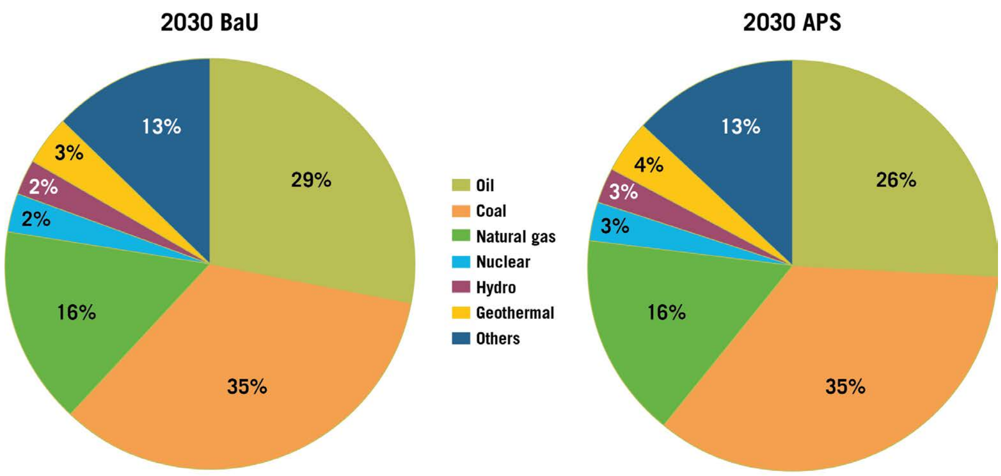
The energy technology development and deployment program needs to be based on consideration of geographic location, population growth, economic growth, living standards and patterns, environmental impact of technologies, and the endowment of energy resources. These key elements will influence the implemenation of national long-term energy plans. On the demand side, 'social readiness' will influence the willingness of consumers to reduce CO_2 intensive energy consumption to address climate change. Developing this 'social readiness' to encourage consumers to change their pattern of energy consumption should be considered in every step of energy policy design.

ASEAN Long-term energy path

ASEAN is one of the fastest growing economic regions in the world, driven by a growing middle class, urbanisation and industrialisation, as well as economic integration of its ten member countries. This growth had a consequential increase in primary energy consumption which was calculated at 3.6% per annum from 1995 to 2007. Total primary energy consumption increased from 339 MTOE (million tonnes of oil equivalent) in 1995 to 511 MTOE in 2007, in which fossil fuels (oil, coal and gas) accounted for 64.6% in 1995 and increased to 72.4% in 2007.

Among the fossil fuels consumed in the region, coal had the fastest growth rate, increasing at an annual rate of 13.0%, mostly due to the installation of coal-fired power plants in the region. Natural gas had the second fastest growth at 6.5% per annum increasing its share from 16.4% in 1995 to 21.4% in 2007. Oil remains the major energy source in the ASEAN economies but its growth was relatively slower than other sources of energy at 2.2% per annum. As a result, its share in the primary energy mix decreased from 43.6% in 1995 to 36.2% in 2007. Renewable fuels, such as geothermal and hydropower, also grew in the same period, however their share remains low. The primary energy mix composition is shown in Figure 2.

Figure 2: ASEAN Primary Energy Mix, 1995 and 2007



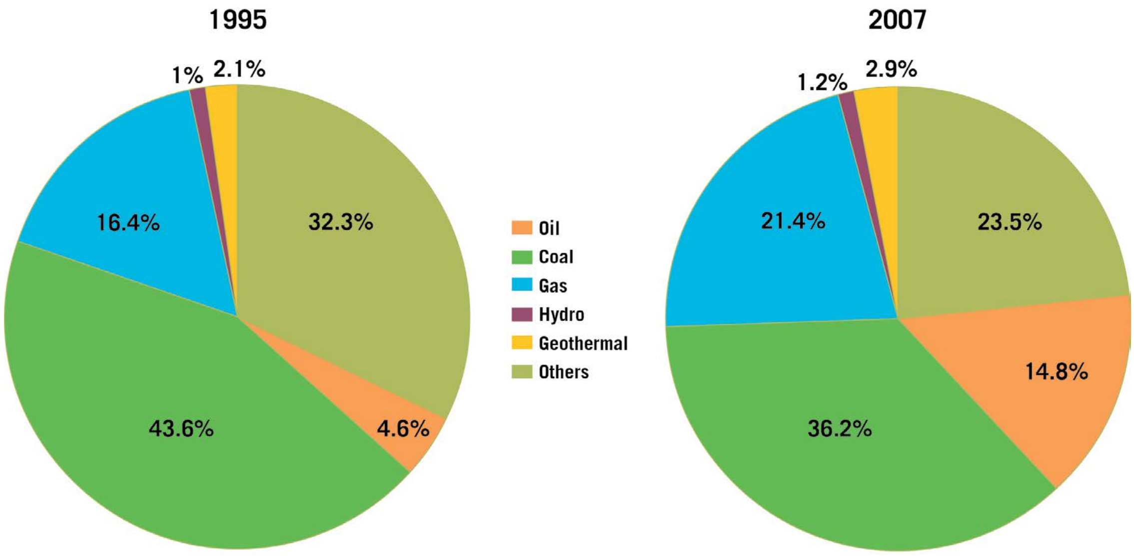
A similar pattern can be seen in the electricity generation mix. The individual shares of coal, oil and natural gas in the ASEAN has changed substantially from 1995 to 2007; coal increased from 13.4% to 27.3%, oil decreased from 31.4% to 10.6% while the gas increased from 36.7% to 45.9%. The total share of fossil fuels increased from 81.4% in 1995 to 83.8% in 2007.

This fossil fuel growth is expected to continue into the future. As described in the 3rd ASEAN Energy Outlook (ACE, 2011), the current trend of the energy path will stay the same, where fossil fuels are expected to remain the dominant source of energy and the biggest share in region's energy mix. Until 2030, it is expected that fossil fuels remain the major energy driver to fulfill regional energy demand growth.

Under a Business-as-Usual (BaU) Scenario, with an assumed GDP growth rate of 5.2% per annum from 2007 to 2030, the primary energy consumption is expected to grow at 4.5% per annum on average, to reach 1,414 MTOE in 2030. Hydropower is expected to grow at 7.1% per annum as countries in the Greater Mekong Sub-region develop their vast hydropower potential for electricity trade with their neighbours, nuclear power is expected to be introduced, and the region continues to promote renewable energy. Nevertheless, the share of fossil fuels is still growing, and anticipated to reach 80.4% in 2030.

Under an Alternative Policy Scenario (APS), the growth of primary energy consumption will be slower at 3.6% per annum, representing 1,152 MTOE in 2030. This is the result of implementing energy efficiency, conservation action plans and saving targets of member countries. However even under the APS, the share of fossil fuels remains higher than the year 2007 level, at 77.3% in 2030. The energy mix for both scenarios can be seen in Figure 3 below.

Figure 3: ASEAN Primary Energy Mix 2030, BaU and APS



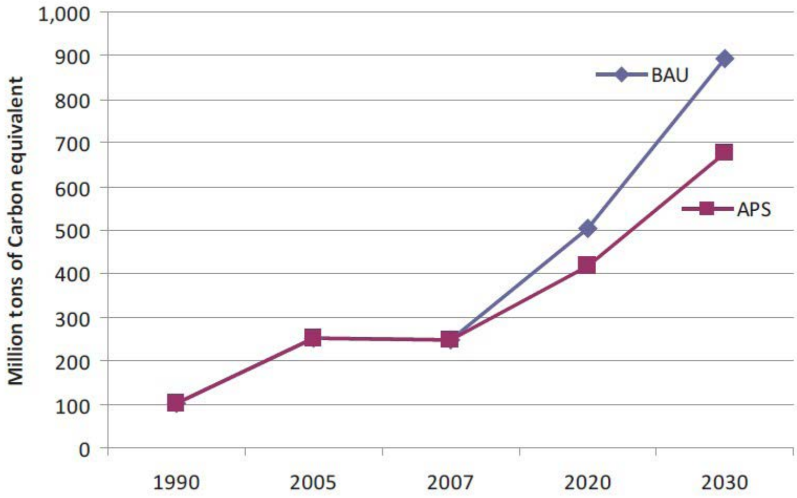
Current and long-term CO_2 emission path

As ASEAN continues to pursue its economic and development goals by being heavily dependent on fossil fuels (coal, oil and gas), CO_2 emissions will consequently continue to grow if low-carbon technologies are not utilised. As depicted by Figure 4, CO_2 emissions from the energy sector in 2007 was 283 Mt-CO_2e (million tonnes of carbon dioxide equivalent). The Outlook (ACE, 2011) projected that the 4.5% annual growth in primary energy consumption under the BaU scenario will result in a corresponding 5.7% growth in CO_2 emissions. This is due largely to the escalation of coal consumption which is the most carbon-intensive fossil fuel, along with oil and natural gas consumption. This increasing energy consumption will have a corresponding increase in CO_2 emissions contributing to global warming. To counter this trend, the introduction of large scale, low-carbon energy technologies is required to be embedded into long-term national energy programs.

The implementation of the APS for reduction of associated greenhouse gas emissions is expected to slow the CO_2 emissions annual growth rate to 4.4%. This is the result of implementing the energy efficiency and conservation (EE&C) action plans, reduction in fuel consumption from end-users and power generation, as well as the deployment of low-carbon and zero-carbon energy technologies.

Total CO_2 emission in the APS is estimated to be about 679 Mt-CO_2e, 24% lower than the BaU scenario (895 Mt-CO_2e).

Figure 4: CO_2 Emission in the Reference and Alternative Scenarios, in Mt-C



Under the BaU growth rate, emissions are expected to continue to rise along with population growth and increases in standards of living – factors that drive the demand for energy. CO_2 emissions per unit of energy consumption would therefore increase from 0.49 t-CO_2e (tonnes of carbon dioxide equivalent) in 2007 to 0.63 t-CO_2e in 2030 under the BaU scenario, and 0.59 t-CO_2e under the APS. CO_2 emissions per unit of GDP would also increase at the average annual rate of 0.5% from 283 t-CO_2e/million USD in 2007 to 317 t-CO_2e/million USD in 2030 in BaU. In APS, on the other hand, CO_2 intensity is expected to decrease by 0.7% per year to 240 t-CO_2e/million USD.

In line with the above trend, it's required that the ASEAN long-term CO_2 emissions path needs to be curbed. This requires an increased role for low-carbon and zero-carbon energy technologies to be embedded in the long-term national energy programs in order to achieve low carbon development path in the ASEAN energy sectors. With its ability to reduce emissions up to 90% from large point source emitters - such as coal fired power plants, coal gasification and liquefaction plants, and oil and gas processing plants – CCS is an important low-carbon technology.

Climate Change Considerations

ASEAN'S REGIONAL RESPONSE TO CLIMATE CHANGE

With the projected continued dominance of fossil fuels, ASEAN may become one of the big contributors to global warming. At the same time, ASEAN is also at risk from the impacts of climate change with lesser ability and capacity to cope with its effects, compared to other regions. Some governments, already faced with financial constraints, will be confronted with additional costs associated with climate change mitigation and adaptation in the future.

Acknowledging this situation, the 25th and 26th ASEAN Ministers of Energy Meeting (AMEM) held in November 2007 in Singapore and in August 2008 in Bangkok, Thailand, respectively, provided the guidelines and directives towards, among other things: enhance regional cooperation on energy; to further intensify cooperation in the area of energy efficiency and conservation; and to mitigate greenhouse gas emissions.

Through the ASEAN Plan of Action for Energy Cooperation (APAEC) 2010-2015 adopted at the 27th AMEM in Mandalay, Myanmar on 29 July 2009, ASEAN recognised global and regional issues and challenges on energy and climate change. Furthermore, energy and climate change was the theme of the 28th AMEM in Da Lat, Viet Nam on 22 July, 2010. The Ministers noted the Leaders' vision for an ASEAN Community resilient to climate change, as set out in the 2009 ASEAN Leaders' Statement on Joint Response to Climate Change. In this respect, the Ministers re-affirmed their commitment towards strengthening efforts to address climate change and enhancing ASEAN energy cooperation towards a low-carbon, green economy. This is in line with the overall APAEC 2010-2015 goals to enhance energy security and sustainability for the ASEAN region including health, safety and environment through accelerated implementation of the action plans.

EMISSION GOALS

Despite ASEAN not yet setting a specific target for CO_2 emission reductions, energy efficiency is seen as one of the most cost effective ways to enhance energy security and address climate change in the region. The ASEAN Energy Ministers agreed to pursue the aspirational goal of reducing regional energy intensity of at least 8% by 2015 based on 2005 levels, as stipulated in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2010-2015, Program Area No. 4 Energy Efficiency and Conservation.

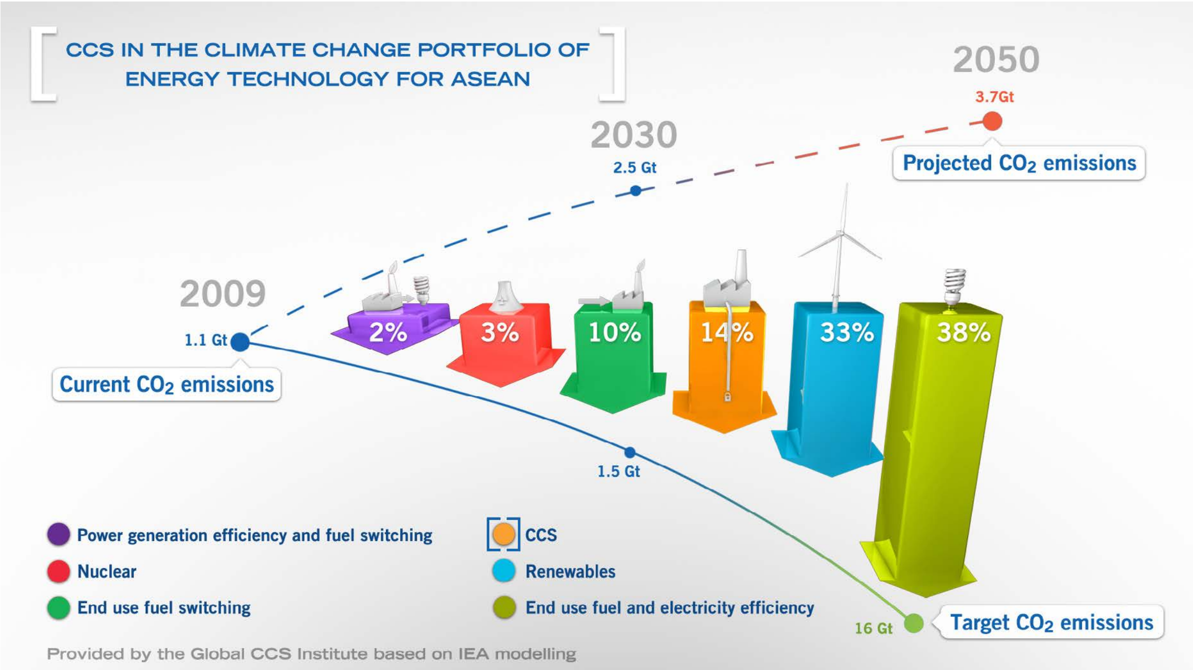
On a more technical level, through APAEC 2010-2015, ASEAN also set collective actions to strengthen cooperative partnerships in the promotion and utilisation of coal and clean coal technologies among the Member States. In supporting this plan, it is the view of ASEAN that the ASEAN long-term CO_2 emissions path needs to be curbed which requires an increased role for low-carbon and zero-carbon energy technologies. The implementation of these low-carbon technolgoies needs to be embedded in the long-term national energy programs in order to achieve a low carbon development path in ASEAN energy sectors.

The widespread use of existing energy-efficient technologies and the development and deployment of new low-carbon and zero-carbon energy technologies will be necessary to reduce greenhouse gas (GHG) emissions globally in order to stabilize GHG atmospheric concentrations at a safe level, and contribute to a coherent global mitigation effort. It is of critical importance to achieve this target without sacrificing economic progress, and balance the cost of GHG emissions mitigation and its supporting policies.

It is important that the full range of technological options should be eligible for abating climate change. A suite of policies and regulations should establish performance criteria including environmental criteria for suitable energy technologies while also encouraging further research and innovation.

CCS CONTRIBUTION TO EMISSION REDUCTIONS IN ASEAN

Figure 5: Portfolio of technologies needed to achieve emission reduction targets in ASEAN



The International Energy Agency (IEA) has modelled the lowest cost pathway to achieving the required emissions reductions to cap temperature rise at 2°C relative to pre-industrial times. The IEA have undertaken this modelling on a global, regional, and in some cases country level.

The IEA estimates that CCS could contribute 14% of global emission reductions out to 2050. If CCS were to be excluded as a low-emission technology option in the electricity sector, the IEA estimates that the investment costs over the period to 2050 – to reach the same CO_2 abatement – could increase by 40%, or approximately US$2 trillion. The costs of reducing emissions and addressing climate change are likely to be substantially higher if CCS is excluded.

The diagram above illustrates the portfolio of technologies required to achieve the necessary emissions reductions in ASEAN. It can be seen that CCS is a vital component of the ASEAN-specific portfolio, also contributing an estimated 14% cumulatively, i.e. from 2009 to 2050.

CCS ACTIVITIES IN ASEAN

This section provides a brief snapshot of CCS activities in ASEAN Member States.

Cambodia

Cambodia is participating in The Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP) regional storage program. With support from the Global CCS Institute and the Norwegian Ministry of Foreign Affairs, CCOP is developing a cross-border mapping program to characterise storage reservoirs within the Southeast Asia region. The project is designed to support existing CO_2 geological storage activities and kick-start implementation of storage mapping in member countries without an existing program. The mapping program aims to provide a forum for knowledge sharing among the member countries and develop a guideline for national CO_2 storage mapping along with a CCOP CO_2 Storage Atlas.

Useful references

More information on the CCOP storage program can be found on the CCOP website: http://www.ccop.or.th/ccsm/

Indonesia

Indonesia was the first of the ASEAN Member States to commence comprehensively investigating the potential for CCS, and is arguably the most advanced. An Indonesian CCS Working Group produced a report in 2009 called *Understanding Carbon Capture and Storage Potential in Indonesia*. This Working Group comprised of LEMIGAS, British Embassy Jakarta, Kementerian Lingkungan Hidup, Shell Interantional, PT PLN (PERSERO) and the World Energy Council (Komite Nasional Indonesia). The study found that the two regions with the most potential for CCS linked to enhanced oil recovery were in East Kalimantan and South Sumatra.

CCS PROSPECTS IN SOUTH SUMATRA

The Asian Development Bank (ADB) has more recently published a report called Prospects for Carbon Capture and Storage in Southeast Asia, which explores the prospects for CCS in Indonesia, Philippines, Thailand and Viet Nam (and was supported by the Global CCS Institute). The study identifies major CO_2 sources and sinks within these countries. The study focused on significant sources of emissions in the South Sumatra region for Indonesia. The study identified five significant sources of CO_2 emissions in this region, including a natural gas processing facility, a power plant, a cement plant, a fertiliser plant and a petroleum refinery.

The report found there were a number of natural gas processing facilities that would also represent significant sources of CO_2 in the region; although data was not available for these plants so they were not further investigated as part of the study. Although natural gas processing plants emit lower quantities of CO_2 than the other identified sources, the high purity of CO_2 flows resulting from the separation process already undertaken make natural gas potentially more economically viable for CCS. The five sources of emissions that were assessed had a total of approximately 8 million tonnes (Mt) per annum (pa), with the fertiliser plant the single largest contributor.

The study ranked the emission sources using a two-step process. The first step identified emission sources that had "(i) remaining operating life of at least 20 years, and (ii) plants must have limited operational variability (i.e. exceed an 80% operating factor) so that a steady stream of CO_2 is produced." (ADB, 2013, p19) The second step ranked the emission sources against 11 preferential criteria. Based on this ranking process, the sources that emerged as well placed for a pilot or demonstration project in South Sumatra were:

1. a natural gas processing plant, which produces 0.15 Mt CO_2 pa
2. a sub-critical pulverized coal power plant which produces1.8 Mt CO_2 pa
3. a fertilizer (urea) plant which produces 2.7 MT CO_2 pa. However currently all of this CO_2 is consumed for the production of urea; but with a possible switch from natural gas to coal as the fuel source, this may produce more CO_2 for sequestration.

STORAGE CAPACITY

The study also looked at potential storage capacity, in different geologic storage 'containers'. The study estimated CO_2 storage capacity in the South Sumatra region to be:

- Saline aquifers – theoretical capacity 7.7 giga-tonnes
- Oil fields – effective capacity of 0.1 giga-tonnes
- Gas fields – effective capacity 0.8 giga-tonnes
- Coal bed methane – theoretical capacity of 2.7 giga-tonnes.

This indicates that, theoretically at least, there is enough storage capacity to store the CO_2 emissions from the identified significant sources in the region. Other regions of Indonesia might present further storage opportunities. It is also important to note that only 59% of all existing oil fields and 47% of all gas resources in the South Sumatra basin were evaluated, due to the availability of information. This means that the effective capacity of storage in the oil and gas fields would likely be higher than the statistics noted above.

It can be seen from the figures above, that the greatest storage capacity exists in saline aquifers. However, storage in depleted oil and gas fields, and storage linked to enhanced oil recovery, represent more cost effective options in the shorter term. Depleted oil and gas fields also have the most storage data available for assessment.

Of the 85 oil and gas fields assessed in the South Sumatra region, 44 were judged to have 'medium' suitability for storage. The top three or four highest ranking fields are oil fields that could provide 28 Mt CO_2 of storage.

FIRST-MOVER PROJECT OPTIONS

The study authors used their analysis of CO_2 sources and storage options - known as 'sinks' - to identify suitable pilot scale projects that could be scaled-up to commercial-scale projects in time.

They found the gas processing plant is well located in relation to storage for a pilot scale project, but would have to be combined with another source of CO_2 for a commercial-scale project. Fortunately, there are other CO_2 sources within a 150 km radius, making this an option.

The coal fired power plant emerges as the best source for a commercial scale source of CO_2 located near the oil reservoirs in the south and central South Sumatera Basin. There are attractive CO_2-EOR opportunities in Indonesia that could be utilised for pilot or commercial scale projects.

LEGAL AND REGULATORY

A legal and regulatory analysis was undertaken as part of the study, to identify what aspects of Indonesia's existing framework would be applicable to regulating CCS. A high-level overview is available in the summary report, and Indonesian government officials have access to the more detailed country-level report.

The ADB, Japan International Cooperation Agency and Pertamina are collaborating on a CCS Feasibility Study for a test injection plant in South Sumatra. This project fits within Indonesia's Roadmap for CCS Pilot in Indonesia, 2012 – 2018. In addition, this project will review in more detail the legal and regulatory aspects required to undertake a CCS pilot project in Indonesia.

Indonesia is also participating in the CCOP regional storage programme, and is in fact one of the 'case study' countries.

Useful references

- Asian Development Bank, Prospects for Carbon Capture and Storage in Southeast Asia, http://www.adb.org/publications/prospects-carbon-capture-and-storage-southeast-asia
- Indonesia CCS Study Working Group, Understanding Carbon Capture and Storage Potential in Indonesia, http://www.ukccsrc.ac.uk/system/files/ccspotentialindonesia.pdf

Lao PDR

Lao PDR is also participating in the CCOP regional storage programme.

Malaysia

Following the completion of a Malaysian CCS Study, the Global CCS Institute has implemented a tailored CCS capacity development program in partnership with the Ministry of Energy, Green Technology and Water (KeTTHA) and other Malaysian stakeholders. This program has included the introduction of a CCS course into key Malaysian Universities and preliminary legal and regulatory analysis. The legal and regulatory analysis builds on the analysis of the Malaysian legal and regulatory framework undertaken as part of the APEC study on *Permitting Issues Related to Carbon Capture and Storage for Coal-Based Power Plant Projects in Developing APEC Economies*.

The University of PETRONAS (UTP) has established the Research Centre for Carbon Dioxide Capture, part of the university's nine mission-oriented research areas, this one focused on CO_2 management. This research complements UTP's parent company, PETRONAS', CO_2 mitigation plan which includes CCS in the future.

MALAYSIAN CCS SCOPING STUDY

The Malaysian CCS Scoping Study was completed in January 2011 and concluded that "Malaysia is well positioned to develop a strategy that includes CCS in its future energy supply and infrastructure, and there is a strong rationale for doing so." (CCI, 2011) Given Malaysia's active oil and gas industry, and high CO_2 content gas fields, it is likely that suitable storage would be available, particularly offshore. Onshore storage may also be a possibility; however there has been no geologic storage analysis for onshore.

The Scoping Study identifies some 'source-sink' clusters that have good potential in Malaysia. These include:

- cluster of point sources in eastern Peninsular Malaysia near Kerteh, which can access potential storage areas in the offshore Malay and Penyu Basins, and are connected via the Peninsular Gas Utilisation network
- cluster of point sources in Sarawak near Bintulu, which can access potential storage areas in the offshore Greater Sarawak, and are being connected via the Sabah-Sarawak Gas Pipeline under construction by PETRONAS
- cluster of point sources in northern Peninsular Malaysia near Kedah, which can access potential areas in the offshore Thailand-Malaysia Joint Development Area, and are connected via the Trans Thailand Malaysia pipeline
- cluster of point sources on the west coast of Peninsular Malaysia near Kuala Lumpur and Port Dickson which can access potential storage areas in the Penyu Basin or, assuming the resolution of trans-boundary transportation and storage issues, in basins located in neighbouring countries
- cluster of point sources in southern Peninsular Malaysia near Johor, which can access potential storage areas in the Penyu Basin or, assuming the resolution of trans-boundary transportation and storage issues, in basins located in neighbouring countries. (CCI, 2011, p25)

The Kerteh area has 21 facilities with large CO_2 emissions, totalling approximately 40 MT pa, and the Bintulu area has 9 large CO_2 emission facilities totalling more than 15.1 MT pa. With high-potential storage areas nearby, these two clusters may be particularly promising. (CCI, 2011)

Useful references

› Clinton Climate Initiative, Ministry of Energy, Green Technology and Water, Global CCS Institute, Malaysia CCS Scoping Study, January 2011 - available to Malaysian Government officials

› Hart, C., Tomski, P., Coddington, K., Permitting Issues Related to Carbon Capture and Storage for Coal-Based Power Plant Projects in Developing APEC Economies http://publications.apec.org/publication-detail.php?pub_id=1322

› Global CCS Institute, Malaysian CCS legal and regulatory workshop report, http://www.globalccsinstitute.com/publications/malaysian-ccs-legal-and-regulatory-workshop-report

Myanmar

It has been reported that a 600MW power plant being planned for the Dawei Special Economic Zone in Myanmar, is intending to utilise Japanese CCS technology as part of its environment management. (SNL, 2013) If this goes ahead, Myanmar could emerge as the ASEAN CCS front-runner.

Philippines

The potential for CCS in the Philippines was examined as part of the ADB's study on *Prospects for Carbon Capture and Storage in Southeast Asia*. The Philippines is also a participating country in the CCOP regional storage programme.

CCS PROSPECTS IN CALABARZON

The ADB study focused on the CALABARZON region in the Philippines, which is the acronym for the five provinces in the immediate vicinity of the National Capital Region or Metro Manila – CAvite, LAguna, BAtangas, Rizal and QueZON.

The total emissions in the Philippines in 2009 are estimated to be 69 Mt CO_2 e. The CALABARZON region in the Philippines has emissions of approximately 18 MT CO_2 pa, which includes three coal fired power plants, three gas-fired power plants, three cement plants and an oil refinery. The top CO_2 sources identified as part of the study were:

- a sub-critical pulverized coal power plant which produces 3.1 Mt CO_2 pa in Mauban, Quezon
- a natural gas combined cycle power plant, which produces 3.1 Mt CO_2 pa in Batangas
- a natural gas combined cycle power plant, which produces 2.8 Mt CO_2 pa also in Batangas.

However, the ADB's two-step ranking process of CO_2 sources outlined in the 'Indonesia' section above also included an examination of future capture sources from coal and gas fired power plants for the Philippines. This ranking revealed only one future natural gas plant with estimated CO_2 emission of 1.5MT pa that met the conditions to be considered a candidate for capture by 2020.

STORAGE CAPACITY

The storage estimates for the Philippines were based on only two sedimentary basins (Cagayan and Central Luzon Basin) representing one eighth of the possibilities that exist in the country. For these basins, the study estimates storage capacity to be:

- Saline aquifers – theoretical capacity 22.7 giga tonnes. This could theoretically hold all the emissions from Calabarzon for more than 100 years.
- Gas fields – effective capacity 0.3 giga tonnes.

FIRST-MOVER PROJECT OPTIONS

The study found that the best source-sink combination for a pilot/demonstration plant in the Philippines links the CO_2 sources in the CALBARZON region with the storage potential in the currently producing offshore gas fields. This scenario assumes that a 504 km natural gas pipeline could be utilised for CO_2 transport, once the gas field stops producing. However, it is unlikely that the production of gas will cease before 2030.

The Central Luzon Basin – a saline aquifer – is located within a viable distance from the large sources of CO_2 in CALBARZON. However, the Central Luzon Basin has more seismic activity than the Northwest Palawan Basin, which is further away from the CO_2 sources, but is nevertheless a possible storage option (and was not analysed as part of the study).

Given the Philippines has limited 'near-term' opportunities for storage in their oil and gas fields, other potential storage options include geothermal, ophiolites and coal seams. For instance, "there are three geothermal areas within 150 km of CALABARZON which warrant further consideration as potential storage sites." (ADB, 2013, p39)

LEGAL AND REGULATORY

Philippine Government officials have access to the more detail country-level study, which includes a legal and regulatory review. Like Indonesia, there are aspects of the Filipino legal and regulatory framework that are applicable to CCS (e.g. environmental protection requirements, occupational health and safety standards etc) but any CCS projects will require the consideration of CCS-specific issues, such as legal liability and CO_2 pipeline transport.

Thailand

Thailand was also examined as part of the ADB's study on *Prospects for Carbon Capture and Storage in Southeast Asia*, and is also a participating country in the CCOP regional storage programme. The Thai Ministry of Energy has established a CCS Taskforce and is working towards the development of CCS.

CCS PROSPECTS IN THAILAND

The ADB study identified that Thailand's total greenhouse gas (GHG) emissions were 230 MT CO_2 equivalent (eq) in 2000. The study surveyed "over 50 potential sources of CO_2 across four sectors – power, cement, natural gas processing, and oil and gas production, which represented the best capture sources. Collectively, these sources produce approximately 108 Mt per year." (ADB, 2013, p19) Of these sources, and using the two-step screening process, the study authors identified the top three CO_2 capture candidates in Thailand:

- a natural gas processing plant that produces 2.0 Mt CO_2 pa in central Thailand
- a natural gas processing plant that produces 0.9 Mt pa in south Thailand
- a super-critical coal (bituminous) power plant that produces 3.1 Mt pa in central Thailand.

STORAGE CAPACITY

The study estimated CO_2 storage capacity in Thailand to be:

- saline aquifers – theoretical capacity 8.9 giga tonnes
- oil fields – effective capacity 0.1 giga tonnes
- gas fields – effective capacity 1.3 giga tonnes.

"Thailand's top three oil and gas fields best suited for CO_2 storage could store as much as 350 Mt CO_2. Two of these three fields are primarily producing gas… The highest ranked storage site is also Thailand's largest single volume storage option in an oil and gas field. The site is estimated to be able to hold 240Mt CO_2…and could become available for storage by 2017." (ADB, 2013, p33)

FIRST-MOVER PROJECT OPTIONS

Thailand has a number of good opportunities for pilot scale projects that could transition to a commercial scale project. For instance, CO_2 from the 2.0Mt pa natural gas processing plant in central Thailand could store CO_2 in adjacently located gas fields – one which has a storage capacity of 22 Mt CO_2 and other with a storage capacity of 41 Mt CO_2. For emission sources located near the coast, there are a number of offshore sinks in the Gulf of Thailand. A cluster of power plants near Bangkok produces a large amount of CO_2 which could be stored in offshore storage sites 200 km away; this distance makes it more suitable for commercial-scale project. The study recommends a demonstration project associated with enhanced oil recovery (EOR) as the most cost effective option, with both onshore and offshore fields available.

Viet Nam

Viet Nam was also investigated as part of the ADB study, and it is also a participating country in the CCOP storage programme. In addition, PetroVietnam has undertaken the 1st phase of an in-house study on CO_2 injection sites for EOR. Interestingly, a proposed CCS project in Viet Nam, White Tiger, kicked started the debate of CCS in the Clean Development Mechanism (CDM) in 2005. In 2011, CCS became an eligible mitigation technology under the CDM.

FUTURE PROSPECTS FOR CCS

For Viet Nam, the ADB study examined future CO_2 capture sources that are expected to come online from 2012 to 2016, including 35 coal power plants, four gas power plants and several smaller steel and cement plants. This was because "none of the existing CO_2 sources had favorable characteristics to contribute to pilot and commercial-scale CCS projects." (ADB, 2013, p22) The potential emissions from these future capture sources are expected to be 325MT in 2025. Of these future plants, the study's two-step selection process identified the top three ranked capture candidates to be:

- a natural gas combined-cycle plant expected to produce 2.2Mt CO_2 pa located in Dong Nai Province
- a subcritical domestic coal power plant expected to produce 15.2 Mt CO_2 pa located in Binh Thuan Province
- a subcritical domestic coal power plant, expected to be produce 4.0Mt CO_2 pa located in Ha Tinh Province.

The sub-critical power-stations have large CO_2 streams and other characteristics which meant they were ranked as good capture candidates; however, they are not ideal for CCS given their low efficiency. It is expected that future gas-processing facilities, which will likely process higher CO_2 content gas, will strip out the CO_2 as part of normal operations to meet gas specifications. This will produce a high-volume, high-purity CO_2 stream amenable to capture and storage more cost effectively (similar to the situation in Indonesia and Thailand).

STORAGE CAPACITY

The storage assessment of the study focused only on saline aquifers for which data was available as part of the petroleum system. However, there may be other saline aquifer storage options available in Viet Nam that were not assessed. For this reason, the saline storage estimate will most likely be lower than what is actually available. Nevertheless, based on the assessment undertaken, the study estimates:

- Saline aquifers – theoretical capacity 10.4 giga tonnes
- Oil fields – effective capacity 0.6 giga tonnes
- Gas fields – effective capacity 07 giga tonnes
- Coal bed methane – theoretical capacity 0.5 giga tonnes.

Viet Nam has some of the best ranked oil and gas fields suitable for storage, and the best storage sites also offer good EOR potential in Viet Nam. "The largest single volume site has an estimated storage capacity of 357 Mt CO_2 with 200 production wells and could be immediately available for EOR." (ADB, 2013, xxiii)

FIRST-MOVER PROJECT OPTIONS

The storage in the northern part of the country is too small to be scaled up for a commercial-scale project. There are good storage opportunities in the southern part of the country, with a major CO_2 'storage hub' of eight offshore oil-bearing fields in the Cuu Long Basin. This 'storage hub' is within a viable transport distance (of ~150 km) of three 'emission hubs'. These emission hubs include the NGCC plant and the proposed supercritical and subcritical coal power plants. As noted above, the large gas-processing plants that may become available in the future may offer even better opportunities for capture.

Once coal-bed methane production becomes commercial in Viet Nam, this might also offer good storage opportunities.

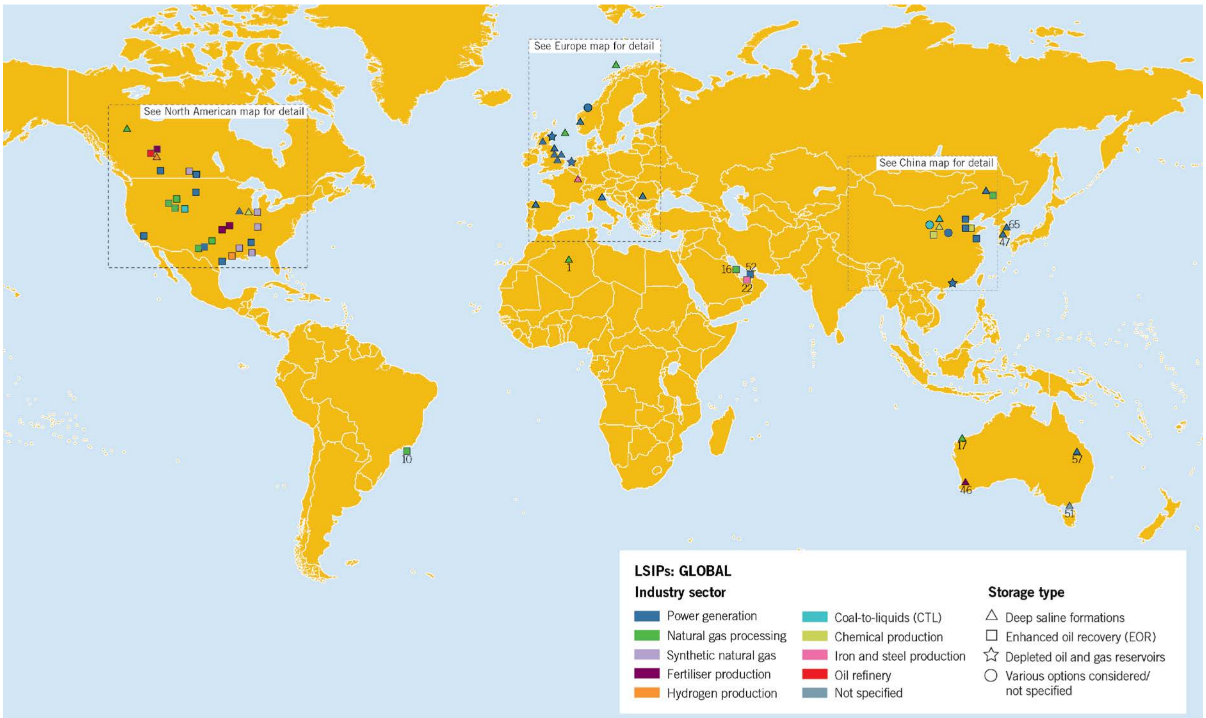
OVERVIEW OF CCS READINESS

As at October 2013, there are 65 large-scale integrated projects (LSIPs), either active or planned, around the world. To be counted as 'integrated' the project must have all three elements of the CCS chain – capture, transport and storage. Large scale means that the project is capturing:

- at least 800,000 tonnes of CO_2 annually for a coal-based power plant, or
- at least 400,000 tonnes of CO_2 annually for other emission-intensive industrial facilities (including natural gas-based power generation).

The map below illustrates where these projects are located.

Figure 6: Map of LSIPs



Of these 65 LSIPs, 12 are already operating, and a further 8 are under construction. A further 45 are in the Define, Evaluate, or Identify stages. The table in Appendix I summarises the 20 projects either operating or under construction. It can be seen from this table that most projects are associated with industry, where CO_2 capture is already an inherent part of the process, thus making these projects economically viable at this stage of development.

It is important to note that this does not include the numerous smaller scale, often non-integrated, projects around the world. For instance, the Global CCS Institute is tracking 23 important smaller-scale projects in the Asia-Pacific region alone (projects located in Australia, Japan, China, South Korea, and Taiwan).

The component parts of carbon capture and storage have been in operation in various industries for decades. For instance, removal of high purity CO_2 is an inherent part of the process in: chemical production, coal gasification, coal-to-liquids, ethanol plants, fertilizer production, hydrogen production, and synthetic natural gas. The oil and gas industry has been storing CO_2 as part of the enhanced oil recovery (EOR) process for the last 50 years, and there are approximately 6,000 km of CO_2 pipelines in North America alone.

The challenge for CCS is integrating all three elements of the technology into a unified project, and scaling up the technology to capture the large volumes of CO_2 produced – especially at a power facility.

There are a number of well-known technical and non-technical challenges to CCS implementation, such as: cost, lack of legal and regulatory frameworks, addressing investor uncertainty, and public opposition. However, the successful demonstration of the technology at scale implies that the technical challenges can be overcome.

CCS already contributing to emissions abatement

CCS already plays an important role in tackling climate change. As can be seen in Figure 16 (page 27) in the Storage section, the 12 large-scale CCS projects in operation are already storing more than 25 million tonnes of CO_2 each year. With a further 8 projects under construction (including two in the electricity generation sector), that figure will increase to over 36 million tonnes of CO_2 a year by 2015.

In addition to these 65 LSIPs there are numerous pilot or smaller-scale demonstration projects around the world. These projects are not all integrated projects; often they are just capture and transport projects, or just storage projects. The table below lists the smaller-scale projects the Global CCS Institute is tracking in the Asia-Pacific region. These projects provide valuable lessons and contributions to the industry's understanding of different aspects of the technology, whether this is about performance, cost, monitoring measurement and verification, or even non-technical aspects such as public engagement and regulation.

Table 1: Smaller-scale operational projects in the Asia-Pacific region

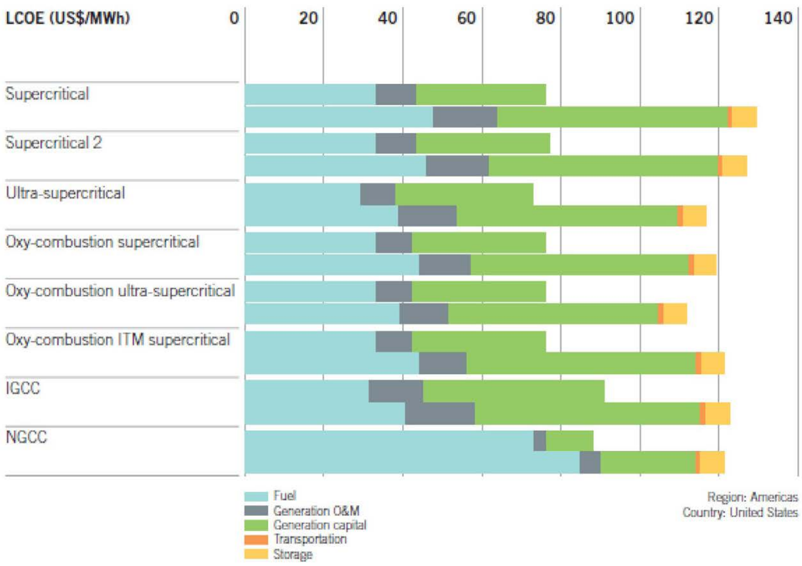
AUSTRALIA
Alcoa Kwinana Carbonation Plant
Callide Oxyfuel Project
CO_2CRC Otway Project
Hazelwood CO_2 Project
HRL IDGCC Demonstration Project
Lang Lang BassGas CO_2 Recovery Project
Loy Yang Power Large Scale PCC Demonstration Project
Perdaman Collie Urea Project
JAPAN
Course 50 Steel Project
Osaki CoolGen
Tomakomaj Integrated Project (several pilot and bench scale projects)
Wakamatsu EAGLE Project
CHINA
CPI Lang Fang IGCC-CCS Project
Guodian CO_2 Capture and Utilisation Project
HuaNeng GreenGen IGCC Project
Jilin Oil Field PetroChina EOR Project – Phase 1

Shanghai Shidongkou 2nd Fired Power Plant	
Shenhua Ordos CTL Project	
Sinopec Shengli oil field EOR Project	
Huazhong University 35 MW Oxy-Combustion Project	
KOREA	
Boryeong 10 MW thermal capture facility	
TAIWAN	
Taiwan Cement Corp calcium looping plant	
CPC YHS gas field CO_2 injection	

COST OF CCS

Figure 7 below is a 2009 analysis comparing the levelised cost of electricity (LCOE) [1]of a non-CCS plant with a CCS plant using numbers from the US Gulf Coast. It shows that capture and compression costs represent the largest proportion of CCS costs, followed by storage and then transport. For instance, on a post combustion capture CCS project approximately 94% of the CCS costs are for capture and compression, transport costs represents 1%, and storage costs represents about 5%.

Figure 7: Comparison of LCOE for reference generation, with and without CCS

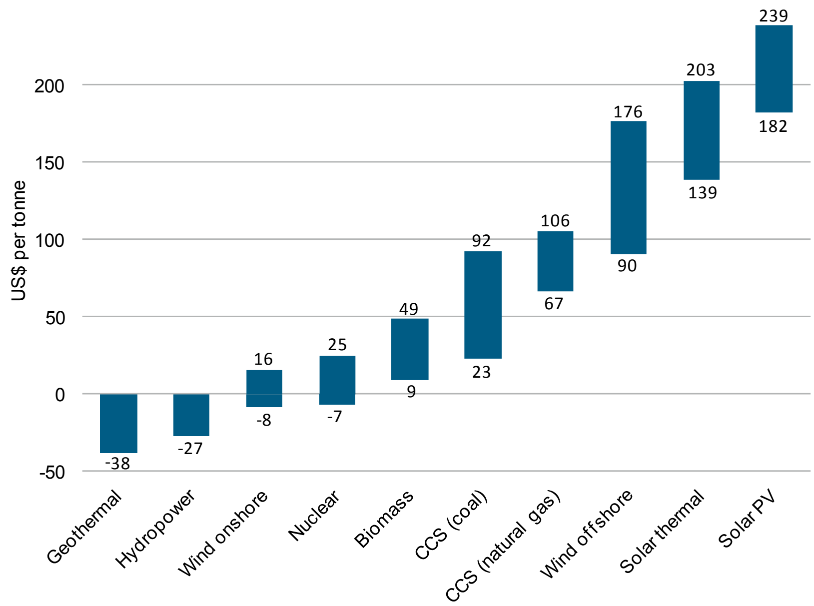


The cost of CCS is one of the key barriers to deployment. However, CCS is in fact cost competitive with other low-emission technologies (when compared without subsidies). The diagram below uses 'cost of CO_2 avoided' to compare the cost of different low emission technologies; this is the best method to compare the cost of low-emission technologies because it compares 'like with like'. It can be seen that CCS is more expensive than some low-emission technologies in terms of reducing CO_2 emissions, but cheaper than solar and off-shore wind. Using the best cost studies for CCS, it is estimated that CCS with coal costs between US$23-92 per tonne of CO_2 avoided; while CCS with natural gas costs between US$67-106 per tonne of CO_2 avoided[2]. The wide range illustrates that the actual costs are very site specific, and depend on the size of the plant, the technology being used, the labour and equipment costs etc.

[1] Levelised Cost of Electricity is the break-even electricity price for which a project owner can pay investors and creditors.

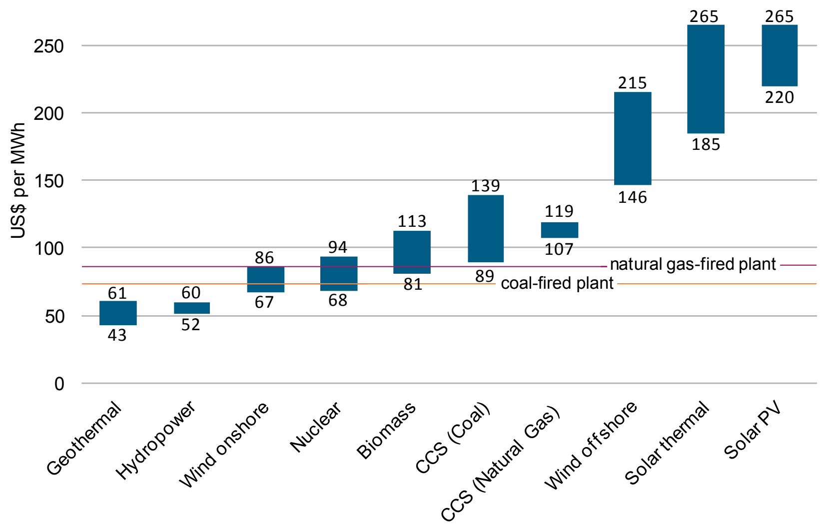
[2] These costs are based on a review of technologies costs studies by a number of agencies including the IEA, the IPCC, the US Energy Information Agency, WorleyParsons, the US National Energy Technology Laboratory and the US National Renewable Energ Laboratory. The discussion paper can be found at: http://www.globalccsinstitute.com/publications/costs-ccs-and-other-low-carbon-technologies

Figure 8: Costs of CO_2 avoided



Comparing the costs of low-emission technologies using 'levelised cost of electricity' illustrates the same story in terms of relative cost.

Figure 9: Levelised cost of electricity



It is important to remember that like all new technologies, costs are expected to dramatically decrease with implementation. The cost of the 'first-of-a-kind' projects, will be more expensive than 'nth-of-a-kind'.

Useful references

- Global CCS Institute, The Global Status of CCS:2013 Chapter 5: Capture, October 2013, http://www.globalccsinstitute.com/publications/global-status-ccs-2013
- NETL, DOE/NETL Advanced Carbon Dioxide Capture R&D Program: Technology Update, May 2013, http://www.netl.doe.gov/technologies/coalpower/ewr/pubs/CO_2Handbook/

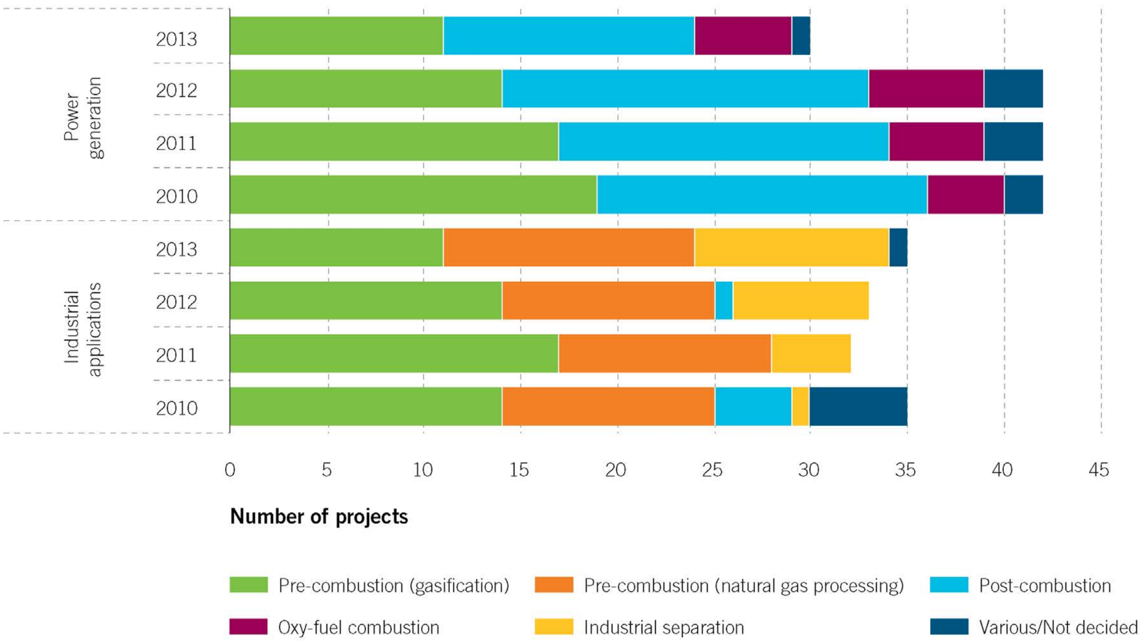
CO_2 CAPTURE TECHNOLOGIES

Capture technologies for power generation are generally grouped into three categories:

- Pre-combustion
- Post-combustion
- Oxyfuel

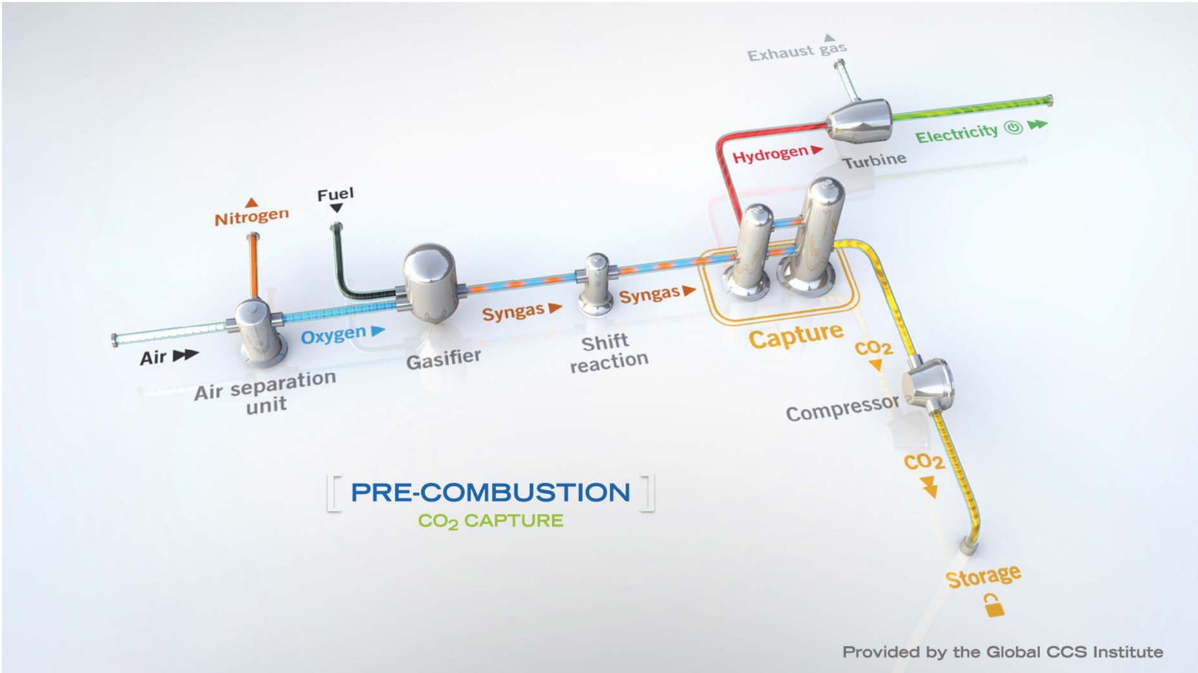
Figure 10 below illustrates the capture technologies either being used, or planned to be used, in the 65 large scale projects around the world. Pre-combustion (represented by the orange bars) is the most dominant type of capture technology at this stage, but all capture categories are represented.

Figure 10: LSIPs by capture type



Pre-Combustion

Figure 11: Pre-combustion capture



As the name implies, pre-combustion is where the CO_2 is stripped out before the combustion of the fuel. As can see on the diagram above, in electricity generation the process involves the production of syngas, from which the CO_2 is stripped out and sent to be compressed, and the remaining hydrogen is sent to the turbine for electricity generation.

Pre-combustion technologies currently use chemical or physical absorbents; with physical absorbents being predominant. Absorption is where a substance (e.g. a gas or liquid) sticks to the surface of another substance. This technology is mature and commercially available, given it has been used in various industrial applications for decades. The challenge lies in scaling up this technology for use in the power industry. It is in the scale-up where the significant 'energy penalty' and cost lie. Nevertheless, the volume, composition and the properties of the gas in the pre-combustion process holds the promise of lower parasitic power requirements than the post-combustion process.

The table below lists the smaller-scale power generation projects that are currently utilising pre-combustion capture, and notes the large-scale pre-combustion integrated projects (both power and industrial plants).

Table 2: Pre-combustion power generation projects

Plant	Country	Approx. Capacity (tpa CO_2)	Status		
			Under construction	Operational	Completed
Pre-Combustion Capture					
HuaNeng GreenGen	China	80,000	Y	By 2015	
Nuon Buggenum	Netherlands	10,000		Y	
Puertollano	Spain	35,000		Y	
Osaki CoolGen	Japan	200,000	Y	By 2017	
Wakamatsu EAGLE	Japan	8,000		Y	
Large-scale integrated projects					
10 projects in operation (refer Appendix I)					
5 projects under construction (refer Appendix I)					
20 projects in the planning stages (refer The Global Status of CCS: 2013 report, Appendix A.5)					

Advantages

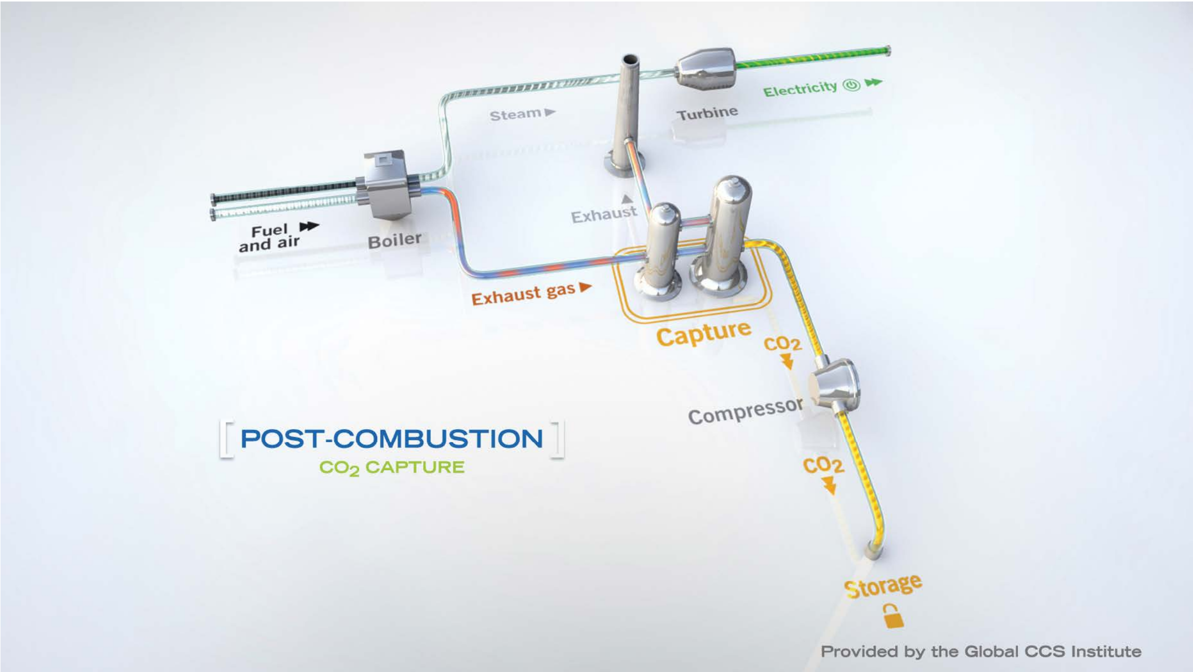
- CO_2 separation via solvent absorption is proven
- Lower parasitic load (compared to post-combustion) due to high CO_2 partial pressure
- Compression costs likely to be lower than post-combustion
- Lower SOx and NOx emissions
- Syngas can be utilised for other commercial applications after CO_2 removal
- A wide range of hydrocarbon fuels can be utilised as feedstock (oil, gas, coal, petroleum coke) (APEC 2009)

Challenges

- Energy penalty around 20%
- Commercial scale hydrogen turbine still to be demonstrated
- Gasification plants – with increased chain complexity beyond electrical engineering – are unfamiliar to the power sector.

Post Combustion

Figure 12: Post-combustion capture



Post combustion, again as the name implies, is where the CO_2 is stripped out of the flue gas derived after combusting fossil fuels in air.

Post combustion technology can utilise chemical and physical absorption, physical and chemical adsorption, cryogenic separation, membrane separation, or a combination of these. However, amine absorption technology is the most widely utilised. Absorption is where the CO_2 molecules are 'absorbed' into another material, e.g. CO_2 is dissolved into liquid amine solution. This solution is then heated, which releases the CO_2 back into a gas stream, leaving behind the amine solution, which is regenerated and can then be re-used.

Amine processes are commercially available and widely used in some industrial processes. Again the challenge lies in scaling-up the technology to strip out the massive amounts for CO_2 from a power station flue gas. However, it is notable that there are at least 9 test facilities operating and demonstrating post combustion capture from coal fired power generation, capturing (collectively) over 500,000 t of CO_2 per annum.

Table 3 below lists the smaller-scale power generational projects that are currently utilising post-combustion capture, and notes the large-scale integrated projects (both power and industrial plants).

Table 3: Post-combustion power generation projects

Plant	Country	Approx. capacity (tpa CO_2)	Status		
			Under construction	Operational	Completed
Post-combustion capture					
Aberthaw	UK	15,000		Y	
Boryeong	Korea	70,000		Y	
Ferrybridge	UK	15,000		Y	
Guodian	China	10,000	Y	by 2015	
Hazelwood	Australia	15,000		Y	
Mountaineer	USA	100,000			Y
Plant Barry	USA	167,000		Y	
Shanghai Shidongkou	China	120,000		Y	
Shengli	Shina	40,000		Y	

Technology Center Mongstad	Norway	100,000		Y	
Wilhelmshaven	Germany	25,000		Y	
Large-scale integrated projects					
1 project under construction (refer Appendix I)					
12 projects in planning stages					

Advantages

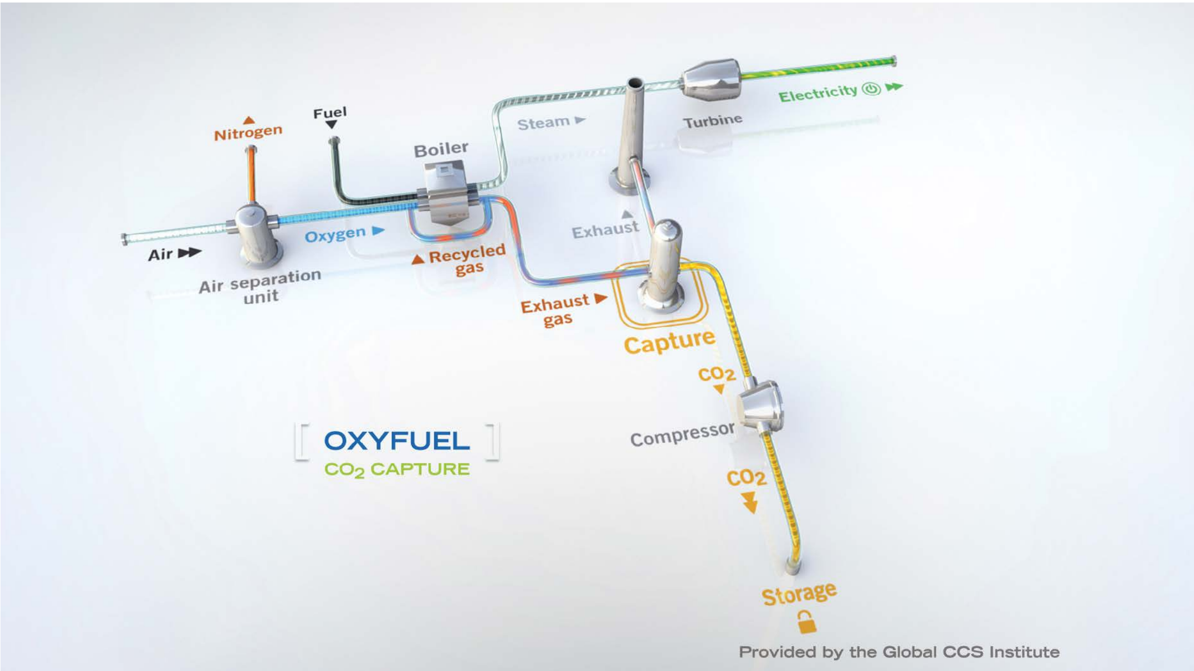
- Moderate temperatures and pressure imposes less stress on equipment
- Potential for retro-fit and integration (e.g. heat integration, gas recycling, etc)

Challenges

- Most technologies need significant scaling-up to be relevant to power generation
- High energy penalty around 30%
- Pre-treatment of flue gases (SOx and NOx)
- Highly integrated system increases complexity of system
- Increase in water required around 35%
- Significant space requirements could be a challenge at well-established sites
- Possible amine emissions into atmosphere.

Oxyfuel

Figure 13: Oxyfuel capture



Usually air is used to combust with fossil fuel. Air comprises about 78% nitrogen and 21% oxygen. Therefore when fossil fuel is combusted in air, the resulting flue gas has a lot of nitrogen – which leads to the low concentration of CO_2 in the flue gas. In the oxyfuel process, nitrogen is removed from the air in the air separation unit, leaving relatively pure oxygen. This relatively pure oxygen is combusted with the fossil fuel; this has the advantage of producing a relatively pure stream of CO_2 in the flue gas – which is a great benefit for capture and storage.

Oxyfuel plants have a number of major component systems. From the diagram, we can see these include: the air separation unit to provide a pure stream of oxygen; a boiler for burning the coal and oxygen (this is often under negative pressure and it produces the steam that can be used to drive a steam turbine); a capture unit that mainly separates moisture from a CO_2 stream.

The challenge for oxy-fuel capture is integrating all these major system components at a large scale which requires highly coupled and complex automation control.

The table below lists the smaller-scale power generation projects that are currently utilising oxy combustion capture, and notes the large-scale integrated projects both power and industrial plants).

Table 4: Oxyfuel power generation projects

Plant	Country	Approx. capacity (tpa CO_2)	Status		
			Under construction	Operational	Completed
Oxy combustion capture					
Callide	Australia	25,000		Y	
CUIDEN	Spain	<10,000		Y	
Huazhong	China	50,000	Y	By 2014	
Lacq Pilot CCS Project	France	<75,000		Y	
Schwarze Pumpe	Germany	60,000		Y	
Large-scale integrated projects					
5 projects in the planning stages					

Advantages

- Very high purity of CO_2 stream
- NOx formation is reduced
- Reduction in size and capital costs of plant equipment compared to conventional air-based combustion system
- Potential for retro-fit of power stations (APEC 2009)

Challenges

- Requires an integrated plant
- High temperatures and negative pressures put stress on equipment
- Development will require a whole of plant approach
- Air separation unit requires around 25% of electricity produced
- Start up using air may require additional gas treating equipment
- Increased water consumption.

There is currently no capture technology which stands out as a 'clear winner'; all the technologies have advantages and disadvantages. This may indicate that future carbon capture technology will be a highly diversified portfolio of technologies. While solvent-based technologies are more mature, other capture technologies currently being developed and/or demonstrated may offer step-change in the cost of capture.

Useful references

› Global CCS Institute, The Global Status of CCS:2013 Chapter 5: Capture, http://www.globalccsinstitute.com/publications/global-status-ccs-2013

› IEA, Technology Roadmap: Carbon Capture and Storage, http://www.iea.org/publications/freepublications/publication/name,39359,en.html

› NETL, DOE/NETL Advanced Carbon Dioxide Capture R&D Program: Technology Update, May 2013, http://www.netl.doe.gov/technologies/coalpower/ewr/pubs/CO_2Handbook/

CO_2 TRANSPORT

There are four options for the transportation of CO_2: pipelines, train, truck, ship, or a combination of these.

Sources (clockwise from top left): Environmental News Service, accessed 2013, Winnipeg Free Press, accessed 2013, Smartplanet, accessed 2013, CEM, accessed 2013.

Transportation of CO_2 and other gases by pipelines, trains, trucks and ships is already a reality, occurring daily in many parts of the world.

Given the large volumes of CO_2 that will be transported as part of large-scale CCS projects, pipelines will be responsible for the majority of the CO_2 to be transported. The total length of pipelines that would be required for all 65 large-scale integrated projects (LSIPs) globally is around 6,000 km. Pipeline engineering is a mature profession. Extensive networks of pipelines already exist around the world, both on land and under the sea. In the United States alone, there are about 800,000 km of natural gas and hazardous liquid pipelines, in addition to the 3.5 million km of natural gas distribution lines. Some 6,000km of pipelines actively transport CO_2 today.

However, ship transportation can be an alternative to pipelines in some parts of the world; in particular in regions where there is limited access to nearby CO_2 storage reservoirs. There are currently three LSIPs in the planning stages that are considering shipping their CO_2 to offshore storage locations: these include two CCS projects developed by the Korean Electric Power Corporation, and the Dongguan Taiyangzhou IGCC-CCS project in the Chinese province of Guangdong.

Truck and train transportation – suitable for much smaller volumes of CO_2 – may be an option for pilot-scale projects.

Risks and environmental impacts

CO_2 pipelines and ships pose no higher risk than that which is already safely managed for transporting hydrocarbons (such as natural gas and oil). Given the maturity of the pipeline profession, there are a number of standards and best practice guidance documents for CO_2 pipelines design, construction and operation[3]. "CO_2 is largely inert and easily handled" (DNV GL, 2013, p12). Nevertheless, CO_2 pipelines need to regulated to ensure management to mitigate corrosion and leaks to avoid CO_2 inhalation above normal levels (which can have a number of health impacts, e.g. from dizziness to asphyxiation), and cryogenic burns or physical impact injuries (that could potentially occur from pressurised leaks). CO_2 leaks from pipelines may also impact surrounding flora and fauna if not dispersed sufficiently.

In addition to the large number of best practice guidance documents for pipelines, the International Organization for Standardization (ISO) has commenced the development of standards for the full life-cycle of CCS, including CO_2 transportation.

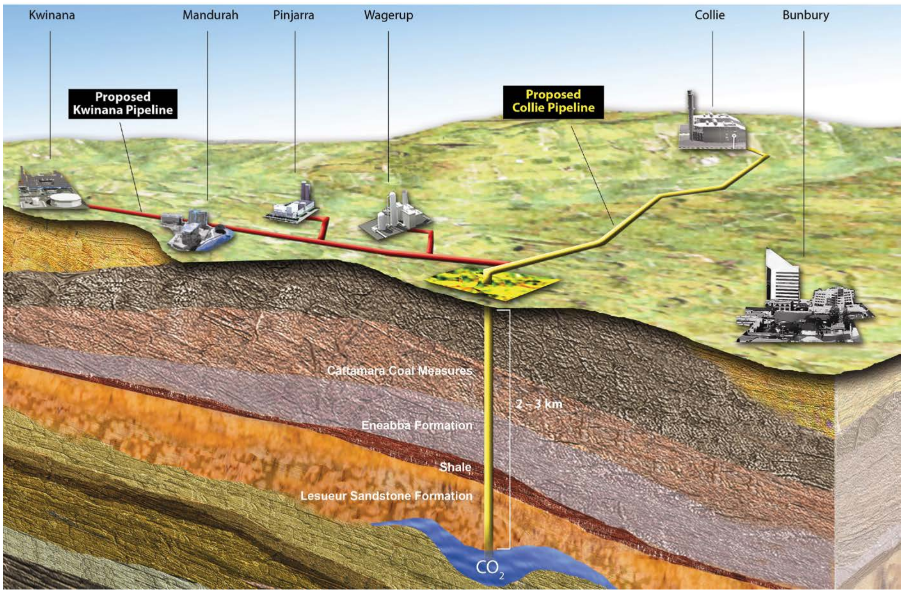
Useful references

- Petroleum Technology Research Centre & Global CCS Institute, What Happens When CO_2 is Stored Underground? Q&A from the IEAHGHG Weyburn-Midale CO_2 Monitoring and Storage Project, http://www.globalccsinstitute.com/publications/what-happens-when-co2-stored-underground-qa-ieaghg-weyburn-midale-co2-monitoring-and-storage-project

Transport Networks

The initial demand for CO_2 transportation capacity will likely unfold in an incremental and geographically dispersed manner as new dedicated capture plants, storage and EOR facilities are brought online. However, large-scale deployment of CCS would benefit from linking proximate (i.e. geographically close) CO_2 sources with suitable storage sites, either by ship or more likely by so-called 'back bone' pipelines, as illustrated in Figure 14, below.

Figure 14: Schematic overview of the South West Hub in Western Australia



Source: Government of Western Australia

The table on page 24 identifies the major CO_2 network initiatives related to CCS around the world.

[3] For instance DNV GL's CCS CO_2 Safety and Environment Major Accident Hazard Risk Management provides a comprehensive summary of key CCS risks and mitigation strategies, as just one well respected guidance document.

Table 5: CO_2 network initiatives related to CCS

CO_2 network proposals for CCS	Desciption and anchor LSIPs
Rotterdam CO_2 Hub (The Netherlands)	The Rotterdam CO_2 Hub aims to capture and store 5 Mtpa of CO_2 from anchor projects like ROAD and other industries in the port in 2015-17, expanding to 20 Mtpa in 2020-25 and providing the basis for low-carbon industrial and economic growth in Rotterdam.
Humber cluster (UK)	The Humber and Yorkshire region has the long-term potential to capture and store upwards of 40 Mtpa of CO_2 from many soures. Anchor projects include the White Rose Oxyfuel project, C.GEN North Killingholme Power Project, and Don Valley Power Project.
Teesside cluster (UK)	The cluster in the Teesside region would capture and store up to 15 Mtpa of CO_2 from the Teesside Low Carbon project, an aluminium smelter, and emission from other surrounding industries.
Scottish CCS cluster (UK)	The Captain Clean Energy Project could accelerate the development of a Scottish CCS cluster. The CO_2 captured in the Firth of Forth area will be transported by pipeline to the St Fergus terminal in close proximity to SSE's Peterhead project, where CO_2Deep Store will store it in depleted reservoirs under the North Sea.
South West Hub (Australia)	The South West CO_2 Geosequestration Hub project in Western Australia aims to collect 5-6 Mtpa of CO_2 by 2018-22 from industrial processes, including the Perdaman Collie urea project, as well as from alumina production and power facilities for storage in the Lesueur formation in the Southern Perth Basin.
CarbonNet Project (Australia)	The CarbonNet CCS network aims to integrate multiple CCS projects across the entire CCS value chain within the next 10 years. The network is initially sized to capture and store around 1 Mtpa of CO_2 from emission sources in the Latrobe Valley by 2018, with the potential to rapidly scale up to support more than 20 Mtpa thereafter.
Masdar CCS Project (UAE)	The Abu Dhabi CCS network (Masdar) aims to capture CO_2 emissions from existing power and industrial sites, as well as develop a network of CO_2 pipelines to transport the CO_2 to Abu Dhabi's oil reservoirs for EOR. Anchor projects include ESI CCS Project and the Emirates Aluminium CCS Project.

The incentives for CCS projects to be developed as part of a hub or a network include economies of scale (lower per unit costs for constructing and operating CO_2 pipelines). These costs are lower than can be achieved with stand-alone projects where each CO_2 point source has its own independent and smaller scale transportation or storage requirement (for example well over 25% lower). A coordinated network approach can also lower the barriers of entry for all participating CCS projects, including for emitters, that don't have to develop their own separate transportation and storage solutions.

Benefits and opportunities of integrated network projects are not only linked to economies of scale or technical performance of the transportation network. Network projects can also minimise and streamline efforts in relation to planning and regulatory approvals, negotiations with landowners, and public consultations. However, the establishment of a network brings its own challenges with multiple stakeholders.

Given the economies of scale that can be achieved, the benefits of integrated CO_2 transportation networks are apparent, but a network approach can also entail additional challenges, in particular from commercial, financial, and legal perspectives, including:

- design of a multi-user charging framework that reflects the separate infrastructure development, operation, and decommissioning costs and is linked to the allocation of capacity in the system;
- development of innovative commercial structures for CO_2 networks and hubs to accommodate numerous partners/owners and their different priorities for access to the network;
- obtain financing for assets that will initially be 'oversized' in anticipation of future volumes of CO_2 being added to the transportation infrastructure; and
- metering or monitoring different sources of CO_2 which feed into a common network. Each source could fluctuate, so sources need to be individually tracked and emitters need to receive specific benefits for each tonne of CO_2 supplied.

Regional Considerations

Given the benefits of a CO_2 transportation network, ASEAN may wish to investigate transport optimisation networks within the region.

Useful references

› Global CCS Institute, The Global Status of CCS: 2013, Chapter 6: Transport, http://www.globalccsinstitute.com/publications/global-status-ccs-2013

CO_2 UTILISATION

There are a number of existing and emerging commercial uses for CO_2 which are listed in Appendix II. Most of these uses require very small amounts of CO_2, making them niche industries. Of the uses that are estimated to use 5MT+ of CO_2 globally per annum most are in the early stages of development – refer Table 6, below.

Table 6: CO_2 Utilisation Technology Maturity

A - Mature technologies already in commercial use	B – Promising technologies ready for commercialisation	C – Promising technologies at a conceptual stage that need to be proven further through technical pilots and/or demonstration plants
EOR	Bauxite residue (red mud) carbonation	Mineral carbonation
Urea yield boosting	Renewable menthanol	Concrete curing
		ECBM
		EGS
		Polymers
		Algae
		Formic acid

Source: Parsons Brinckerhoff, 2011, p 42

It is important to note the following about CO_2 utilisation:

1. Many uses of CO_2 do not 'store' the CO_2 permanently and therefore are not a 'climate change' solution.
2. A single 300MW power project may capture (for example) 2.5MTpa of CO_2. "This single 300MW (net) demonstration project represents a rate of CO_2 production that is greater than the current non-captive industrial consumption of Japan, South Korea and Australia combined." (Parsons Brinckerhoff, 2011, p14) I.e. supply from a capture project may significantly outstrip demand, thereby requiring geological storage of the remaining CO_2 captured.
3. Even if the CO_2 use is not a permanent 'storage' solution, and/or does not utilise all the CO_2 available from a capture project, nevertheless the CO_2 use could provide a revenue stream to help offset the costs of a CCS project. It is also important to note that increased supply of CO_2 will also impact the cost of that CO_2 (i.e. increased supply many translate into decreased cost and therefore lower revenue streams).

CO_2 Enhanced Oil Recovery (CO_2-EOR) can be considered as both utilisation and storage, given that a significant percentage of CO_2 utilised for enhanced oil recovery is trapped permanently. At this stage, CO_2-EOR is a significant commercial driver for CCS deployment. In such situations, CO_2 is a valuable commodity, instead of a costly responsibility.

Useful references

› Parson Brinckerhoff, Accelerating the Update of CCS: Industrial Use of Capture Carbon Dioxide, http://www.globalccsinstitute.com/publications/accelerating-uptake-ccs-industrial-use-captured-carbon-dioxide

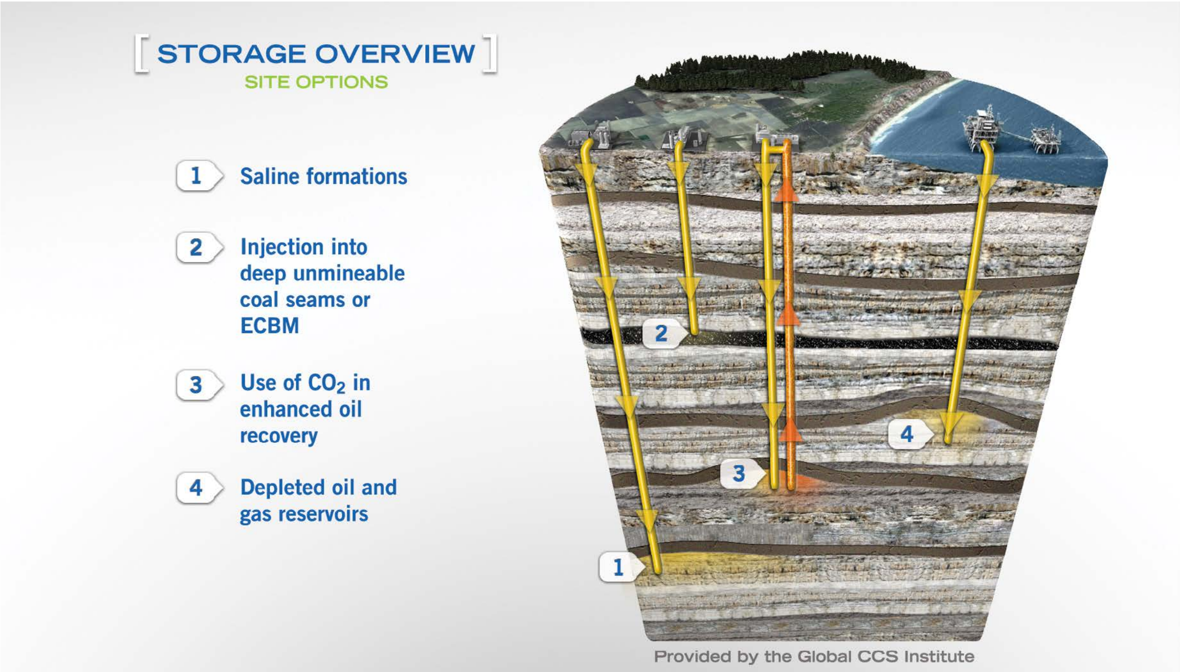
› Australian National Low Emissions Coal Research & Development, Novel CO_2 Capture Taskforce Report, http://www.globalccsinstitute.com/publications/novel-co2-capture-taskforce-report

CO_2 STORAGE

Injection of CO_2 into geologic formations has been performed for more than 40 years, beginning with attempts to increase oil production from aging reservoirs in western Texas, USA. This process, known as CO_2–EOR, has proven successful in many reservoirs. As a result, more oil has been produced and more CO_2 stored within the reservoir. It is estimated that more than 130 CO_2–EOR projects are in operation globally, most in North America. It is also estimated that during the past 40 years nearly 1Gt of CO_2 has been injected into geological reservoirs as part of CO_2-EOR activities, a significant percentage of this CO_2 remains permanently stored underground. It is therefore important to realise that injecting CO_2 safely underground is not a new activity.

As highlighted in Figure 15 below, CO_2 can be permanently stored in: saline formations, deep un-mineable coal seams, used to enhance oil recovery (EOR); or depleted oil and gas reservoirs. These types of sites have securely contained fluids and gases for millions of years, and with careful selection they can securely store CO_2 for just as long.

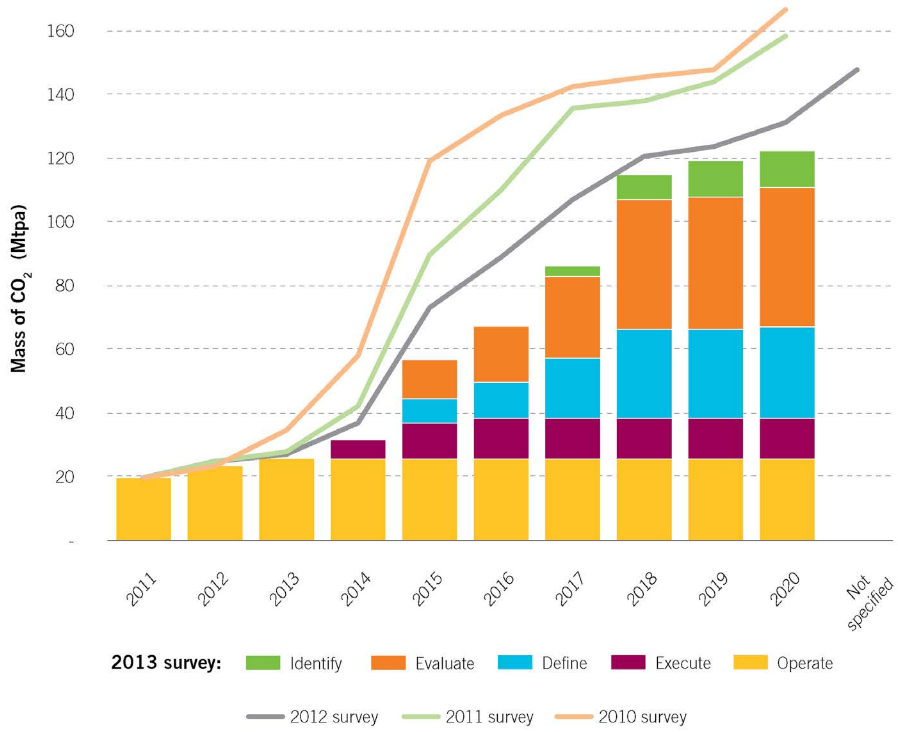
Figure 15: Storage Overview



In 1996, the first large–scale dedicated CO_2 storage project (i.e. not an EOR project) called Sleipner in Norway, began injecting CO_2 into a sandstone reservoir in the North Sea. In operation for around 17 years, it has so far stored more than 14 Mt of CO_2. Similar dedicated storage projects generally target deep rocks filled with saline or non-potable water, often referred to as saline formations. The CO_2 storage capacity of saline formations is significantly greater than that of oil fields. Therefore, in the future, there will need to be more CCS projects storing CO_2 in deep saline reservoirs to mitigate CO_2 emissions to the atmosphere. However, at this stage of development, CO_2-EOR is helping to advance deployment of large-scale projects, because EOR revenues can help offset costs.

As can be seen Figure 16 on page 27, the current 65 LSIPs have the potential to store 122 Mtpa; the storage capacity of the 12 LSIPs in operation totals 25 Mtpa.

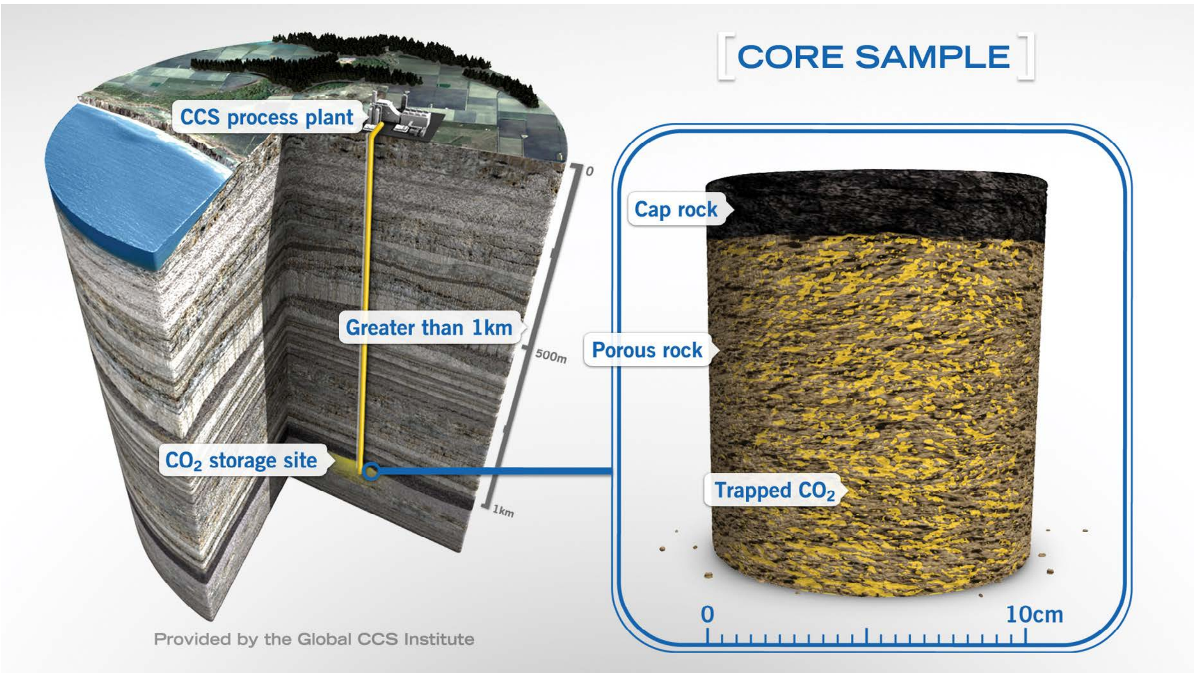
Figure 16: Mass of CO_2 potentially stored by LSIPs



Site selection

Figure 17 below illustrates that the CO_2 is stored greater than 1 km underground. At this depth, the temperature and pressure keep the CO_2 as a dense fluid, so that it takes up far less volume in the rock. The CO_2 slowly moves through the porous rock, filling the tiny spaces known as pore spaces. A safe store site requires a 'cap rock' or a relatively non-porous rock above the porous rock to prevent the CO_2 from migrating up towards the surface.

Figure 17: Storage cross-section



A project must identify a suitable site for safe and permanent storage. The process of identifying an appropriate storage site is called 'site characterisation' and requires the collection of a great deal of data, and takes significant time and effort. During this process, there is a series of questions that must be answered (stated very simply in Table 7 below) when progressing from screening to final decision to inject for any type of geological storage. The answers to these questions will not be, for the most part, a simple yes or no: they will be qualified. For example, a response to question 3 (containment) might be that the storage asset is unlikely to leak, as long as a given pressure is not exceeded and this can be monitored.

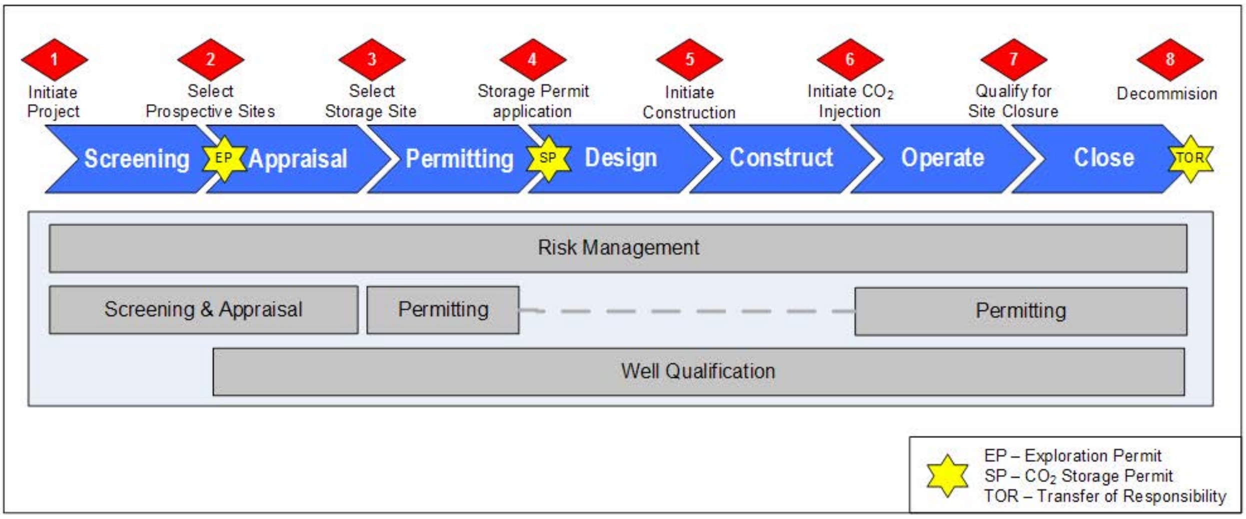
Table 7: Site characterisation questions

	Storage - key questions in plain English	Phases
1	Is it there (is there a receptacle)?	Screening
2	Is it deep enough/not too deep?	
3	Will it leak (containment)?	Exploration
4	How much can we put in?	Characterisation
5	How fast (injectivity)?	
6	How far will the CO_2 migrate? How long will this take?	
7	Could it affect other resources?	Monitoring
8	How will we know where it is going?	Verification
9	What will we do if it goes somewhere unintended?	Mitigation

Many ASEAN countries have started this process through engagement with the CCOP project. This site characterisation process utilises the same or similar tools and methodologies that the oil and gas industry have been using for decades to assess oil and gas reservoirs; so again, this is not a new process.

There are a number of guidelines that outline the process for comprehensive storage site characterisation. For instance, DNV GL has published a recommended practice called *Geological Storage of Carbon Dioxide*, which provides guidance on the whole geological storage project lifecycle – illustrated in the diagram below.

Figure 18: Geological storage project lifecycle



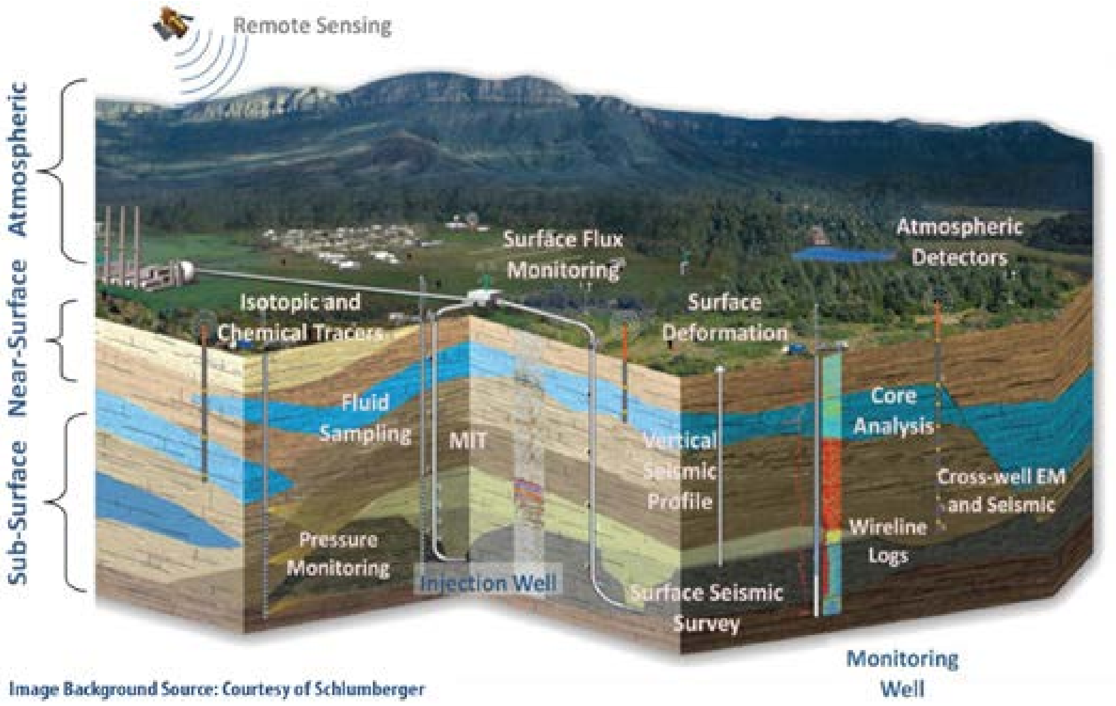
Source: DNV GL, 2012, page 7

Monitoring, measurement and verification

The CO_2 injected underground as part of a CCS project needs to be monitored to ensure permanent storage. Monitoring begins before injection to ensure good baseline data is obtained, in order to compare the conditions after injection. For example, CO_2 might already be present underground, and CO_2 levels naturally fluctuate in the soil near the surface and in the atmosphere. It is therefore essential to have baseline data to identify natural fluctuation compared to fluctuations due to injected CO_2. Monitoring, measurement and verification (MMV) continues during and after injection to ensure permanent storage of the CO_2.

Various monitoring tools – at the subsurface, surface and atmospheric level – developed originally for the oil and gas industry are available and are constantly being improved.

Figure 19: Monitoring, measurement and verification tools



MMV starts with modelling how the CO_2 is predicted to behave underground. Modelling also draws on simulation tools developed by the oil and gas industry that have been utilised for decades. Each project will have to develop an appropriate MMV plan for that site; usually in consultation with the relevant regulatory body. There are many MMV tools that can be utilised as part of the MMV plan, such as:

- Utilisation of isotopic and chemical tracers
- Vertical Seismic Profiles (VSP)
- Cross-well electromagnetic and seismic
- Surface seismic: 2D, 3D, time-lapse 3D (4D)
- Electrical Resistance Tomography (ERT)
- Pressure monitoring
- Down-hole fluid sampling
- Well logging
- Core analysis
- Ground water monitoring
- Soil gas monitoring
- Atmospheric CO_2 detectors
- Remote sensing (from satellites)

More information on MV tools is available under 'Useful references' on page 30.

Risks and environmental impacts

A well prepared and implemented MMV plan is essential to monitor the movement of CO_2 plume underground and correct or remedy any leaks (i.e. where CO_2 migrates from the storage site back into the atmosphere) or any unintended migration (i.e. where the CO_2 migrates from the intended storage site to other sub-surface areas).

The MMV plan should be based on a rigorous risk assessment, and will form a key element of the project's risk mitigation and management plan. There are a number of methods to undertake risk assessments, and it is likely that the operating company will have their preferred method. Extensive work has been undertaken on potential risks and hazards of CO_2 storage projects and/or EOR projects, which can help the operating company (and regulators) to develop project specific risk and mitigation plans – including the associated MMV plan.

The IEA's Model Regulatory Framework summaries the key health and safety, and environmental risks associated with CO_2 storage that a risk/MMV plan will need to address.

- Surface release, potentially resulting in [if not dispersed] asphyxiation and ecosystem impacts (effects of leaked CO_2 on surrounding populations, worker safety, and effects on the biosphere and hydrosphere such as tree roots, ground animals, and ground and surface water quality).
- Effects of any impurities present in the injected material on the surface populations, biota and the sub-surface storage media.
- Impact of CO_2 on the sub-surface, through metal or other contaminant mobilisation. This risk may be augmented by the presence of certain impurities.
- Quantity-based (physical) effects such as ground heave, induced seismicity, displaced groundwater resources and damage to hydrocarbon production.
- Occupational and civil EHS [environmental, health and safety] risks posed by the presence of, and potential release of, large volumes of pressurized CO_2 at injection facilities and storage sites. (IEA, 2010, p 91)

Underground Injection of natural gas for storage and CO_2 for EOR, as well as naturally occurring CO_2 leaks, provide lessons on how these risks can and have been mitigated and corrected should they occur.

Useful references

Site characterisation

- DNV GL, Recommend Practice Geological Storage of Carbon Dioxide, http://www.dnv.com/industry/oil_gas/services_and_solutions/technical_advisory/process_integrity/ccs_carbon_capture_storage/recommended_practices/MMV tools
- US Department of Energy National Energy Technology Laboratory (NETL) Monitoring, Verification and Accounting Focus Area http://www.netl.doe.gov/technologies/carbon_seq/corerd/mva.html
- CSLF Technical Group, 2013 Annual Report by the CSLF Task Force on Reviewing Best Practices and Standards for Geologic Storage and Monitoring of CO_2 http://www.cslforum.org/publications/documents/ReviewingBestPracticesStandards_2013Report.pdf

Risk assessment

- DNV GL, CO_2RISKMAN: Guidance on CCS CO_2 safety and environment major accident hazard risk management, http://www.dnv.com/industry/energy/segments/carbon_capture_storage/recommended_practice_guidelines/co2riskman/

LEGAL AND REGULATORY FRAMEWORK DEVELOPMENTS

Early action regarding CCS regulation was focused on international regulatory mechanisms – and removal of barriers to the implementation of CCS. For instance, the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Protocol) was amended in 2006 to allow for offshore CO_2 storage. It included CO_2 as one of the materials, or 'wastes', which could be injected into the subsea bed. This amendment was made to the Annex to the Protocol, which meant that the amendment came into force without having to be ratified by contracting parties. This is of particular relevance to the Philippines which is a party to the London Protocol.

The London Protocol was again amended in October 2009 to allow for cross-border transportation of CO_2 for the purposes of storage. The 2009 Protocol amendment will only enter into force after two-thirds (28 of 43) of all Contracting Parties to the

London Protocol have adopted the amendment.

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) was also amended in 2007 to adopt similar provisions. This required ratification by at least seven contracting parties – and in 2011 it received the required ratification and entered into force.

The Intergovernmental Panel on Climate Change showed early support for CCS by releasing Guidelines for National GHG Inventories which included a specific chapter on providing guidance to estimating emission reductions for CCS.

In the 2010 at the United Nations Climate Change Convention (UNFCCC) Conference of the Parties (COP) held in Mexico, CCS was provisionally adopted into the Clean Development Mechanism (CDM, providing that a limited number of issues were resolved. In 2011 at COP17 held in Durban, most of these issues were addressed, and CCS was confirmed as eligible under the Clean Development Mechanism. Two issues remain outstanding – the cross-border movement of CO_2 and the development of a global reserve fund. Despite these unresolved issues, CCS projects can now apply for CDM credits.

With the current low value of CDM credits, it is unlikely that this alone will be able to incentivise a large scale CCS project. Nevertheless, the international climate change community now acknowledges that CCS is a viable mitigation technology, officially recognised in the UNFCCC framework.

There are other aspects or mechanisms of the UNFCCC which are relevant to CCS. For instance – countries can identify CCS as one of the key mitigation technologies in their Nationally Appropriate Mitigation Actions – their NAMAs. If CCS is recognised in a country's NAMA this may facilitate funding and support from other countries that can 'match' this.

Dedicated CCS Legislation

There are a number of jurisdictions – at the regional, national, and state or provincial level – that have developed, or are developing, CCS legislation. For instance:

Jurisdictions with enacted CCS-related legislation:

- Australia
  - Victoria
  - South Australia
  - Queensland
- Canada
  - Alberta
  - Saskatchewan
- United States
  - Illinois
  - Louisiana
  - Montana
  - North Dakota
  - Texas
  - Wyoming
- European Union
  - Most of the 27 Members States either have transposed – or are currently transposing – the European CCS Directive into their legislation.

Jurisdictions currently developing legislation:

- Australia
  - New South Wales
  - Western Australia
- Canada
  - British Columbia
  - Nova Scotia
- Japan

- New Zealand
- Norway
- South Africa.

In addition, there are a number of countries, including ASEAN countries (as discussed above) which have undertaken CCS regulatory reviews. In some cases the legislation developed takes a reasonably holistic approach to regulating CCS (e.g. the European Union and Australia), while in some jurisdictions (e.g. the US) the legislation deals with discrete aspects of the process.

The existing body of legislation, and the lessons being learnt from 'second generation regulators'[4], provides a good basis for countries just beginning to think about their CCS regulatory environments. There are several organisations which provide updates on the progress of regulatory developments around the world, which next generation CCS regulators may find useful – these are listed under 'Useful References' on page 29.

The IEA's Model Regulatory Framework identifies 29 CCS regulatory issues – listed in the box below. The Framework discusses each of these issues, and identifies regulatory options for addressing the issue. Even the most comprehensive legislation does not address all 29 issues, but it is also a useful reference document for policymakers. In addition, the document provides legislative 'example' text which may be a good starting point for policy makers and regulators.

Box 1: List of CCS regulatory issues

Classification of CO_2	Incentivising CCS as part of climate change mitigation strategies
Engaging the public in decision-making	Authorisation of storage site exploration activities
Corrective measures and remediation measures	Sharing knowledge and experience through the demonstration phase
Property rights	Protecting human health
CO_2 capture	Regulating site selection and characterisation activities
Liability during the project period	CCS Ready
Competition with other users and preferential rights issue	Composition of the CO_2 stream
CO_2 transportation	Authorisation of storage activities
Authorisation for storage site closure	Using CCS for biomass-based sources
Transboundary movement of CO_2	The role of environmental impact assessment
Scope of framework and prohibitions	Project inspections
Liability during the post-closure period	Understanding enhanced hydrocarbon recovery with CCS
International laws on protection of the marine environment	Third-party access to storage site and transportation infrastructure
Definitions and terminology applicable to regulating CO_2 storage	Monitoring, reporting and verification requirements
Financial contributions to post-closure stewardship	

Source: IEA Model Regulatory Framework

Regional Considerations

TRANS-BOUNDARY ISSUES FOR ASEAN

Trans-boundary issues may be of particular relevance to ASEAN as a region.

Trans-boundary transport of CO_2

This may entail transportation of CO_2 from the source in one jurisdiction to a storage site in another jurisdiction; or the transportation of CO_2 from the source to the storage site, through a third jurisdiction.

Trans-boundary storage sites

This may entail a storage site straddling the border of two jurisdictions, or it may entail unintended migration of CO_2 from a storage site in one jurisdiction, impacting on the sub-surface in another jurisdiction. For example, CO_2 from a storage site may unintentionally migrate into a producing gas field in a neighbouring jurisdiction.

These trans-boundary issues require a harmonised or agreed approach between relevant jurisdictions in regulating, and therefore

[4] The jurisdictions that already have CCS legislation in place have pioneered the way; second generation regulators and policymakers are those that have now commenced the process of reconciling their future policy commitments with their existing regulatory regimes.

managing, these issues. Relevant regulatory mechanisms include "exploration permit applications and authorisations; storage permit applications, authorisations and reviews; monitoring requirements; inspections; closure requirements; post-closure requirements; and the handling of long-term responsibility for the storage site and any associated liabilities." (IEA, 2010, p 31)

LIABILITY

The issue of legal liability for the stored CO_2 is of interest to many countries considering CCS. 'Liability' for stored CO_2 could mean "any legal liabilities arising from a storage site (for example, through civil law, for damage to the environment, human health or third party property); responsibility for undertaking and bearing the cost of any corrective or remediation measures associated with a storage site; and responsibility for making good any leakage of CO_2 to the atmosphere, where CCS operations are undertaken as part of a CO_2 emissions reduction scheme. 'Long-term liability' is generally used to refer to any liability arising after the permanent cessation of CO_2 injection and active monitoring of the site." (IEA, 2011, p 9)

Like liability for most industrial activities during operation, liability for stored CO_2 during the injection phase and for a defined period of time after injection, rests with the operator. However, the approach jurisdictions have taken to long-term liability of stored CO_2 is often of particular interest. Two options have emerged from the existing legislation for managing 'long-term liability':

1. Long-term liability is transferred from the operator to the State after a specified period of time
2. Long-term liability remains with the operator in perpetuity; this may be the default option if the legislation is silent on the issue of long-term liability.

Both the Australian and European Union legislation (countries that have reasonably comprehensive CCS regulatory regimes) transfer responsibility from the operator to the State after certain conditions have been met. The European Union's CCS Directive includes provisions to allow a Member State's competent authority to assume liability for the stored CO_2 once "all the available evidence indicates that the stored CO_2 will be completely and permanently contained." (EU Directive, 2009) The EU Directive includes a 'post-closure' period of 20 years (i.e. the operator retains liability for at least 20 years following the cessation of injection and closure of the site); but if the competent authority is convinced that the CO_2 is safely stored, and is willing to accept the liability, this period may be shortened. The competent authority is able to seek a financial contribution from the operator to cover their expected costs of monitoring the site once they have taken over liability; but they must seek this cost recovery before they accept liability.

As European Member States transpose the CCS Directive into their own legislation, differences in the length of the 'post closure' period have emerged. However, it is a generally accepted principle that the likelihood and therefore risk of leakage reduces over time after injection has ceased; i.e. if the storage site were to leak, it would most likely do so either during injection or within the first years after injection.

The Australian Government will assume liabilities, including common law liabilities, for CCS projects that are undertaken in Commonwealth waters. It will do so no less than 20 years after injection ceases, subject to the responsible Commonwealth Minister being satisfied that the risks can be managed. This process involves four steps:

1. Once injection ceases, the title holder applies for a site closure certificate. The Minister must make a decision within five years on whether to grant this certificate, and will only grant a certificate if the post injection monitoring shows that the stored substance does not pose a significant risk to human health or the environment.
2. A closure certificate will also require the pre-payment by the operator of monies to fund a longer-term monitoring program.
3. Once the closure certificate is issued, the title holder's statutory obligations cease but common law liabilities will continue.
4. At least 15 years after the closure certificate is issued, and subject to the behaviour of the stored substance being as predicted, the Commonwealth may then indemnify the operator against the relevant liabilities.

CCS READY

The introduction of a CCS-Ready (CCSR) policy anticipates a future transition to broader carbon capture and storage (CCS) deployment. Some countries are implementing CCSR policies as an intermediate step towards to CCS; a step that ASEAN countries may wish to consider. The Global CCS Institute's definition of CCSR, developed in consultation with a wide range of CCS stakeholders, is widely accepted:

> A CCSR facility is a large-scale industrial or power source of CO_2 which could and is intended to be retrofitted with CCS technology when the necessary regulatory and economic drivers are in place. The aim of building new facilities or modifying existing facilities to be CCSR is to reduce the risk of carbon emission lock-in or of being unable to fully utilise the facilities in the future without CCS (stranded assets). CCSR is not a CO_2 mitigation option, but a way to facilitate CO_2 mitigation in the future. CCSR ceases to be applicable in jurisdictions where the necessary drivers are already in

place, or once they come in place.

ESSENTIAL REQUIREMENTS OF A CCSR FACILITY

The essential requirements represent the minimum criteria that should be met before a facility can be considered CCSR. The project developer should:

- carry out a site-specific study in sufficient engineering detail to ensure the facility is technically capable of being fully retrofitted for CO_2 capture, using one or more choices of technology which are proven or whose performance can be reliably estimated as being suitable
- demonstrate that retrofitted capture equipment can be connected to the existing equipment effectively and without an excessive outage period and that there will be sufficient space available to construct and safely operate additional capture and compression facilities
- identify realistic pipeline or other route(s) to storage of CO_2
- identify one or more potential storage areas which have been appropriately assessed and found likely to be suitable for safe geological storage of projected full lifetime volumes and rates of captured CO_2
- identify other known factors, including any additional water requirements that could prevent installation and operation of CO_2 capture, transport and storage, and identify credible ways in which they could be overcome
- estimate the likely costs of retrofitting capture, transport and storage
- engage in appropriate public engagement and consideration of health, safety and environmental issues, and
- review CCSR status and report on it periodically.

A CCSR policy requires project proponents to expend upfront costs to carry out engineering and cost estimate studies as well as undertaking storage assessments. As a guide, the Government of the United Kingdom estimates that the overall costs of a CCSR requirement per new combustion power station is equivalent to less than 0.1% of the capital cost of a 1600 MW coal fired power station and about 0.3% of the capital cost of an 800MW gas fired power station.

Useful references

› Global CCS Institute, CCS Ready policy and regulations state of play, http://www.globalccsinstitute.com/publications/ccs-ready-policy-and-regulations-state-play

› Global CCS Institute, CCS Ready Issues Brief, http://www.globalccsinstitute.com/publications/ccs-ready-issues-brief

› ICF International, CCS Ready Policy: Considerations and Recommended Practices for Policymakers, http://www.globalccsinstitute.com/publications/ccs-ready-policy-considerations-and-recommended-practices-policymakers

Approach to development

The Global CCS Institute has developed an approach to help countries start the process of legal and regulatory development. The Institute has facilitated either part of the process or the full process in, Malaysia, Romania, Scotland, Trinidad & Tobago, and Victoria. This process may be of interest to ASEAN countries interested in exploring CCS legal and regulatory issues. Essentially the process has four key steps that can be adapted to suit a country's needs, interests or conditions:

1. Stakeholder analysis
2. Legal and regulatory analysis, to identify existing permits, approvals, or certificates etc. that would most likely be required for a CCS project in the current regulatory framework, as the basis to identify gaps, overlaps and areas of improvement in the existing framework.
3. Legal and regulatory workshop, aimed at discussing the gaps, overlaps and areas of the improvement revealed in the review, potentially utilising a CCS project scenario (either real or hypothetical) to 'walk through' the existing framework as a good way to consider the issues.
4. Develop an action plan, based on the recommendations or conclusions of the earlier steps, develop and action plan that is ultimately aimed at legislative development.

Useful references

› Global CCS Institute, The Global Status of CCS:2013 Chapter 4: Policy, Legal and Regulatory Developments, October

2013, http://www.globalccsinstitute.com/publications/global-status-ccs-2013

- Global CCS Institute, Carbon Capture Legal Program, http://www.globalccsinstitute.com/networks/cclp
- International Energy Agency (IEA), Carbon Capture and Storage Legal and Regulatory Review (Edition 2), http://www.iea.org/topics/ccs/ccslegalandregulatoryissues/ieainternationalccsregulatorynetwork/

PUBLIC ENGAGEMENT

The importance of public engagement as part of a successful CCS project is becoming increasingly recognised. Responses to the Global CCS Institute's annual survey of project proponents over the past couple of years have demonstrated a growing awareness of best practice in public engagement and recognition of the importance of proactive, successful public engagement to enable CCS demonstration projects to proceed.

The Institute is four years into its partnership with Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) to conduct an international research program into the social factors that can affect the successful deployment of CCS projects. The Institute–coordinated program has delivered a total of 14 research projects undertaken by 10 international research institutions, and 29 final reports, as well as several ongoing journal publications. There are therefore numerous guidelines and case studies which countries can draw upon to develop best practice public engagement plans.

With several CCS projects in 2013 progressing through, or making substantial developments within, their lifecycle phases, more projects around the world are utilising this best practice learning that has emerged from early CCS demonstrations. Developers are making serious attempts to understand the social context in which they operate and manage the potential social effects of their projects.

However, challenges remain. Following the global financial crisis, funding for large, capital intensive infrastructure projects is scarce, and sensitivity to higher energy bills is increasing, resulting in a stronger need to persuasively articulate the need for, and value of, commercial-scale CCS projects. Persistent issues relate to a lack of understanding of CCS, CO_2, and energy more generally, leading to confusion, misinformation, and increased perceptions of risk – particularly about CO_2 transportation and storage.

Understanding local communities – social site characterisation

There has been very little change in the types of communities in which CCS projects report having interactions; the majority of project sites are based in industrial and farmland areas. However, among the newly developing projects in the Asia Pacific region (particularly China, which has experienced the most new growth in number of CCS projects over the past few years), more are considering sites that transect moderately in highly populated areas.

A high-level stakeholder engagement is standard practice for most large energy infrastructure projects. However, when high profile projects seek to operate in, or near, residential areas, a critical part of project management involves gaining a comprehensive understanding of the local community and its socio-political context. This process can also help to inform a sound public engagement strategy.

> *If we could turn back the clock, I think we would invest in a more comprehensive community profile. Many of the challenges we face now have very little to do with CCS safety and more with legacy issues. Comprehensive baseline data would support regular monitoring for changes in behaviour and help us better target our messaging and engagement activities.*
>
> Dominique van Gent, SouthWest Hub Project, Australia

This process of understanding the local communities likely to be impacted by a project is called 'social site characterisation'. The term is purposefully similar to the technical terminology used on projects (storage site characterisation) in order to emphasise the equal importance of understanding the socio-political context of a potential project site.

The Institute's 2013 CCS Project Survey results revealed a growing confidence in the comprehensiveness of social site characterisation data collected by projects. However, some projects in the Evaluate and Define stages of the project lifecycle did report shortcomings in their very early site analysis. These issues most often arise during early land access negotiations, and to manage them can prove expensive and labour intensive. If land access for initial investigations is not granted, extensive delays at an early stage of project development can occur.

The challenge is not always the result of inadequate early research or poor characterisation of stakeholder issues. Because of the long lead times associated with most CCS projects, changes in social circumstances are inevitable, so it is important to monitor the situation and keep key stakeholders informed of developments.

The Institute has recently published a set of comprehensive case studies from the ULCOS Blast Furnace Project in France which examine the processes of social site characterisation and stakeholder management, in an effort to demonstrate useful methods for collecting and analysing social site data.

Trends in social research

The CSIRO and the Institute recently completed a review and analysis of the key themes emerging from the recent body of CCS related social research. The full analysis and helpful extended references are published on the Institute's website, however the seven key themes and recommendations emerging from the review are provided in the box on the next page.

Box 2: Key themes and recommendations from a synthesis of CSIRO-led social research

Framing CCS

- Perceptions of climate change vary from belief in climate change to scepticism and denial. Therefore, in contextualising CCS, consideration should be given to all positions and not focus on mitigation alone.
- In discussing CCS, clearly define the rationale for the technology's implementation and take into consideration the national and international policies that underpin CCS.
- Compare energy options transparently and communicate clearly, include issues and explanations of the wider energy debate.

Local context

- Take into account a community's social, cultural, economic, and political characteristics and the impact a CCS project may have on the community (the social site characterisation tool can be a useful aid).
- Establish a baseline of knowledge and awareness across affected communities to better understand information needs, minimise misunderstandings, and avoid false expectations.
- To anticipate and prevent any unplanned issues, consider a community's local history and pre-existing concerns, as well as the overarching local, state, and national perspective.

Trust

- Identify reliable individuals, organisation, and institutions within the community to ensure that those communicating messages on CCS are trusted.
- Ensure that advice and information provided to stakeholders is trusted, reliable, and informative and provided in a way that allows sufficient time for it be absorbed.
- To assist in smooth information transfer and feedback, consider established a citizen's advisory committee or some form of community participation group.

Communication and engagement processes

- Target gaps in local knowledge about CCS (identified through baseline research).
- Engage in meaningful dialogue with stakeholders and the public well in advance of finalising project plans, making use of trusted advocates within different stakeholder groups.
- Use a wide variety of engagement processes and tools that promote open and transparent dialogue and help to establish effective relationships.
- Embed experienced, high-level communication/engagement resources in a CCS project development team.

Information

- Provide wide-ranging information (i.e. formal, informal, technical, simple) to stakeholders through a variety of reliable sources to develop trust and ensure stability of opinion.
- Provide information that is balanced, of high quality, relevant, of minimal complexity, appropriately toned, and readily accessible to a range of stakeholders.
- Develop information delivery programs tailored to different audiences e.g. courses on broad issues such as climate change, energy options, and potential mitigations solutions delivered through educational institutions.

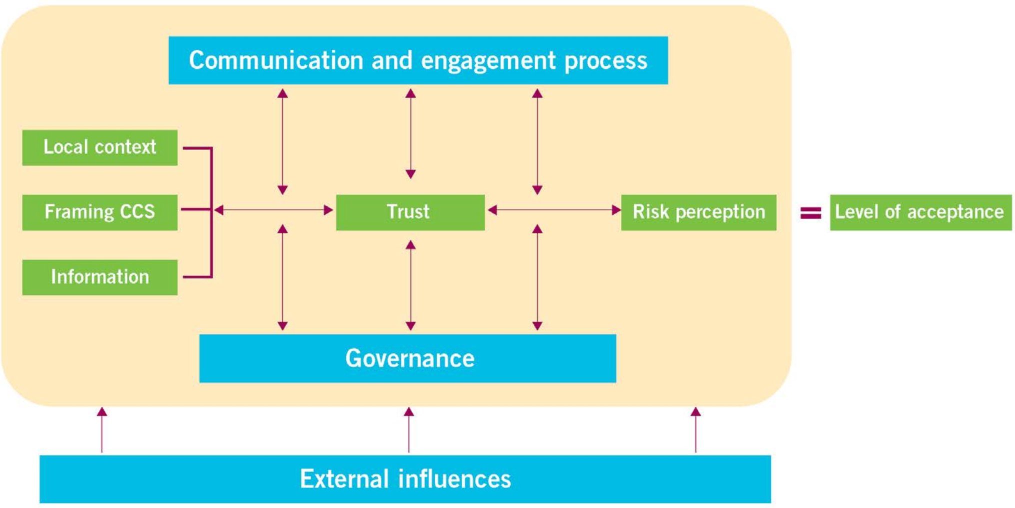
Risk perception

- To help minimise perceptions of risk, establish two-way communication processes that recognise individual risk perceptions and tailor responses to allay fears.
- Include information that adequately addresses the multiple facets of risks associated with CCS, including capture, transport, and storage.
- Ensure risk communication personnel are well trained to be aware of, recognise, and be sensitive to, varying perspectives associated with the risks of CCS.

Governance

- Clearly define processes for communities and other key stakeholders to provide input into project decisions and develop a partnership approach toward shared outcomes.
- Align CCS legal and regulatory frameworks across local, state, and national contexts to reduce conflict between different levels of government and minimise any erosion of public confidence in a project.
- Create a unified vision of the need for a project across project funders, development teams, and team members.
- If risk perceptions are high, provide some flexibility in project plans to allow the public to influence the outcome and thereby minimise such risk perceptions.

Figure 20: A framework of interactions for CCS projects



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SUPPORTING MECHANISMS

Government policies for accelerating the development and deployment of CCS are driven by broader climate change policy to meet domestic targets and international commitments to reduce greenhouse gas emissions. The importance of CCS in supporting climate change policy is also influenced by objectives regarding energy security in a carbon-constrained world that will continue to use fossil fuels, at least for the medium term. Depending on the country, other complementary policy objectives might include:

- fostering a clean energy technology sector that can compete globally in offering CCS technologies or services
- reducing the carbon footprint of exports
- promoting regional economic development where opportunities exist to establish a CO_2 'hub'
- injecting CO_2 to undertake enhanced hydrocarbon recovery in conjunction with permanent geological storage.

A key challenge is that the benefits to society from innovation cannot be fully captured by those undertaking costly research and development including pilot or large-scale demonstrations. Investments in innovation generates knowledge that spills over to other firms and users, reducing the returns to innovators and the incentive to marshal sufficient resources to fully support innovation in new technologies. Overall, this leads to underinvestment in developing new technologies and a slower and less efficient path of innovation, including for responding to the challenges of climate change. In large energy-intensive industries, this issue is exacerbated due to the long life span of capital investments and the significant uncertainty about the long-term future.

To overcome this lack of investment in the early stage of development, governments – through technology and innovation policies – directly address the risks and barriers faced along the cycle in commercialising new technologies. CCS policy 'frameworks' define the support measures, initiatives, or interventions undertaken by governments to accelerate it through the technology development cycle.

Different policy instruments should be utilised at the different phases of the technology development lifecycle. At the early stages of demonstration and deployment, policy instruments should be specifically focused on advancing the technology, to demonstrate its viability and help make cost reduction innovations; not aimed at emission reductions per se. As the technology reaches more mature levels of development, policy instruments should move towards technology-neutral, economy wide measures, such as putting a price on carbon. The report *A Policy Strategy for Carbon Capture and Storage* discusses the different policy and financial instruments that can be utilised domestically at different stages along the CCS technology lifecycle.

Start small and scale up

It's broadly accepted that a good approach to CCS development is to start with a pilot-scale project, scale this project up to a demonstration project, before moving to a commercial scale project. This approach enables a step-wise approach to 'learning-by-doing' which is essential for CCS deployment. The ADB developed a useful 'illustrative roadmap' that identifies these three main stages for CCS development which can be found at Appendix III.

If ASEAN Member States decide that CCS is a technology it wants to support as part of its greenhouse gas reduction strategies – and possibly to achieve the related policy aims listed above – then it is prudent to start with a pilot-scale project; an approach Indonesia has adopted. Governments can self-fund such a small scale project, or alternatively, there are international finance mechanisms that could support the development of pilot and even demonstration scale projects.

INTERNATIONAL SUPPORT MECHANISMS FOR DEVELOPING COUNTRIES

Dedicated CCS financial contributions

Since 2009 a number of governments and organisations have collectively contributed or allocated hundreds of millions of dollars to current and future activities in developing countries to support:

- knowledge sharing, capacity development, raising awareness about different aspects of CCS
- pre-investment activities such as high-level storage assessments, country-level scoping studies, pilot-level investigative studies
- bilateral and/or multilateral projects
- contributions to organisations that in turn undertake these CCS outreach activities (such as APEC, Bellona, Clinton Climate

Initiative, International Energy Agency).

Organisations and countries that have contributed significant funds in this space include the EU, the Australian Government, the Global CCS Institute, the Norwegian Government, the UK Government and the US Government.

$138 million of this funding has been contributed to dedicated CCS Trust Funds or capacity development programs to support pre-investment and enabling activities as detailed in Table 8 below.

Table 8: Funding allocations for CCS in developing countries

Fund/program	Contributors	Allocated contributions (US$)[1]	Funds still available (US$)[2]	Funding focus
Asian Development Bank (ADB) CCS Trust Fund	Global CCS Institute US Government	74 million	67 million	The ADB fund focuses on China, India, Indonesia, and Viet Nam.
Carbon Sequestration Leadership Forum (CSLF) – Capacity Building Fund	Norwegian Government UK Government Global CCS Institute	2.96 million	514,000	The CSLF Fund focuses on the emerging economy CSLF member countries including: Brazil, China, India, Mexico and South Africa.
EuropeAid Grant Programme for Cooperation on clean coal technology (CCT) and carbon capture and Storage (CCS)	EU	Up to 4 million	0 (call for proposals closed)	The Grant Programme targeted India, Indonesia, Kazakhstan, the Russian Federation, South Africa and Ukraine.
Global CCS Institute Capacity Development Program	Global CCS Institute US Government	3 million[3]	Program ongoing	The Global CCS Institute's capacity development countries of focus include: China, India, Indonesia, Malaysia, Mexico and South Africa. In addition capacity development support has been provided to Brazil and Trinidad and Tobago.
The World Bank Group CCS Trust Fund	Norwegian Government UK Government Global CCS Institute	54 million	44 million	To date support has been provided to: Botswana, China, Egypt, Jordan, Kosovo, Maghreb, Mexico and South Africa.

1. Actual final amounts are subject to exchange rate variation, so these should be considered as rounded estimates.

2. As at March 2013. These figures should be considered as rounded estimates, and it should be noted that there are projects in the pipeline that will call on some of these available funds.

3. For the Global CCS Institute Capacity Development Program funds shown are only those expended (but not funds allocated to out-years).

Carbon Credits

As reported in the 'Legal and Regulatory Framework Developments' section, in 2010 at the United Nations Climate Change Convention (UNFCCC) Conference of the Parties (COP) held in Mexico, CCS was provisionally adopted into the Clean Development Mechanism (CDM), providing that a limited number of issues were resolved. In 2011 at COP17 held in Durban, most of these issues were addressed, and CCS was confirmed as eligible under the CDM. Two issues remain outstanding – the cross-border movement of CO_2 and the development of a global reserve fund. Despite these unresolved issues, CCS projects can now apply for CDM credits. With the current low value of CDM credits (currently under €1) this will offset only a very small proportion of a CCS project.

The European Union Emissions Trading Scheme (EU ETS) is the world's largest market for certified emission reduction credits, and CCS projects are eligible under the EU ETS. The price of EU credits fell from an all-time high in April 2006 of €30 per tonne of CO_2 abated, to its current price of around €5. Again, at this stage the EU ETS would only offset a small proportion of cost. As they develop, there may be other carbon credit mechanisms which can help offset the cost of a CCS project in developing countries, such as Japan's Bilateral Offset Carbon Mechanism.

UNFCCC Green Climate Fund

The UNFCCC Green Climate Fund (GCF) is being positioned to become the main global fund for climate change finance, and in time will seek to leverage additional private and public finance. It was announced at the UNFCCC's Conference of the Parties (COP 15) in the Copenhagen Accord – with an ambition of raising $100 billion a year by 2020 of public and private finance.

The GCF Governing Instrument for the Green Climate Fund was endorsed at COP17, 2011. The instrument includes funding for a broad set of eligible activities, including: capacity building, technical assistance for 'readiness' activities, such as preparing climate change related strategies, and technology development and transfer. CCS was explicitly stated as being eligible.

Developed countries kick-started their commitment by pledging what has become known as 'fast-start financing'. The UNFCCC has reported that the collective commitment from developed countries to provide new and additional resources was approaching US$30 billion for the period 2010-12. Many countries managed the disbursement of their own fast-start financing (e.g. Australia, USA, Canada, Sweden), and many countries have committed all or most of these funds.

The GCF has since established a Board, a Secretariat, and an interim Trustee (the World Bank), and is headquartered in Seoul, Korea. In June 30, 2013, the total amount of pledges and contributions to the GCF Trust Fund amounted to USD equivalent of $9 million; noting that this does not include the 'fast-start financing'. It is expected that the GCF will be a significant source of financial contributions to CCS in the future.

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STRATEGIC ISSUES AND NEXT STEPS

Strategic Issues

To effectively mitigate climate change and provide energy security, there is an urgent need to progress CCS pilot and demonstration projects around the world, including in ASEAN Member States where there is a high reliance on fossil fuel in industry and/or the power sector, which is expected to continue in the future.

The policy driver for CCS remains reduction of CO_2 emissions. However, other strategic considerations flagged in the 'Supporting Mechanism' include:

- fostering a clean energy technology sector that can compete globally in offering CCS technologies or services
- reducing the carbon footprint of exports, which may become necessary in an increasingly carbon-constrained world
- promoting regional economic development where opportunities exist to establish a CO_2 'hub'

- injecting CO_2 to undertake enhanced hydrocarbon recovery (associated with enhanced hydrocarbon revenues) in conjunction with permanent geological storage.

Successful demonstration of CCS will facilitate 'learning by doing', while innovation combined with advances in capture technology, will bring down costs – one of the major barriers to CCS deployment. It is vital that CCS is included in a portfolio of low-carbon technologies to tackle climate change at least cost. *The Global CCS Status: 2013* identifies important CCS recommendations for policymakers around the world:

- implement sustained policy support that includes long-term commitments to climate change mitigation and strong market–based mechanisms that ensure CCS is not disadvantaged
- boost short-term support for the implementation of pilot or demonstration projects. This will require targeted financial support measures that enable first mover projects to progress faster through development planning into construction and provide necessary support during operations
- implement measures to address existing regulatory uncertainties, such as long-term liability. This will involve learning from the efforts of jurisdictions within Australia, Canada, Europe and the US, where significant legal and regulatory issues have been, and continue to be, resolved
- continue strong funding support for CCS research and development activities and encourage collaborative approaches to knowledge sharing across the CCS community
- create a positive pathway for CCS demonstration by advancing plans for storage site selection
- encourage the efficient design and development of transportation infrastructure through shared hub opportunities to become 'trunk lines' for several carbon dioxide capture projects.

Learning by doing

Given the significant – but manageable – challenges associated with implementing CCS projects, many developing countries are opting to take a 'wait and see' approach – in terms of proving the technological reliability, community acceptability and affordability of CCS projects. So why should ASEAN countries start the process of demonstrating CCS now? Given the long lead times associated with implementing CCS projects, ASEAN countries should start undertaking the pre-investment, enabling and demonstration activities now (many of which will need to address country-specific requirements), in order to be in a position to benefit from emission reductions from CCS in the coming decades.

For CCS to be sustainably deployed, ASEAN countries should be supported to engage directly in 'testing' CCS at a demonstration scale before moving towards its wider deployment when the costs and energy penalty have decreased. By participating in this 'learning-by-doing' demonstration phase, skills and knowledge will be transferred to the ASEAN Member Countries allowing for indigenously based solutions to be sourced to address identified challenges.

There are some aspects of CCS that are 'transferrable' from countries that have already implemented CCS. However, there are some things that must be tested or developed domestically, which mitigate against taking a wait and see approach. Key among these is an understanding of the local geology to identify geological basins and sites that are suitable for permanent, safe geological storage of CO_2 which is essential for CCS. Storage characterisation from a basin down to a site specific level, can take 3-6 years depending on how much is already known. Developing appropriate legislative and regulatory frameworks must also be done domestically, and can take considerable time, depending on the individual circumstances of each country or region.

Avoiding the 'wait and see' approach is particularly relevant for countries which have a high reliance on fossil fuel, and where CCS is going to have to play a significant role in its emission reductions strategy. The following section suggests some concrete next steps around the key strategic 'themes' highlighted above for ASEAN and ASEAN Members States, to progress CCS.

The steps in the green boxes must be ultimately driven by ASEAN Member States. However, the ASEAN forum can provide support for the implementation of these steps based on knowledge sharing mechanisms that ASEAN Member States may be interested in. The steps in the red boxes are well placed to be facilitated through the ASEAN forum.

Next Steps

Table 9: Next steps

	Undertake storage assessment	Implement pilot project	Develop legal and regulatory framework	Develop regional approach to transboundary issues	Develop good practice public engagement and knowledge sharing approaches
1	ASEAN Member States to commence or continue to participate in CCOP Regional Storage Program	Drawing on existing recommendations for first-mover projects, develop scoping study for pilot/ demonstration scale projects	Undertake next steps in regulatory review and development	Undertake regional source-sink mapping and scope potential transport network	Case Study on applying good practice public engagement in ASEAN country/region
2	Utilising knowledge and tools from CCOP develop storage charactertisation from country, basin, to site-specific levels	Progress implementation of pilot/demonstration scale project according to scoping study	Make required legislative changes to accommodate pilot/ demonstration scale project	Discuss trans-boundary issues in ASEAN forum	Agree ASEAN knowledge sharing practices to learn from CCS projects in the region

UNDERTAKE STORAGE ASSESSMENT

1. ASEAN MEMBER STATES TO COMMENCE OR CONTINUE TO PARTICIPATE IN CCOP REGIONAL STORAGE PROGRAM

Identifying suitable storage sites is essential for CCS, yet storage assessment can take many years to complete. Some jurisdictions with CCS flagship financial support programs (e.g. Australia, European Union) found that the technical readiness for capture was more advanced than the characterisation of suitable storage sites – necessitating more time in preparing for CCS through storage assessment.

It is therefore important that ASEAN Member States continue their engagement with the Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP) regional storage programme. CCOP is developing a cross-border mapping program to characterise storage reservoirs within the Southeast Asia region. The project is designed to support existing CO_2 geological storage activities and kick-start implementation of storage mapping in member countries without an existing program. The mapping program aims to provide a forum for knowledge sharing among the member countries and develop a guideline for national CO_2 storage mapping along with a CCOP CO_2 Storage Atlas. It is expected to be implemented over four years, starting 1 July 2013.

Key outcomes from CCOP could be shared through an ASEAN CCS knowledge forum to help keep policy-makers informed.

2. UTILISING KNOWLEDGE AND TOOLS FROM CCOP DEVELOP STORAGE CHARACTERISATION FROM COUNTRY, BASIN TO SITE-SPECIFIC LEVELS

The CCOP program will provide geological experts in ASEAN Member States with an understanding of the geological storage assessment process and introductions to international storage experts and organisations. This knowledge can help Member States continue to develop the pre-commercial geological assessment work, from country level, to basin level, to site specific assessment.

ASEAN Member States are encouraged to develop their own storage assessment programs building on the CCOP regional program.

IMPLEMENT PILOT PROJECT

1. DRAWING ON EXISTING RECOMMENDATIONS FOR FIRST-MOVER PROJECTS, DEVELOP SCOPING STUDY FOR PILOT/DEMONSTRATION SCALE PROJECT

The Asian Development Bank (ADB) in its report Prospects for Carbon Capture and Storage in Southeast Asia, has made concrete recommendations for first-mover pilot scale projects in Indonesia, Philippines, Thailand and Viet Nam. The production of high-content CO_2 fields coming on-line in Malaysia might also present an opportunity for a CCS-related pilot project. In addition, it has been reported that Myanmar may be considering a CCS project in its Dawei Special Economic Zone.

Given the long lead times for developing CCS, ASEAN Member States are encouraged to start the process of development and 'learning by doing' now, according to the ADB illustrative roadmap in Appendix III. Following the example set by Indonesia, it is suggested that ASEAN Member States develop a scoping study for a first-mover CCS project. There may be international support, either bilaterally, or through dedicated CCS Trust Funds for this work.

2. PROGRESS IMPLEMENTATION OF PILOT/DEMONSTRATION SCALE PROJECT ACCORDING TO SCOPING STUDY

The scoping study will provide the project-specific roadmap to implement a pilot scale projects at a specific location. An ASEAN CCS knowledge forum could help to facilitate deployment by discussing and addressing challenges and barriers, and keep policy-makers informed.

DEVELOP LEGAL AND REGULATORY FRAMEWORK

1. UNDERTAKE NEXT STEPS IN REGULATORY REVIEW AND DEVELOPMENT

As discussed in the section on *CCS Activities in ASEAN*, a number of ASEAN Member States have already completed an initial legal and regulatory review. The regulatory development process can be adapted to meet the specific needs of each country. However, key aspects of this process may include:

a. Assess if CCS pilot project can be undertaken within existing regulatory regime;

b. Analyse regulatory framework to identify if and how CCS could be accommodated within existing regime (identification of gaps, overlaps and areas for improvement).

- Some countries may wish to adopt project-level legislation before adapting their broader frameworks for CCS, or developing CCS-specific legislation. This may be a good approach for a CCS pilot project that is not able to be accommodated within the existing regime. These decisions will be influenced by the outcome of the regulatory analysis.
- There is likely to be various iterations of the regulatory analysis step, starting with a preliminary analysis and getting progressively more detailed depending on the specific barriers to implementation in a country.

c. Develop options for legislation, regulations and/or standards to address gaps, overlaps and areas for improvement - according to each Member State's regulatory development process, e.g:

- identification of legislative, regulatory or quasi-regulatory approaches
- assessing impact of these options (e.g. from a cost, benefit and risk perspective)
- consultation throughout development process.

d. Draft legislation, regulation or quasi-regulation, according to each Member State's drafting process.

e. Manage the introduction of legislation or regulation through Parliament or relevant approval process.

Organisations like the Global CCS Institute and potentially the World Bank and ADB may be able to help facilitate this process. An ASEAN CCS knowledge forum could help policy-makers and key stakeholders discuss key policy issues that are relevant to a number of states, and options for addressing them.

2. MAKE REQUIRED LEGISLATIVE CHANGES TO ACCOMMODATE PILOT/DEMONSTRATION SCALE PROJECT

Legislative changes to facilitate the implementation of pilot or demonstration scale projects should be a priority.

DEVELOP REGIONAL APPROACH TO TRANSBOUNDARY ISSUES

1. UNDERTAKE REGIONAL SOURCE-SINK MAPPING AND SCOPE POTENTIAL TRANSPORT NETWORK

Given the potential benefits of a CO_2 transport network, including economies of scale, lowering barriers to entry for industry in the medium-to-long term, and better technical performance of transport systems, it is suggested that the ASEAN region investigate possible transport networks based on a regional-source sink mapping exercise.

ASEAN is uniquely placed to facilitate such a study for the ASEAN region.

A transport network study could be based on the regional storage assessment which is a key deliverable of the Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP) regional storage programme. It is anticipated that this regional storage assessment will not be completed for a couple of years, which will have an impact on the timing of such a transport network study.

2. DISCUSS TRANS-BOUNDARY ISSUES IN ASEAN FORUM

A regional source-sink mapping study coupled with the identification of optimal regional transport networks provides a good basis for identifying trans-boundary transport and storage issues that will be relevant to the ASEAN region. The ASEAN provides an optimal forum to discuss those strategic issues and identify possible solutions.

DEVELOP GOOD PRACTICE PUBLIC ENGAGEMENT AND KNOWLEDGE SHARING APPROACHES

1. CASE STUDY ON APPLYING GOOD PRACTICE PUBLIC ENGAGEMENT IN ASEAN COUNTRY/REGION

Social research has already been undertaken on the development and implementation of good practice guidelines regarding communication and public engagement on CCS. As discussed in the 'Importance of Public Engagement' section, much of this research has been facilitated by the Global CCS Institute in partnership with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia. However, these good practice approaches have not been applied or tested within the context of a developing country.

It is suggested that ASEAN could make a very useful contribution in this social research space by participating in a case study on applying good practice public engagement in an ASEAN country or as a region.

If this is of interest, the Global CCS Institute could propose a study outline to be discussed, revised and agreed by ASEAN Centre for Energy.

2. AGREE ASEAN KNOWLEDGE SHARING PRACTICES TO LEARN FROM CCS PROJECTS IN THE REGION

As discussed above, a number of CCS-related activities will need to be progressed at the ASEAN Member State level, for instance: country-level storage assessment, pilot project, and country specific legal and regulatory frameworks.

Nevertheless, ASEAN Member States may like to utilise the ASEAN forum as a way to share lessons learnt and discuss challenges in addressing both Member State actions as well as regionally-based activities. There are a number of knowledge-sharing mechanisms that could be utilised in the ASEAN forum. For instance:

- establishing a CCS network
- establishing a dedicated extranet website
- regular updates on topics of interest during at ASEAN Centre for Energy, Senior Officials and relevant Ministerial meetings;
- dedicated series of webinars
- identification of existing networks.

It is suggested that ASEAN Member States discuss and identify knowledge-sharing mechanisms and topics of interest. The Global CCS Institute is a preeminent CCS knowledge-sharing organisation, and manages a number of international CCS networks in partnership with the CCS community, for instance:

- European CCS Demonstration Project Network, managed on behalf of the European Union
- International Test Centre Network, associated with Mongstad facility located in Norway
- Japanese Knowledge Sharing Network
- Korean Knowledge Sharing Network in partnership with the Korea CCS Association
- Stakeholder Strategy Peer Support Network, for Australian-based projects
- Junior Professionals CCS Network.

The Institute would be happy to facilitate a discussion on knowledge-sharing mechanisms and may – depending on the outcomes – support these mechanisms.

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APPENDIX I: LARGE-SCALE PROJECTS IN THE OPERATE AND CONSTRUCTION STAGE

LSIP NO. 2013	OVERALL PROJECT LIFECYCLE STAGE	PROJECT NAME	DISTRICT	COUNTRY	PRIMARY INDUSTRY	CAPTURE TYPE	TRANSPORT TYPE	TRANS-PORT DISTANCE (km)	CAPTURE LIFECYCLE STAGE	TRANSPORT LIFECYCLE STAGE	STORAGE LIFECYCLE STAGE	PRIMARY STORAGE OPTION	PRIMARY STOR-AGE SUBTYPE	CAPTURE CAPACITY (mtpa)	OPERA-TION YEAR	LSIP NO. 2012
1	Operate	In Salah CO_2 Storage	Wilaya de Ouargla	Algeria	Natural gas processing	Pre-combustion capture (natural gas processing)	Pipeline	14	Operate	Operational transport	Suspended injection of CO_2.	Dedicated geological storage	Onshore deep saline formations	0 (Injection	2004	6
2	Operate	Val Verde Natural Gas Plants	Texas	US	Natural gas processing	Pre-combustion capture (natural gas processing)	Pipeline	132	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	1.3	1972	1
3	Operate	Enid Fertilizer CO_2–EOR Project	Oklahoma	US	Fertiliser production	Industrial separation	Pipeline	225	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	0.7	1982	2
4	Operate	Shute Creek Gas Processing Facility	Wyoming	US	Natural gas processing	Pre-combustion capture (natural gas processing)	Pipeline	403	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	7	1986	3
5	Operate	Sleipner CO_2 Injection	North Sea	Norway	Natural gas processing	Pre-combustion capture (natural gas processing)	No transport required (i.e. direct injection)	0.11	Operate	Operational transport	Operate	Dedicated geological storage	Offshore deep saline formations	0.9	1996	4
6	Operate	Great Plains Synfuel Plant and Weyburn–Midale Project	Saskatchewan	Canada	Synthetic natural gas	Pre-combustion capture (gasification)	Pipeline	315	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	3	2000	5
7	Operate	Snøhvit CO_2 Injection	Barents Sea	Norway	Natural gas processing	Pre-combustion capture (natural gas processing)	Pipeline	152	Operate	Operational transport	Operate	Dedicated geological storage	Offshore deep saline formations	0.6–0.8	2008	7
8	Operate	Century Plant	Texas	US	Natural gas processing	Pre-combustion capture (natural gas processing)	Pipeline	69	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	8.4	2010	8
9	Operate	Air Products Steam Methane Reformer EOR Project	Texas	US	Hydrogen production	Pre-combustion capture (gasification)	Pipeline	101–150	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	1	2013	9
10	Operate	Petrobras Lula Oil Field CCS Project	Santos Basin (off the coast of Rio de Janeiro)	Brazil	Natural gas processing	Pre-combustion capture (natural gas processing)	No transport required (i.e. direct injection)	Not specified	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	0.7	2013	new
11	Operate	Coffeyville Gasification Plant	Kansas	US	Fertiliser production	Industrial separation	Pipeline	112	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	1	2013	17
12	Operate	Lost Cabin Gas Plant	Wyoming	US	Natural gas processing	Pre-combustion capture (natural gas processing)	Pipeline	Not specified	Operate	Operational transport	Operate	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	0.8–1.0	2013	10
13	Execute	Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project	Saskatchewan	Canada	Power generation	Post-combustion capture	Pipeline	100	Execute	Design of pipeline	Define	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	1	2014	13
14	Execute	Kemper County IGCC Project	Mississippi	US	Power generation	Pre-combustion capture (gasification)	Pipeline	75	Execute	Design of pipeline	Execute	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	3.5	2014	14
15	Execute	Illinois Industrial Carbon Capture and Storage Project	Illinois	US	Chemical production (ethanol plant)	Industrial separation	Pipeline	1.6	Execute	Construction of pipeline	Execute	Dedicated geological storage	Onshore deep saline formations	0.8–1.0	2014	11
16	Execute	Uthmaniyah CO_2–EOR Demonstration Project	Eastern Province	Saudi Arabia	Natural gas processing	Pre-combustion capture (natural gas processing)	Pipeline	70	Execute	Construction of pipeline	Execute	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	0.8	2014	New
17	Execute	Gorgon Carbon Dioxide Injection Project	Western Australia	Australia	Natural gas processing	Pre-combustion capture (natural gas processing)	Pipeline	7	Execute	Construction of pipeline	Execute	Dedicated geological storage	Onshore deep saline formations	3.4–4.1	2015	15
18	Execute	Quest	Alberta	Canada	Hydrogen production	Pre-combustion capture (gasification)	Pipeline	65	Execute	Design of pipeline	Execute	Dedicated geological storage	Onshore deep saline formations	1.1	2015	16
19	Execute	Alberta Carbon Trunk Line (ACTL) with Agrium CO_2 Stream	Alberta	Canada	Fertiliser production	Industrial separation	Pipeline	240	Execute	Design of pipeline	Execute	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	0.4–0.6	2015	12
20	Execute	Alberta Carbon Trunk Line (ACTL) with North West Sturgeon Refinery CO_2 Stream	Alberta	Canada	Oil refining	Pre-combustion capture (gasification)	Pipeline	240	Execute	Design of pipeline	Execute	Enhanced hydrocarbon recovery	Use of CO_2 in EOR	1.2–1.4	2016	19

APPENDIX II: EXISTING AND EMERGING USES OF CO_2

Source: Parson Brinckerhoff, Accelerating the Update of CCS: Industrial Use of Capture Carbon Dioxide, http://www.globalccsinstitute.com/publications/accelerating-uptake-ccs-industrial-use-captured-carbon-dioxide, 2011, pages 9-12

Existing Uses	Brief Description
Enhanced oil recovery (EOR)	CO_2 is injected into depleted oil fields. The CO_2 acts as a solvent that reduces the viscosity of the oil, enabling it to flow to the production well. Once production is complete, the CO_2 can potentially be permanently stored in the reservoir. [A high percentage of CO_2 injected is also trapped in the reservoir during injection.]
Urea yield boosting (non-captive use only)	When natural gas is used as the feedstock for urea production, surplus ammonia is usually produced. A typical surplus of ammonia may be 5 % to 10 % of total ammonia production.
	If additional CO_2 can be obtained, this can be compressed and combined with the surplus ammonia to produce additional urea.
	A number of projects have been implemented to capture CO_2 from ammonia reformer flue gas for injection into the urea production process.
Other oil and gas industry applications	CO_2 is used as a fluid for the stimulation/fracturing of oil and gas wells. It is typically trucked to site and injected as liquid carrying propping agents (sand and other materials which prop open the pores of the rock to prevent closure after stimulation).
Beverage carbonation	Carbonation of beverages with high-purity CO_2.
Wine making	CO_2 is used as a seal gas to prevent oxidation of the wine during maturation. CO_2 is also produced during the fermentation process, and it is already captured on-site for reuse for its inert gas properties.
Food processing, preservation and packaging	CO_2 is used for various applications in the food industry, including cooling while grinding powders such as spices and as an inert atmosphere to prevent food spoilage.
	In packaging applications, CO_2 is used in modified atmosphere packaging (MAP) with products such as cheese, poultry, snacks, produce and red meat, or in controlled atmosphere packaging (CAP), where food products are packaged in an atmosphere designed to extend shelf life.
	Carbon dioxide is commonly used in MAP and CAP because of its ability to inhibit growth of bacteria that cause spoilage.
Coffee decaffeination	Supercritical CO_2 is used as the solvent for decaffeinating coffee. It is preferred due to its inert and non-toxic properties.
Pharmaceutical processes	Use of CO_2 in the pharmaceutical industry may overlap with other uses identified, as it typically includes inerting, chemical synthesis, supercritical fluid extraction, product transportation at low temperature, and acidification of wastewater.
	80-90 % of material consumption by mass in the pharmaceutical industry is attributable to solvent consumption. US pharmaceutical solvent consumption in 1995 was ~80,000tpa, but supercritical CO_2 was not used in significant enough quantities to be reported.
Horticulture	CO_2 is provided to greenhouses to maintain optimal CO_2 concentration and maximise plant growth rate. Sources include on-site cogeneration schemes as well as off-site industrial sources connected via pipeline networks.
Pulp and paper processing	CO_2 is used to reduce pH during pulp washing operations.
Water treatment	CO_2 is used for re-mineralisation of water following reverse osmosis and for pH control (reduction).
Inerting	CO_2 is used in a wide range of applications where the physical properties of an inert gas are desirable. This includes applications covered under other use categories, such as a welding shielding gas and gas used in food packaging and in wine production.
Steel manufacture	CO_2 is used in a minority of basic oxygen furnaces as a bottom stirring agent. It is also used for dust suppression.
Metal working	Used for varied purposes, including chilling parts for shrink fitting, and hardening of sand cores and moulds.
Supercritical CO_2 as a solvent	CO_2 is useful for high-pressure extraction and as a solvent to isolate targeted compounds, such as fragrances and flavours.
	Because of its low critical temperature and moderate pressure requirements, natural substances can be treated particularly gently. It is gaining favour as a solvent in the dry cleaning industry for this reason.
Electronics	Printed circuit board manufacture uses small quantities of CO_2 in niche applications, predominately as a cleaning fluid.
Pneumatics	Pneumatic applications for CO_2 include use as a portable power source for pneumatic hand tools and equipment, as well as a power source for paintball guns and other recreational equipment.
Welding	Used as a shrouding gas to prevent oxidation of the weld metal.
Refrigerant gas	CO_2 is used as the working fluid in refrigeration plant, particularly for large industrial air conditioning and refrigeration systems. It replaces more toxic refrigerant gases that also have much greater global warming potential.
Emerging uses	**Brief description**
Fire suppression technology	When applied to a fire, CO_2 provides a heavy blanket of gas that reduces the oxygen level to a point where combustion cannot occur. CO_2 is used in fire extinguishers, as well as industrial fire protection systems.

Enhanced coal bed methane recovery (ECBM)	In CO_2-ECBM, CO_2 is injected into coal seams, where it preferentially adsorbs onto the coal, displacing and releasing adsorbed methane, which can then be recovered at the surface. A key constraint on practical application of this concept has been the decrease in permeability and injectivity that accompanies CO_2 induced swelling of the coal.
	Nitrogen (N_2) can also be used for ECBM, but it utilises a different mechanism, by reducing the partial pressure of the gaseous methane. This has led to the consideration of direct flue-gas injection for CO_2, which would utilise both the mechanisms of CO_2 and N_2-ECBM.

Enhanced geothermal systems (EGS) – CO_2 as a working fluid	There are two ways in which supercritical CO_2 may be utilised in EGS geothermal power generation.
	Firstly, it may be used as the circulating head exchange fluid. The benefit here is that the significant density difference between the cold CO_2 flowing down the injection well(s) and the hot CO_2 flowing up the production well(s) would elimate the need for a circulation pump.
	Secondly, this concept could be extended, and the circulating CO_2 could also be used directly as the working fluid in a supercritical CO_2 power cycle. There is significant interest in supercritical CO_2 power cycles because of the potential for high efficiency and compact turbo machinery.

Power generation – CO_2 as a working fluid	Supercritical CO_2 power cycles need not be limited to the geothermal power plants, as the benefits of high efficiency and compact turbo machinery are not heat source-specific.
	The nuclear power industry is particularly interested in supercritical CO_2 power cycles for this reason.

Polymer processing	One example of CO_2 as a feedstock for polymer processing involves the transformation of carbon dioxide into polycarbonates using proprietary zinc based catalyst system. A variety of other process routes and end products have been proposed.

Source: Asian Development Bank, Prospects for Carbon Capture and Storage in Southeast Asia, http://www.adb.org/publications/prospects-carbon-capture-and-storage-southeast-asia, September 2013, pages 71-72

	PILOT				DEMONSTRATION				COMMERCIAL	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8–9**	**10–15**	**15+**
	Gate 1: Pilot identified; parties contracted	**Gate 2: Pilot funding secured**	**Gate 3: Pilot construction completed**	**Gate 4: CO_2 Injection of 50–100 tons/day successful**	**Gate 5: Case for demonstration project established; business relationship secured**		**Demonstration funding secured**	**Demonstration construction completed**	**CO_2 injection of 1 Mt/yr successful**	**Commercial project development**
CAPTURE TECHNICAL	Identify CO_2 pilot and commercial sources	Detailed capture pilot design	Pilot construction	Capture CO_2	Confirm demonstration project for CO_2 sourcing	Commence detailed design of CO_2 capture demonstration project	Complete detailed CO_2 capture design and cost estimate	Construct demonstration project	Start up and operate demonstration project	Depending on the success of demonstration project, modify demonstration capture plant to provide a commercial CO_2 supply
TRANSPORT TECHNICAL	Identify transport needs (pipeline for on-shore and off-shore commercial project)	Design pilot transport system	Construct or procure pilot transport system	Transport CO_2 for pilot	Confirm CO_2 transport demonstration system	Commence detailed design for CO_2 pipeline	Complete detailed design and cost estimate	Construct CO_2 pipeline	Start up and operate CO_2 pipeline	Pipeline for demonstration project should have been sized for commercial throughput
STORAGE SITE	Plan storage site (screening and selection)	Design, site characterization, monitoring plan, risk assessment planning	Pilot construction, pilot injection and production plan, monitoring baseline, risk assessment planning	CO_2 injection, data collection and modeling, monitoring and interpretation, risk assessment	Pilot shut-in, pilot assessment and prediction, monitoring and interpretation, risk documentation	Commence detailed design for storage demonstration	Complete detailed design and cost estimate	Construct demonstration project site	Start up and operate demonstration project site	Depending on success of demonstration project, initiate commercial project discussions
LEGAL/ REGULATORY	Develop approach to regulate storage pilot (identify specific laws and regulations that would be involved and propose modifications)	Obtain permits to construct and operate pilot	Pilot project reporting	Pilot project reporting	Draft demonstration-specific regulation and legislation (for demonstration, including subsidies/tariffs)			Apply for permits to operate, if applicable	Reporting	Draft full CCS legislation and regulations
SOCIOECONOMIC/ ENVIRONMENTAL	Information, educational, and communications; and advocacies for CCS, preliminary risk and environmental impact assessments (EIAs)	Public consultations at pilot sites (press releases on detailed risk and EIAs for offshores)	Obtain environment permit to operate pilot(s)	Provide pilot project report to environmental agencies and the public	Define scope and EIA for demonstration project	Prepare EIA that promotes extensive public engagement for demonstration project	Reporting to public	Reporting to public	Reporting to public	Reporting to public

	PILOT				DEMONSTRATION				COMMERCIAL	
	1	2	3	4	5	6	7	8–9	10–15	15+
	Gate 1: Pilot identified; parties contracted	Gate 2: Pilot funding secured	Gate 3: Pilot construction completed	Gate 4: CO_2 Injection of 50–100 tons/day successful	Gate 5: Case for demonstration project established; business relationship secured		Demonstration funding secured	Demonstration construction completed	CO_2 injection of 1 Mt/yr successful	Commercial project development
FINANCING	Plan design and cost estimates	Detailed pilot cost estimate, including pilot CO_2 sourcing	Engage and train pilot project/ operation staff	Engage potential funding partners (donors, private sectors, etc.) and operators (if different from pilot project)	Define business partnership for overall CCS demonstration project	Develop pro-forma business reporting mechanism with partners	Funding available for construction of demonstration project	Funding available for operation (including staff)	Reporting and payback	Will require worldwide consensus on CCS that makes it intrinsically less expensive to proponents than other alternatives in their control
ADMINISTRATIVE AND STUDIES COSTS— ANNUAL ($ million)	1.5	3	1.5	3	3	1	1	1	1	TBD
PROJECT COSTS — ANNUAL ($ million)		5	20	20	5	20	175	100	80	TBD
CUMULATIVE COST ($ million)	1.5	9.5	31	54	62	83	259	460	947	TBD
GOVERNMENT AND OTHER (as necessary)	Conceptualize specific demonstration and commercial development paths and incentive packages	Commitment and support of government for CO_2 reduction (policy intervention, government incentive programs on CCS)		Government support for CCS demonstration projects in the form of subsidies, incentives, and legislation			Finalize concessions/ incentives			Established policy that supports CCS on a wide scale and/or penalizes non-performance on greenhouse gas reduction

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