Carbon Capture Journal

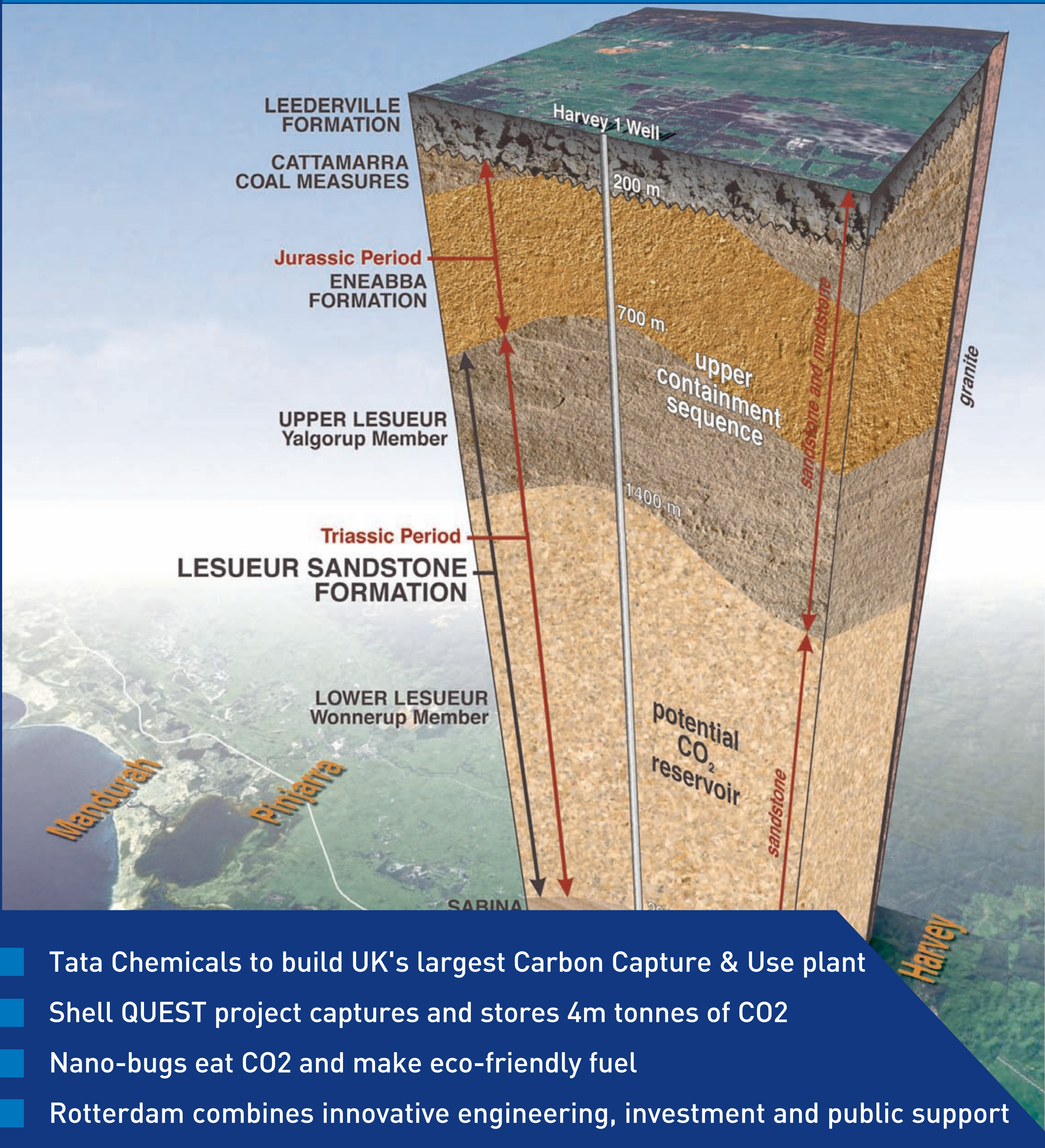
CCS in Australia

Australian South West Hub Project on saline acquifer storage

CO2CRC Otway Stage 3 Project

Australian gas fields show that CO2 storage is secure

July / Aug 2019 Issue 70



Tata Chemicals to build UK's largest Carbon Capture & Use plant

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Rotterdam combines innovative engineering, investment and public support

Investing in CCS: What do financiers need?

For CCS to fulfill its potential, rates of deployment must significantly increase. Enabling this will require a significant increase of private sector investment in CCS.
By Dominic Rassool, Senior Consultant - Policy & Finance (from Global CCS Institute Insights)

Currently, there are 43 large-scale CCS facilities in operation, development or construction. Experts estimate that approximately 2000 large-scale facilities are required to meet global emissions reduction targets by 2040. This equates to hundreds of billions of dollars in investments. Public funding for CCS, the most common funding mechanism to date, cannot sustain this level of investment on its own.

To date, investment in CCS projects have typically been supplemented by capital grants from public funds, with returns relying heavily on revenues from enhanced oil recovery (EOR). Although this arrangement has significantly contributed towards learning rates, an essential driver of cost reductions, it cannot be sustained at scale. The large-scale deployment of CCS will, therefore, require significant investments from the private sector i.e. banks.

However, as outlined in our recent report, a range of barriers and risks are limiting private sector investment in CCS. In the absence of EOR, there is an insufficient value on carbon dioxide to generate the revenues required for a sufficient return on investment. In addition, hard to reduce risks, namely cross chain and liability related risks, drive up the cost of capital. Since CCS facilities are capital intensive, this represents a significant material cost to projects, further reducing their economic viability.

Under these conditions, banks cannot qualify CCS projects for debt financing. As such, government has an important role to play in de-risking CCS investments.

Firstly, a material value must be placed on carbon dioxide, which can be in the form of a carbon price or a financial reward for CO2 storage. This value must be sufficient to incentivise investment in CCS.

Secondly, the cross chain (or counter party) risk must be addressed. This risk emerges from single source, single sink CCS projects, whereby only one capture facility sells carbon dioxide to a storage operator across a pipeline. The possibility of either the capture plant or the storage facility becoming unavailable presents itself as a significant risk to the overall project.

Moving towards a hub and cluster model reduces the risk of either counter party being unable to deliver or accept carbon dioxide. It utilises a transport and storage (T&S) network, connecting clusters of capture facilities together. In addition, this arrangement also reduces the unit cost of CO2 transportation through economies of scale.

Investing in T&S networks is, however, challenging for the private sector. The initial investment will be exposed to all the costs and risks of a single source, single sink model until other facilities join the network. This presents a significant barrier unless guarantees are provided for revenue during the early stages of deployment. This can be achieved through the Regulated Asset Base (RAB) model, which recovers costs from consumers — by way of long-term tariffs — under regulation. In this way, the consumers cover the risks, making it possible for the private sector to invest.

Where the balance of risk and return is insufficient to initiate private sector investment in the T&S network, government can take on the role of first investor. It could make the initial investment, establishing a T&S network for an anchor customer. Over time, more customers are able to join the network until such time that the business becomes an attractive investment. At this point, government can then choose to sell this mature business to the private sector for a profit.

Finally, addressing the liability risk, specifically long-term storage liability, is the last piece of the puzzle to ensure sufficient de-risking of CCS to attract private investments. If there are no limitations on liability, the storage operator will be liable for any leakage that occurs at any time in the future. To mitigate this risk, it is critical for governments to implement a well-characterised legal and regulatory framework that clarifies storage operators' potential liabilities. Therein, it may be that the storage operator bears the risk of short-term liability during the operational period, as has been implemented by the Australian Government, which then goes on to accept the long-term risk. Each government will choose the path that best suits its circumstances.

De-risking will attract debt financing to projects, which can initially be blended with grant funding to reduce the cost of capital. With each successive project, costs are reduced through knowledge spillovers and economies of scale. Further, the perception of risks also decreases as investors can rely on more empirical evidence.

Over time, as the market develops and there is more experience from successfully implementing more and more CCS projects, costs will plateau. Risks will be well understood, reduce or disappear, and grant funding will no longer be needed to incentivise and support investments. The CCS market will attract significant debt funding at pricing comparable to other infrastructure projects, allowing deployment to reach the numbers required. Projects will eventually come to rely exclusively on equity and debt for funding, and acceptable returns will be achieved through diminished costs and the increased value of CO2.

Only then will CCS truly advance and deployment of this vital technology accelerate at the rate required to deliver substantial emissions reductions. Only then can we guarantee we are on the right path to achieving a net-zero emissions future, limiting global warming to 1.5 degrees and avoiding the very worst effects of climate change.

More information

More 'Insights' on the website:
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Carbon Capture Journal

July / Aug 2019 Issue 70

Carbon Capture Journal
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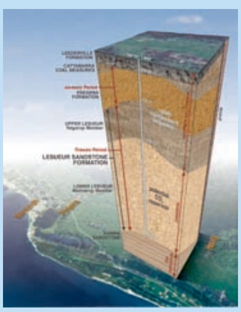

Front cover:

Onshore Southern Perth Basin Stratigraphy Diagram - The Australian South West Hub Project is assessing the suitability of storing CO2 in the deep saline aquifers in the Lesueur Formation of the Southern Perth Basin

Carbon capture journal (Print) ISSN 1757-1995
Carbon capture journal (Online) ISSN 1757-2509

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The Australian South West Hub Project

A unique project seeking containment through migration assisted trapping, the Australian South West Hub Project is assessing the suitability of storing CO_2 in the deep saline aquifers in the Lesueur Formation of the Southern Perth Basin.

By Sandeep Sharma and Dominique Van Gent

Introduction

The Carbon Strategy Branch of West Australian Department of Mines, Industry Regulation and Safety (DMIRS), through the South West Hub Project (SW Hub) is leading the pre-competitive phase of assessing the suitability of storing CO_2 in the deep saline aquifers in the Lesueur Formation of the Southern Perth Basin.

The material and data gathered within the Shires of Harvey/Waroona, will be considered by DMIRS and industry for assessing the suitability of the area for carbon, capture and storage (CCS) and its potential release to the commercial sector for exploration/appraisal leading to a storage licence.

There is no regional shale layer in the area of interest to provide a conventional seal for any injected CO_2. Secure containment is dependent on the effectiveness of migration assisted trapping and solubility mechanisms for CO_2 injected deep in the thick reservoir sequence of the Lesueur formation.

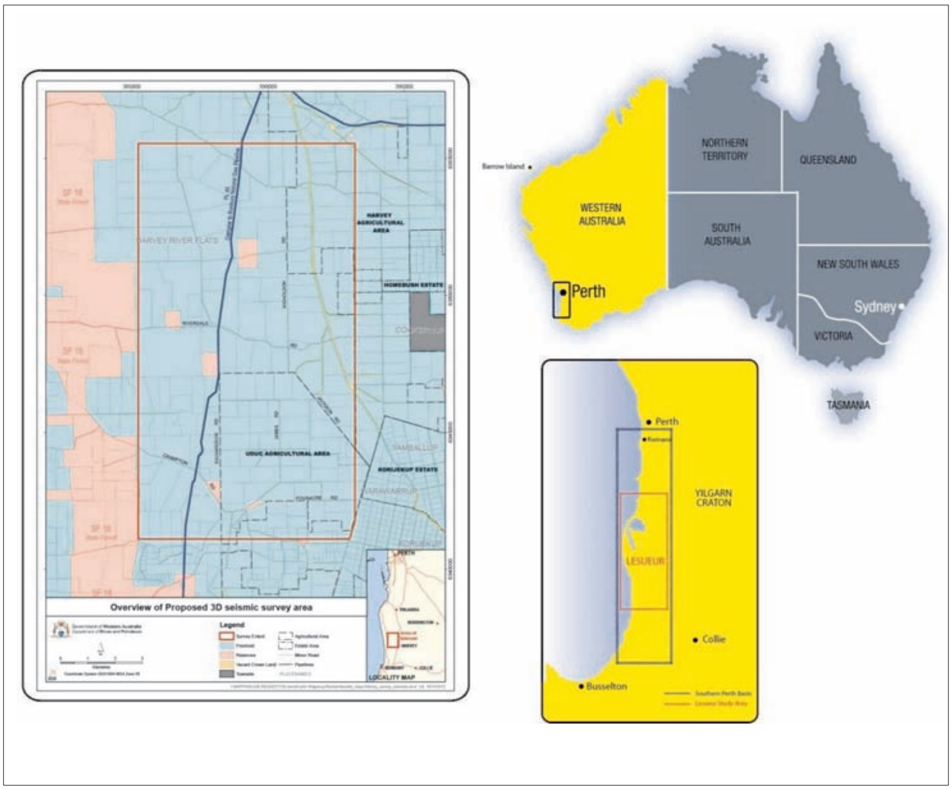

Figure 1: SW Hub Project Location Map

The storage complex consists of the Lower Lesueur formation (injection reservoir), the Upper Lesueur formation as the lower confining layer and the basal Eneabba Shale as the upper confining layer. All the work done to date indicates that secure storage is possible in such formations and once proven can increase storage options around the world which may earlier have been screened out.

As expected in deep saline aquifers, the project started with limited data, particularly when compared to sites based in prolific oil and gas provinces. Working with research institutions and private sector expertise, the project has judiciously acquired data on a stage gated decision basis. New data has been acquired in 4 phases.

In Phase 1, 2D seismic was acquired along 110km of roads in the Harvey and Waroona Shires, which was followed by the drilling of the 2,945 metre deep stratigraphic well GSWA Harvey 1 in Phase 2. This well was decommissioned immediately after all data acquisition was completed. Subsequently, in Phase 3, 3D seismic was acquired over 115km2 and in Phase 4 three additional wells DMP Harvey 2, 3 and 4 were drilled.

Four generation of models have been built following each acquisition phase. Most recently the fourth generation models (Gen 4) were completed and peer reviewed in June 2018 and October 2018 by expert practitioners and results accepted as being robust.

Uncertainties remain and are documented in an uncertainty management plan (UMP). Further uncertainty reduction will need new data acquisition in the form of a new deep well and well tests.

Location

The area of interest (AOI) is in the Harvey and Waroona Shires near large CO_2 emission sources in the industrial centres of Kwinana and Collie. The study area is located in the onshore part of the southern Perth Basin between the Mandurah Terrace in the North and the Bunbury Trough in the South. It covers an area of 332 km2 and is located approximately 13km northwest of the town of Harvey, approximately 120 km south of Perth (Figure 1).

SW Hub Geology

The stratigraphic sequence of the southern and central Perth Basin largely comprises continental deposits of Permian to Cretaceous age. Much of the sequence is associated with the tectonics of the region during this period from infilling and intracontinental rifting to the breakup of Gondwana. Sedimentation in the Perth Basin began in the Late Carboniferous or Early Permian as a result of north-trending regional rifting.

This was followed by the full scale rifting of Greater India from Australia and activation of the dominant structural feature of the north-south striking Darling Fault until the Early Cretaceous. The Perth Basin has since been subjected to several extensional and compressional events [1]. The period from the Middle Triassic to Early Jurassic is represented by two key formations: the Middle to Late Triassic Lesueur Sandstone and the Early Jurassic Eneabba Formation.

The injection target is the Lower Lesueur sandstone (Wonnerup Member), an approximately 1500 m thick reservoir with varying permeability layers that should support residual and solubility trapping. The storage complex has no regional shale layer and depends on migration assisted trapping (MAT) for primary containment, with the 600-800m thick Upper Lesueur (Yalgorup Member) with its numerous paleosol baffles as the lower confining layer and the basal shale part of the Eneabba Formation as the upper confining layer.

Screening studies undertaken by DMIRS identified the Area of Interest (AOI) as having a unique structure compared to the rest of Southern Perth Basin. Here the formations have been uplifted and the major fresh water Yarragadee aquifer (source of potable water supply) had been eroded out of the stratigraphy.

It was postulated that if CO2 was injected deep into the Lesueur, the thick and heterogeneous reservoir sequence, the percolation path of CO2, induced by buoyancy, would be convoluted and that a potentially large pore space could be encountered. Thus, despite the absence of a traditional extensive overlying shale layer acting as a primary seal, containment could be secured through dissolution and residual trapping.

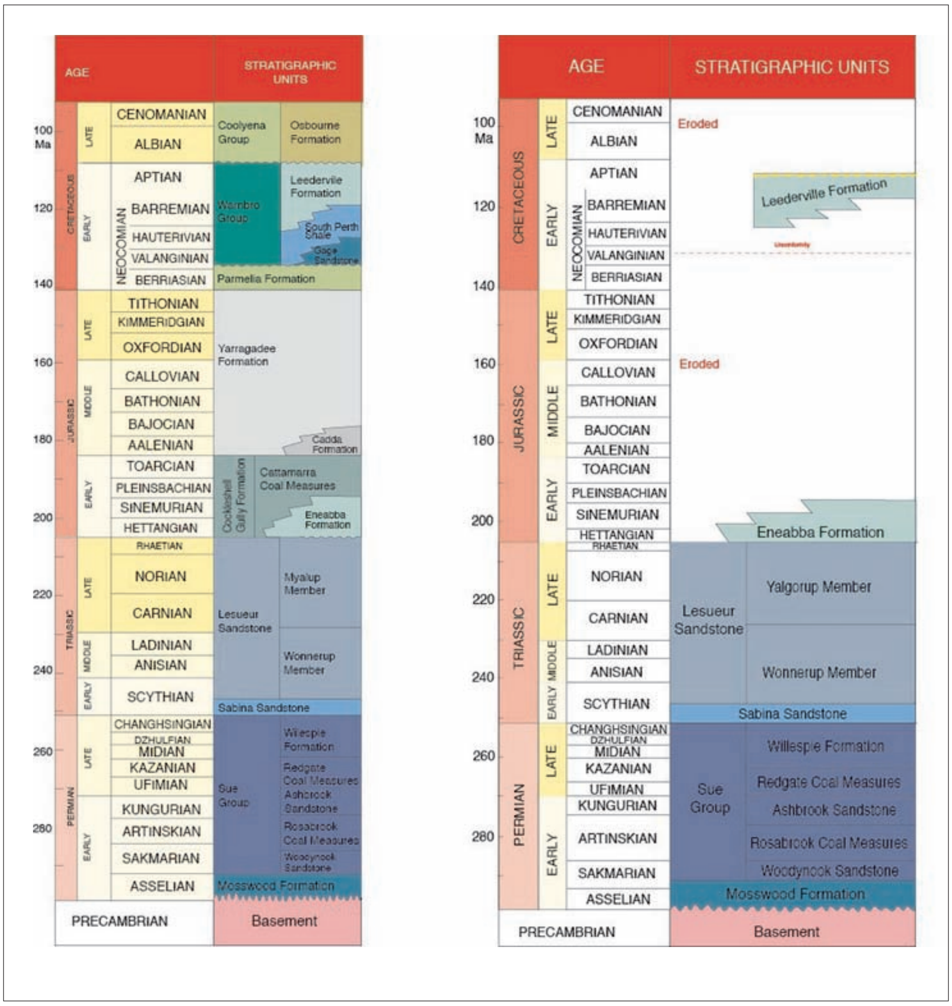

Figure 2: The stratigraphy of the Lesueur in the area of interest (Government of Western Australia Department of Mines and Petroleum, 2012a)

SW Hub Technical Knowledge and Uncertainty Evolution

The SW Hub is in a pre-competitive data acquisition stage aimed at providing technical confidence for acreage gazettal for industrial proponents to consider in the future. Thus, the decision criteria, outlined as under, is to verify the draft minimum acceptance criteria developed by the Petroleum Division of DMIRS as a guideline.

• Deliver >P50 confidence to inject 800,000 tonnes per annum (t/a) over 30 year i.e. 24 million tonnes;

• Deliver >P50 confidence that "the plume" remains below the basal Eneabba unit or 800m and within the storage complex for 1000 years;

• Deliver a >P50 level of confidence that injectivity of > 100-300 Ktpa per well, i.e. no more than 10 wells in total would be required

The SW Hub Project has followed a stage gated development approach wherein financial exposure to acquire new data is only incurred if the modelling results have indicated confidence towards meeting the performance factors. Technical assurance processes include using experienced oil and gas industry professionals to perform the work and an extensive peer assist and review process to ensure that the results are robust.

The peer review group has included oil and gas industry professionals, academics and other independent expert practitioners. Four generations of models have been developed and at each stage the uncertainties have been constrained and the confidence increased. Table 1 summarises this evolution.

In developing the Gen 4 static model all available geophysical and petrophysics data

Timeline	Model Complexity	Comments
Generation 1 (Gen 1) Models: 2010	100 layers, 1 million cells	Initial Uncertainty Identification: Coarse screening model based on offset data from region
Generation 2 (Gen 2) Models: 2012	357 layers, 30 million cells	Uncertainty Rationalisation based on new 2D seismic and data from well Harvey 1
Generation 3 (Gen 3) Models: 2016	1100 layers, 214 million cells	Uncertainty Parameterisation based on new 3D seismic and new data from wells Harvey 2, 3 & 4
Generation 4 (Gen 4) Models: 2018	1100 layers, 256 million cells 1.96 million active cells	Exhaustive review of all data including seismic reprocessing, fault mapping and additional SCAL data from core analysis

Table 1: Data acquisition and modelling timelines

(core and logs) were reviewed and reinterpreted. The seismic cube was processed again and an enhanced higher confidence set of faults mapped. Poro-perm relationships were updated resulting in a lower permeability profile for the Wonnerup Member.

Extensive paleosol analog studies were conducted to place reasonable bounds om the dimensions of these geo-bodies as they play a key role of acting as baffles and retarding any CO2 movement should it be encountered. This should enhance the containment potential of the Yalgorup Member should the plume migrate up from the Wonnerup Member.

The experience from the Gen 3 compositional models was that tuned Black Oil models could be more efficient in modeling multiple scenarios. This was tested and a "Reference Case" Black oil model developed. The geomechanics work reconfirmed that the faults were not likely to be reactivated but, due to limited data and remaining uncertainties, conservative numbers for fracture and activation pressures were considered.

Multiple dynamic modelling scenarios were developed to test the impact of the key parametric uncertainties. "Stress" cases were also simulated combining the effects of uncertainties, such as enhancing the damaged zone permeability of faults and reducing solubility concurrently, to see if the safe storage criteria could be breached. A high rate case wherein 3 million t/a were injected was also tested successfully [2].

While the bulk of the cases were simulated using a Black Oil simulator select cases including the "Reference Case" were tested using a fully compositional simulator to ensure confidence in the results. The results were not materially different and in all cases the injected plume stayed within the storage complex as indicated in Figure 3.

Sensitivity studies indicated that the main factors controlling plume migration are: (i) the solubility of CO2 in brine and (ii) the combination of the transmissibility of fluids across the faults, and high vertical permeability fracture zones close to faults. The plume spread does not vary much between the cases and the plume remains contained within a 3.5kmX6.5km area.

As an illustration (Figure 4) the plume outline (after 1000 years) of the "Reference Case" is overlain on the profile of another simulation case, one in which we would expect to see a higher spatial spread due to reduced vertical permeability.

The results of all the modelled scenarios considering a wide range of geological uncertainties indicate the injected CO2 remains within the Lesueur Formation and below 800mSS even after 1000 years.

Present Status and concluding remarks

The modelling results have concluded that it could be feasible to meet the success criteria and inject at least 800,000 t/a of CO2 over 30 years in the Wonnerup Member of the Lesueur Formation and that all of the injected volume remains safely contained in the defined storage complex. The models have been determined to be robust having considered a wide range of plausible geological properties and the multiple scenarios considered, including the "stress" cases in attempting to break the storage concept. The results have

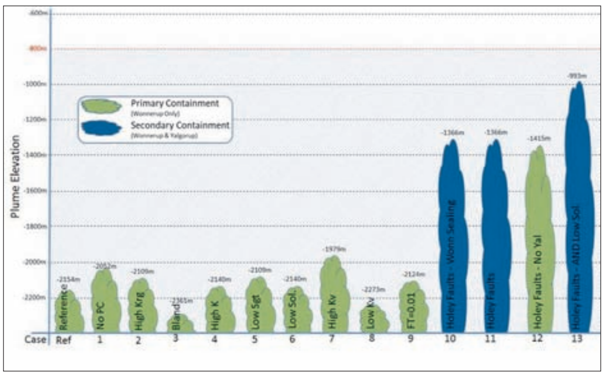

Figure 3: Vertical Plume Migration. The shaded area marks the storage complex

2km of core laid out and being viewed by industry, academia and Geological Survey of WA staff

bolstered the confidence of the SW Hub Project proponents in the potential of the area for storage.

Further uncertainty reduction through deep well drilling and acquisition options have been considered and ranked to determine the recommended way forward. [2]. This drilling and test program could be used to demonstrate feasibility of the storage concept based on MAT as the primary containment mechanism in the absence of a regional seal.

The project thus has the potential of driving a major mindset change and have a significant impact in lowering storage costs in areas of similar geology.

The work to-date has been funded largely by public money through the Australian Government' "CCS Flagships Program" (Department of Industry Innovation and Science) and West Australian State Government funding through the Department of Mines, Industry Regulation and safety.

Research funding was provided with assistance of the coal industry through the Australian National Low Emissions Coal R&D Program. The research work of the CSIRO, Curtin University and the University of Western Australia has been particularly valuable. Industry interest and support is currently being explored as an essential pre-cursor to being able to raise funds to proceed with the identified data acquisition option to reduce the uncertainties further.

The project data is open file and information, such as the modelling and core analysis, can be accessed online (see 'More Information')

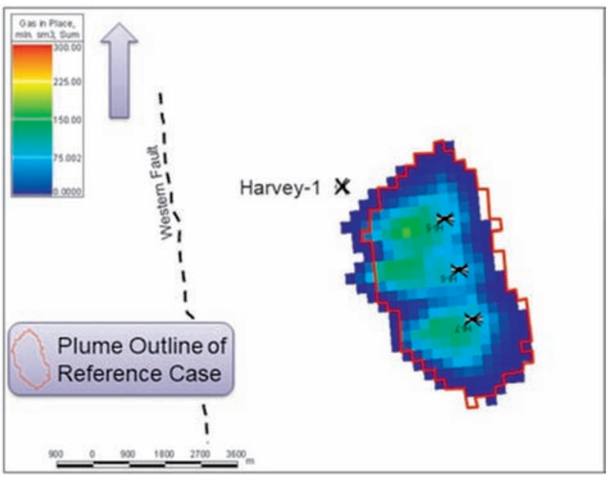

Figure 4: Plume Outline for Case 8 compared to Reference Case

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[1] Crostella, A. & Backhouse, J. 2000. Geology and petroleum exploration of the central and southern Perth Basin, Western Australia. Western Australia Geological Survey.

[2] Sharma S, Van Gent D, 2018, The Australian South West Hub Project: Developing confidence in Migration Assisted Trapping in a saline aquifer – understanding uncertainty boundaries through scenarios that stress the models, GHGT 14, Oct 21-25 Melbourne, Australia, in publication.

More information

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Project information

www.dmp.wa.gov.au/ccs

Technical data

www.dmp.wa.gov.au/wapims

Research projects

www.anlecrd.com.au

CO2CRC Otway Stage 3 Project

CO2CRC's $45 million Otway Stage 3 Monitoring and Verification Project will develop cost effective and reliable monitoring techniques which significantly reduce the cost and environmental footprint of CCUS monitoring.

CO2 storage projects will require monitoring and verification (M&V) operations at the CO2 storage site to understand the behaviour of the CO2 plume and provide assurance of storage complex integrity. M&V programs that rely largely on repetitive surface-based monitoring techniques (such as conventional surface seismic surveillance) may have high continuing costs and may face environmental and societal obstacles in some circumstances.

CO2CRC Limited is a world leading CCUS research organisation and is the operator of Australia's Otway National Research Facility, the only dedicated CO2 storage research facility in Australia. Since 2003, CO2CRC has delivered more than A$100 million in CCS research and demonstration and is now embarking on a new research program focussed on demonstrating and validating enhanced subsurface monitoring and verification (M&V) technologies.

CO2CRC's $45 million Otway Stage 3 Monitoring and Verification Project involves the drilling of five injection and monitoring wells at the Otway National Research Facility (ONRF) in south-west Victoria. The project will develop and commercialize sub-surface monitoring technologies which significantly reduce the cost and environmental footprint of CCUS monitoring.

The proposed monitoring techniques will also provide regulators and communities with ongoing confidence that CO2 injected deep underground is permanently stored within the bounds of the storage formation in large scale CCUS projects. These innovative techniques provide on-demand, permanent monitoring solution and will enable faster acquisition and continuous transmission and analysis of plume data.

The primary monitoring technologies to be evaluated are downhole seismic and pressure inversion and tomography. The downhole seismic data acquisition involves the installation of permanent surface orbital vibrators (SOV) to generate a seismic signal for acquisition by a distributed acoustic sensor (DAS) installed in each of the four monitoring wells by means of fibre optics in the well-bore.

Pressure inversion and tomography involves the use of high-resolution downhole pressure sensors to generate data which will be interpreted in a novel way to create a plume image resulting in continuous, on-demand surveillance of the storage complex.

Preliminary economic analysis shows a cost saving of up to 75 percent of monitoring costs over traditional monitoring technologies.

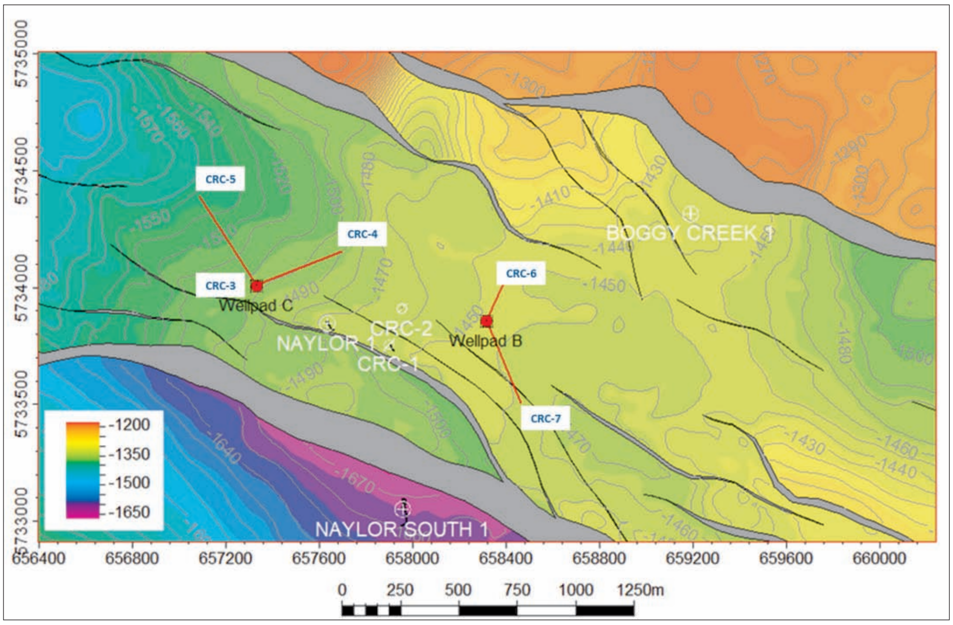


Figure 1: The location of the Otway Stage 3 wells on top PS1 depth map (contours are every 10m). Fault planes are shown in grey

Project Summary

The Otway Stage 3 Project uses five new injection and monitoring wells in addition to the two existing wells onsite. The plan is to inject 15,000 tonnes of CO2 to a depth of 1,500m into the Paaratte Formation, a non-portable aquifer previously used for the Otway Stage 2 experiment[1]. The gas for injection to the storage reservoir will be supplied from CO2CRC's high CO2 content natural gas well (~80% CO2 / 20% CH4), Buttress-1.

The injection zone is Para sequence 1 (PS1) in the Paaratte formation and the injection well (CRC-3) is down dip in the reservoir to provide the buoyancy for CO2 migration. The location of the wells (one injection well, CRC-3, and 4 monitoring wells, CRC-4 to CRC-7 as well as existing wells, CRC-1 and

1. *The Otway Stage 2 Project involved the same injection interval of the Paaratte formation but further East. The project's objective was to detect injected CO2 in the subsurface and determine minimum seismic detection limits as well as demonstration of the plume stabilization.*

CRC-2) is shown in Figure 1.

The single injector well, CRC-3 was drilled in April 2017 to initially serve as the appraisal well, and a wide range of core and log data was collected. In addition, injection tests were performed to confirm pressure continuity to the existing wells. The results were then used to model and select the optimal CO2 storage zone and the final placement of the four monitoring wells to effectively test and validate the downhole seismic and pressure tomography techniques. Commencing in July 2019, the remaining four monitoring wells, CRC- 4, CRC-5, CRC-6 and CRC-6 will be drilled.

Technology Overview

The Otway Stage 3 project will evaluate the following primary monitoring methodologies:

• Pressure inversion and tomography, based on downhole pressure sensors

• Downhole seismic monitoring (Vertical Seismic Profiling, VSP) using well-based distributed acoustic sensors (DAS) and permanently deployed seismic sources known as surface orbital vibrators (SOV).

In addition to these techniques, cross-well seismic will be tested in a one-off experiment and the acquisition of data for the development of ancillary monitoring methods using analysis of earth tides and passive seismic will enable future geomechanical research to be conducted.

Surface seismic surveys will be conducted prior, during and after the injection as benchmarks to validate the results of the technologies above.

To meet the requirements of the proposed monitoring techniques, the following well design and equipment specifications were selected.

1. All wells will be cased and perforated at PS1 level

2. Down hole pressure gauges in each well

3. DAS external to the casing, and inside the well (on tubing for CRC-2 and CRC-3 wells and on wireline for CRC-4, CRC-5 and CRC-6 as a backup.

4. At least one well will contain geophones for detection of the direct wave for the active 4D surveys.

5. All monitoring wells will also be used as water injectors

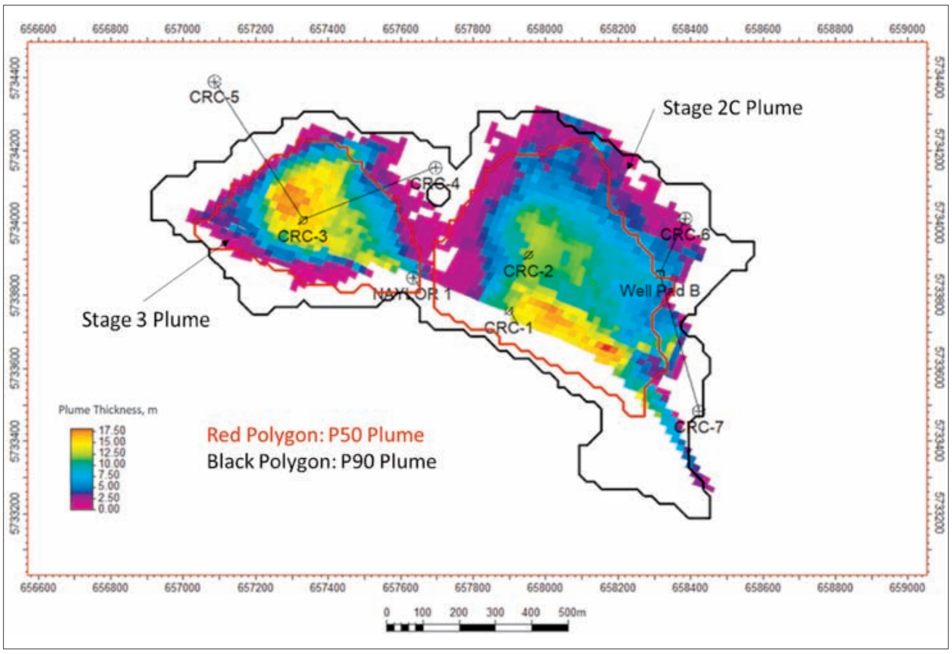


Figure 2: P50 and P90 plume boundaries vs base case plume thickness at the end of stage 3 injection of 15kt

Works performed to date

Reservoir characterization

Extensive reservoir characterization works were performed from April 2017 to May 2019 during the Evaluate and Define phases of the project including seismic interpretation, geological studies, static modelling, reservoir engineering data analysis and dynamic modelling.

Different vintages of seismic are available including the regional Curdie vale survey and all seismic monitoring performed as part of CO2CRC's past Otway storage program investigations. Horizon and fault interpretation were performed in Two Way Time (TWT) on the reprocessed Curdie Vale 3D regional seismic survey. Depth conversion used a new updated velocity model fine-tuned for the Curdie-Vale 3D and using all available data in the Area of Interest.

For the Otway Stage 3 Define phase, a new static model structural framework was built based on the updated Curdie vale seismic interpretation. It captures most of the faults in the modelled area and includes detailed vertical zonation in PS1. A cell size of 20 x 20m allowed for more realistic fault geometries to be preserved in the model grid compared to previous generations of the model.

Property modelling was performed using well data and variograms based on depositional analogues, and the Curdie Vale 3D acoustic impedance volume was used by zone and by facies to constrain the distribution of porosity, which in turn guided the permeability distribution.

A thorough reservoir engineering data analysis was performed including well history evaluation, core and fluid analysis as well as formation pressure test evaluation to provide inputs into the dynamic modelling.

The dynamic model was history matched using available historical data in the Otway site to make it more reliable for predicting injection scenarios for Otway Stage 3. The parameters considered include:

• Single phase water injection test

• Seismic plume shapes from stage 2C

• CO2 saturation from Neutron logs

• In zone and above zone pressure data in CRC-2 during 2C injection

• Injection interference test between CRC-3 and CRC-2

Fit-for-purpose history matching was achieved by adjusting key subsurface parameters including absolute and relative permeability, saturation end point parameters, ratio of vertical to horizontal permeability, aquifer parameters and splay fault transmissibility.

The Otway Stage 3 base case scenario includes injection of 150 tonnes per day of Buttress gas into the reservoir over 100 days. The simulation of this scenario was performed using the tuned model above. Based on this model the injected plume in the Otway Stage 3 project is expected to reach the Stage 2C plume approximately 70 days after the start of injection.

Dynamic and static uncertainty analysis were performed as part of Otway Stage 3 scenario simulation. The main objective of this work was to understand how a combination of uncertainty parameters affect the plume shape and extent.

For uncertainty analysis, Latin Hypercube sampling was used to stochastically select 60 samples from the influential uncertainty parameters (which were aligned with the adjusting parameters mentioned above during history matching and including P10, P50 and P90 static models) and run the simulations.

The obtained P50 and P90 of the plume boundaries at the end of Otway Stage 3 injection of 15,000 tonnes are shown in Figure 2. The base case plume thickness is also shown in this figure to compare the probabilistic results with the base case scenario.

Downhole seismic monitoring

The demonstration and validation of continuous downhole seismic monitoring will involve the monitoring of the evolution of the Stage 3 plume as it passes between monitoring wells equipped with surface orbital vibrators (SOV) and distributed acoustic sensors (DAS).

In 2017, as part of the appraisal program, a pair of DAS fibres was deployed behind casing in CRC-3 and its performance was tested with both SOVs and conventional vibroseis-generated seismic sources. The seismic data acquired was excellent in both cases. In the upcoming injection and post injection phases, the data obtained from each well for each of the SOVs will provide single-offset vertical seismic profiles (VSP) that can be used for continuous monitoring.

These surveys undertaken during the appraisal program in 2017 did, however, show that the directivity of the fibres makes detection of the direct wave a challenge. Therefore, in the upcoming operational phase, the DAS fibres will be augmented with geophones and knowledge of the direct wave generated via geophones will form an important element in the deconvolution step of seismic imaging.

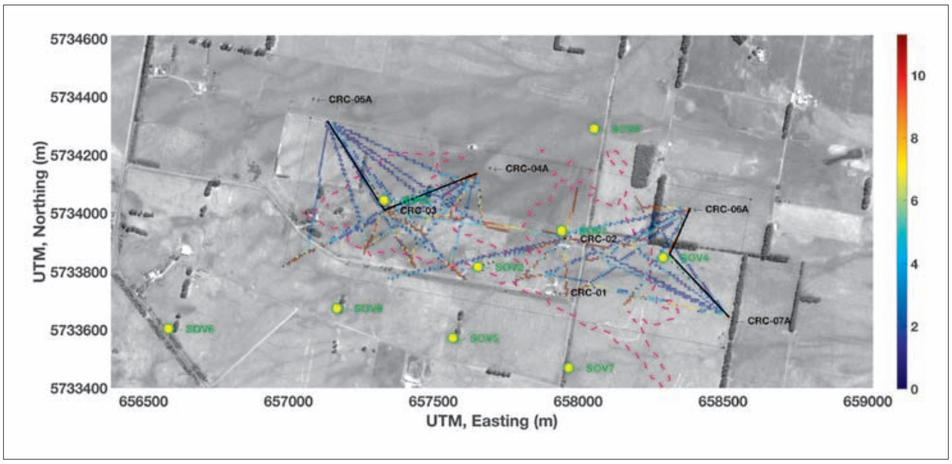


Figure 3: Location of the surface orbital vibrators (yellow/green), well trajectories (black) and seismic transects at 1500 mMD (colour-coded fold for 5x5 m bins). The purple outlay is the predicted plume. The number of transects is estimated to be sufficient to detect the plume

In the data processing area, full-waveform inversion has been proven effective for VSP data acquired at the Otway site.

Algorithms are under development for analysis of the data on-site in close to real time, therefore avoiding the need for large volumes of data to be transported to remote computers. This work translates into requirements for positioning of monitoring wells and SOVs, based on analysis of the detectability of the predicted plumes. The analysis indicates that signal-to-noise ratio is more than adequate and so the emphasis is on the geometry of ensuring there are enough transects across the predicted plume (Figure 3).

Pressure monitoring

Using high resolution pressure gauges, two distinct modalities of pressure monitoring will be investigated.

Pressure inversion locates a pressure source by way of triangulation from pressure measurements in the monitoring wells during and post CO_2 injection. The acquired pressure data will be inverted to identify the compressible pressure boundary as the gas enters and migrates through the formation.

Pressure tomography denotes a cluster of techniques that rely on interpreting the pressure changes that result from perturbing the reservoir with water injections at one of the monitoring wells and monitoring pressure at the other wells.

In a world first, pressure tomography will be demonstrated on a CO_2 plume to test the range and sensitivity of the technique to image a plume's distribution. With the downhole pressure gauges set to acquire data continuously, the pressure data obtained for each survey performed will be inverted to produce an image of the CO_2 plume in the subsurface.

The quality of the tomographic imaging will depend on the signal-to-noise ratio of the pressure measurements, the geometrical arrangement and number of wells, and extent to which variations in permeability affect pressure propagation.

Looking ahead

With the Evaluate and Define phases of the project completed and civil works for drilling close to completion, drilling of monitoring wells will commence in July 2019 and are expected to continue through to November 2019. All base line surveys and pre-injection tests are intended to be completed by Q1 2020.

The CO_2 injection will start in October 2020 at a rate of 150 tonnes per day with an initial injection of 5,000 tonnes. The injection will be paused at this point to perform intermediate subsurface and surface seismic surveys as well as pressure tomography. An injection volume of 5,000 tonnes was selected because it proved detectable from past benchmark surveys at the site and modelling of the downhole acoustic- and pressure-based techniques suggest that 5,000 tonnes will be detectable using the new techniques as well. Further injections will be sized to give information about how sensitivity scales with mass.

The pressure tomography and subsurface seismic results will be compared to surface seismic which represents the benchmark. The injection will resume thereafter, and a decision will be made if the injection will need to be paused after 10,000 tonnes of injection to perform another round of intermediate surveys. The final round of pressure and seismic surveys (subsurface and surface) will be performed once the full 15,000 tonnes of CO2 has been injected.

Benefits for industry

The learnings and outcomes from the Otway Stage 3 project are relevant to oil, gas, fossil fuel based power generation and other industrial processes. A preliminary cost analysis shows the proposed subsurface monitoring techniques can reduce storage monitoring

cost by up to 75%. The subsurface monitoring solution can remove the need for on-going repeat surface seismic acquisition thus saving significant operational costs. This can significantly improve the economics of a CCUS project. Other benefits which have yet to be factored into the economic analysis include:

• Continuous, on demand monitoring of the plume shape and pressure

• All activities take place under the ground, minimising the interface with the environment and other industries such as farming, fishing, shipping, O&G operations and the community

• Lower detection threshold which reduces the risk and cost of developing a CCS project.

Finally, the Otway Stage 3 project is a long-term investment in a research facility that offers industry and the research community an accessible and fully instrumented international test centre for benchmarking M&V tools, testing CO2 storage processes and management techniques.

Acknowledgements

The authors acknowledge funding provided by the Commonwealth Government's Education Investment Fund (EIF), COAL21 through ANLEC R&D, BHP and the Victorian State Government and the support provided by CO2CRC's industry and research members to make this project possible. In particular, CO2CRC would like to acknowledge the contributions from CSIRO and Curtin University to the Otway Stage 3 Project.

More information

www.co2crc.com.au

www.coal21.com

www.csiro.au

APAC Forum highlights CCS as key to developing a low carbon economy

The 2019 APAC CCS Forum was held in Brisbane on Friday 31st May, bringing together over 100 delegates from government, industry, academic and the private sector from across Australia and the region. Presentations and discussions focused on the urgency of addressing rising emissions whilst learning of the opportunities the transition to a low emissions economy presents.

www.globalccsinstitute.com

Titled Developing a low carbon economy, the Forum focused the versatility of CCS to deliver deep emissions reductions across various industry sectors, as well as presenting the enormous opportunities CCS presents in the creation of a new energy economy.

Presentations in the policy and major projects stream included an update from the Australian Government, Chinese Embassy and the CO2CRC about the Australian CCS Network. An update was provided by the Victorian Government on the CarbonNet pilot project in Victoria's Gippsland region, and the related Hydrogen Energy Supply Chain (HESC) project from Kawasaki Heavy Industries.

Representatives from UniSuper, the Japan Bank for International Cooperation (JBIC) and the Minerals Council of Australia addressed CCS opportunities from an ESG, investment and finance perspective, with JBIC drawing on their experience in financing the PetraNova CCS Facility in the US.

Industry streams throughout the afternoon focused on the application of CCS to decarbonise the Iron, Steel, Cement, Hydrogen, LNG and Oil sectors, with speakers from Bridgeport Energy, Santos, China Baowu Steel Group, KHI, Calix Limited, CNPC and the Global CCS Institute. During these sessions, the opportunity for CCS technology to be used for Enhanced Oil Recovery (EOR) in Australia and its role in the development of a clean Hydrogen export industry were highlighted.

The Forum closed with a special CCS case study on the Tomokamai CCS Facility, presented by Japan CCS Co.

It was clear from the presentations and discussions throughout the day that the APAC region's energy transition will be disruptive. However, with the deployment of CCS technology, it can also be a growth story.

Australian gas fields show that CO2 storage is secure

New research shows that carbon dioxide emissions can be captured and securely stored beneath deep-seated and impermeable underground rocks.

Researchers studied natural CO2 gas fields and CO2 mineral springs in south-east Australia to improve the understanding of how to safely store CO2 underground.

By measuring tiny traces of inactive natural gases, known as noble gases, found in the CO2 they were able to show that, in both the gas fields and mineral springs, the CO2 had come from the same source, the Earth's mantle.

The Earth's mantle is around 40 kilometres below the depth where the samples were collected from. Despite such a long distance of travel, the unique noble gas signature preserves the record of the gas origin. The same techniques can therefore be confidently applied for monitoring injected CO2, where travel distances are much shorter than in these natural samples.

Dr Ruta Karolyte, who led the research at the University of Edinburgh said: "We were able to show for the first time that noble gases remain very sensitive tracers of the source of CO2 even after it mixes with large volumes of water. This means that we can use noble gas techniques to sensitively fingerprint stored CO2 once it is injected underground."

Dr Stuart Gilfillan, who directed the study said: "Our work clearly shows the unique capability of using noble gases to monitor CO2 injected for geological storage. This paves the way for safe storage of CO2 in old gas and oil fields, such as those present in the North Sea."

Such an approach can reduce emissions of CO2 and help to limit the impact of climate change. Adoption of CCS technologies could greatly help the UK cut its greenhouse gas emissions to almost zero by 2050, necessary to meet recently announced targets.

The study, published in Geochimica et Cosmochimica Acta, was supported by the UK Engineering and Physical Sciences Research Council and the Australian research organisation CO2CRC. The paper is titled "Tracing the migration of mantle CO2 in gas fields and mineral water springs in south-east Australia using noble gas and stable isotopes".

Ruta Karolyte collecting gas samples for noble gas analysis at the CO2CRC Otway National Research Facility in Australia. Photo: Stuart Gilfillan

Australia news

Minerals Council of Australia advocates for CCS

www.minerals.org.au

Carbon capture and storage is critical to reducing emissions says the Minerals Council of Australia.

BP's Statistical Review of World Energy shows coal generation is now the highest it has ever been – increasing 6.24 percent over the past two years, representing 38 per cent of all electricity generation.

200,000 MW of new coal-fired generation capacity is now under construction globally. Zero emission nuclear energy is also providing more than 10% of all electricity, and continues to grow – now at its highest since 2008.

The global emissions trend means the ongoing development and cooperation in the region on carbon capture, utilisation and storage (CCUS) is more important than ever.

MCA supports participation in global agreements such as the Paris Agreement, which would hold the increase in the global average temperature to well below 2°C.

CCUS is the only clean technology capable of decarbonising major industry.

The Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA) have confirmed that CCUS is the only technology able to decarbonise large industrial sectors, particularly the steel, cement, fertiliser and petrochemical industries.

CCUS has been working safely and effectively for 45 years. There are now 18 large-scale facilities in commercial operation around the world which complement investments in renewables.

Zero emission nuclear energy providing more than 10 per cent of all electricity, and that it continues to grow with it being at its highest since 2008

Australian business and industry are actively working on pathways to net zero emissions. A least cost approach to reducing greenhouse emissions is critical to ensuring Australian businesses and families and our energy trading partners continue to have access to affordable, reliable and sustainable supplies.

Projects and policy news

Tata Chemicals Europe to build UK's largest Carbon Capture & Use plant by 2021

energyfuturesinitiative.org

Tata Chemicals Europe ("TCE") has unveiled plans to build the UK's first industrial-scale CCU Demonstration Plant, which will reduce its carbon emissions, whilst ensuring a secure, sustainable supply of carbon dioxide - a raw material critical to the business's international growth.

The first large-scale CCU project of its kind in the UK, the project also marks a world first in capturing and purifying carbon dioxide from power generation plant emission gases to use as a key raw material to manufacture high purity sodium bicarbonate. The project will help pave the way for other industrial applications of carbon dioxide capture and is an important step in decarbonising industrial activity and supports the Government's recently announced target of net zero carbon emissions by 2050.

With planning permission granted earlier this month, the CCU at TCE's Northwich industrial site, is scheduled to commence carbon dioxide capture operations in 2021. Supporting the Government's Clean Growth Strategy, the £16.7m project will be funded by TCE with the support of a £4.2m grant from the Department of Business, Energy & Industrial Strategy (BEIS) through the Carbon Capture and Utilisation Demonstration ("CCUD") Programme.

Tata Chemicals Europe is the UK's only manufacturer of soda ash and sodium bicarbonate and is one of the UK's leading producers of salt. The high-quality products made by TCE are essential input materials used in glass, food, pharmaceutical and chemical manufacturing sectors. The CCU project supports growth of TCE's largest export product; high-grade sodium bicarbonate used in food and pharmaceutical applications.

TCE is the largest single site user of liquid carbon dioxide in the UK. Food grade liquid carbon dioxide is an essential raw material, used to manufacture high-grade sodium bicarbonate, which is primarily used in the pharmaceutical and hemodialysis sectors.

Global demand for this grade of sodium bicarbonate is growing as more of the world's population has access to healthcare; TCE already exports 60% of its sodium bicarbonate to over 60 countries across the globe. The CCU project will be a springboard for TCE to unlock further growth into its export markets.

In a unique application of CCU technology, the TCE plant will capture carbon dioxide from the flue gases of TCE's 96MWe gas-fired combined heat and power plant ("CHP"), which supplies steam and power to the company's Northwich operations and other industrial businesses in the area. The CCU plant will then purify and liquify the gas for use directly in the manufacture of sodium bicarbonate. Deploying CCU technology will reduce emissions, as captured CO2 will be effectively utilized in the manufacturing process rather than being emitted into the atmosphere.

The CCU plant will be capable of capturing and producing up to 40,000 tons per year of carbon dioxide and will reduce TCE's carbon emissions at the CHP plant by 11%.

Already one of the most efficient power plants in the UK, the CHP plant is a low-carbon source of electricity, currently producing half the amount of CO2 per kWh of electricity generated compared to a typical gas fired power station. Once the CCU plant is operational, this will reduce the CO2 per kWh electricity generated even further.

The project will be completed over the next two years, the CCU plant is to be designed and delivered by TCE alongside a leading supplier of CO2 capture and purification technologies.

TCE has a strong track record of carbon reduction: following investment in its steam turbines in 2015, the business already produces Europe's lowest carbon intensity soda ash and sodium bicarbonate. In another move to reduce its carbon footprint, TCE is also investing £7.2m this year in state-of-the-art boilers at subsidiary, British Salt.

Commenting on the project, TCE MD, Martin Ashcroft, said, "The CCU demonstration plant will enable us to reduce our carbon emissions, whilst securing supplies of a critical raw material, helping to grow the export of our products across the world. Implementing this industry leading project, with such strong environmental and operational benefits is hugely exciting, and we're pleased to be working closely with BEIS to deliver the demonstration plant."

"We hope that this project will demonstrate the viability of CCU and pave the way for further applications of the technology to support the decarbonization of industrial activity. Our parent company, Tata Chemicals Ltd, has supported this innovative project, enabling our UK operations to continue to reduce its carbon emissions. This project is a great example of business and Government working together to rise to the challenge of decarbonising industrial production.

Senate passes the Bipartisan USE IT Act

carboncapturecoalition.org

The USE IT Act will help develop and deploy the next generation of carbon capture and utilization technologies.

The U.S. Senate passed S. 383, the Utilizing Significant Emissions with Innovative Technologies (USE IT) Act, as part of the National Defense Authorization Act (NDAA). U.S. Senator John Barrasso (R-WY), chairman of the Senate Committee on Environment and Public Works (EPW) and sponsor of the USE IT Act, worked with Senate Armed Service Committee Chairman Jim Inhofe (R-OK), who is a cosponsor of S.383, to include the bill in NDAA.

The USE IT Act would support carbon utilization and direct air capture research. This type of research is already taking place at research facilities like the Integrated Test Center outside of Gillette, Wyoming. The bill would also support federal, state, and non-governmental collaboration in the construction and development of carbon capture, utilization, and sequestration (CCUS) facilities and carbon dioxide (CO2) pipelines.

The USE IT Act complements the bipartisan FUTURE Act that passed last year. The USE IT Act would:

• Narrowly amend the Clean Air Act to direct the Environmental Protection Agency (EPA) to support carbon utilization and direct air capture research;

• Clarify that CCUS projects and CO2

pipelines are eligible for the streamlined permitting review process established by the FAST Act;

• Direct the Council on Environmental Quality (CEQ) to establish guidance to expedite the development of CCUS facilities and CO_2 pipelines; and

• Establish task forces to hear input from affected stakeholders for updating and improving guidance over time.

"I want to make American energy as clean as we can, as fast as we can, without raising costs on families," said Barrasso. "The best way to do that is through innovation, not government regulation. The USE IT Act is a bipartisan bill to promote carbon capture technologies that take carbon out of the air and find productive uses for it."

"These promising technologies could result in significant emissions reductions. The USE IT Act will support the type of great research already happening in Wyoming at the Integrated Test Center and around the country. I want to thank Chairman Inhofe for making the USE IT Act a priority. This is an important step toward having the legislation signed into law."

BECCS critical to achieving a net zero Britain

www.r-e-a.net

A paper from the Renewable Energy Association (REA) outlines a number of possible policy options to develop BECCS, including increasing the UK total carbon price to £50t/CO_2 from 2020.

Bioenergy paired with Carbon Capture and Storage (BECCS) technologies has the potential to play a critical role in meeting the UK's net zero ambitions

A new paper from the REA urges action to be taken on a number of levels to ensure progress in hard to decarbonise sectors

The paper outlines a number of possible policy options to develop BECCS, including increasing the UK total carbon price to £50t/CO_2 from 2020 and introducing a mechanism which rewards negative emissions, such as tradeable allowances under an EU-linked UK emissions trading scheme (ETS).

The REA's paper explores a range of possible policy options that would advance BECCS and its wider co-benefits, including: increasing the UK total carbon price to £50t/CO_2 from 2020 to promote rapid emission reductions; supporting BECCS in the Contracts for Difference auctions; and establishing demonstration projects at several scales that use the lowest carbon feedstocks.

The paper follows the publication of the second phase of REA's Bioenergy Strategy, which identified BECCS as an important Strategic Opportunity for the UK, delivering 23 $MtCO_2e$ of carbon savings by 2032 essential to realising the 5th Carbon Budget and our net zero ambition.

The REA urges the Government to establish at least one commercial large-scale BECCS project and several smaller demonstration scale BECCS projects by the late 2020s in order to address residual emissions from hard to decarbonise sectors of the UK economy.

Drax partners for CO2 to protein conversion tech

www.drax.com

Drax is working with biotech start-up Deep Branch Biotechnology to explore the feasibility of using the power station's carbon dioxide emissions to make proteins for sustainable animal feed products.

Deep Branch Biotechnology, a tech start-up based at Nottingham University, will place a pilot plant within Drax's Carbon Capture Usage and Storage (CCUS) Incubation Area at its power station in North Yorkshire.

It will extract flue gases from the power station's renewable electricity generation to feed to microbes, which can make single cell proteins for use in fish food and other sustainable animal feeds.

Drax Power Station is the biggest renewable electricity generator in the UK and the largest decarbonisation project in Europe having converted two thirds of the plant to use sustainable biomass instead of coal.

It is exploring the feasibility of using BECCUS technologies to help further reduce its emissions and contribute towards the UK meeting its climate targets. This is Drax's first incubation project exploring a market for carbon dioxide. The power station has also held discussions with the British Beer and Pub association about the possibility of captured CO_2 being used to carbonate drinks.

A dedicated Incubation Area has been created at the power station to give other technology companies the opportunity to test their processes on its carbon dioxide.

The method they have developed for producing proteins from CO_2, relies on an edible microbe that consumes carbon dioxide.

When fed carbon dioxide, the microbes grow and reproduce, enabling them to be continually harvested for protein whilst maintaining a growing culture. Under optimal conditions, up to 70 per cent of the material produced is protein.

The benefits of this process over other carbon capture technologies is that the CO_2 does not need to be separated from the power station's flue gases before being fed to the microbes.

The new proteins created using the Deep Branch biotechnology could help reduce the quantities of fish removed from the oceans. This not only minimises the impact on ecosystems, but decreases the amount of carbon dioxide in the atmosphere, mitigating the harmful effects of climate change.

The Deep Branch pilot will get underway in the autumn, when a demonstration plant will be installed within the Drax CCUS Incubation Area.

It aims to capture enough CO_2 to produce 100kg of protein to be used to create feedstocks for fish and livestock. The protein generated from the project will be used in a trial project with a major feed producer.

If successful, Deep Branch Biotechnology plans to build a larger production facility by 2020 so it can produce several tonnes of protein per year.

European "3D" industrial scale CCS project launched

www.total.com

A consortium of 11 European stakeholders including ArcelorMittal, Axens, IFP Energies nouvelles (IFPEN) and Total, is launching a project to demonstrate an innovative process for capturing CO_2 from industrial activities — the DMX™ project.

It is part of a more comprehensive study dedicated to the development of the future European Dunkirk North Sea capture and storage cluster.

The "3D" project (for DMX Demonstration in Dunkirk) is part of Horizon 2020, the European Union's research and innovation program. The project has a 19.3-million-euro budget over 4 years, including 14.8 million euros in European Union subsidies. Coordinated by IFPEN, the "3D" project brings together 10 other partners from research and industry from 6 European countries: ArcelorMittal, Axens, Total, ACP, Brevik Engineering, CMI, DTU, Gassco, RWTH and Uetikon.

The objective is threefold:

• Demonstrate the effectiveness of the DMX process on a pilot industrial scale.

The pilot, designed by Axens, will be built starting in 2020 at the ArcelorMittal steelworks site in Dunkirk and will be able to capture 0.5 metric tons of CO2 an hour from steelmaking gases by 2021.

The DMX process, a patented process stemming from IFPEN's Research and to be marketed by Axens, uses a solvent that reduces the energy consumption for capture by nearly 35% compared to the reference process. Additionally, using the heat produced on site will cut capture costs in half, to less than 30 euros per metric ton of CO2.

• Prepare the implementation of a first industrial unit at the ArcelorMittal site in Dunkirk, which could be operational starting in 2025. It should be able to capture more than 125 metric tons of CO2 an hour, i.e. more than one million metric tons of CO2 a year.

• Design the future European Dunkirk North Sea cluster, which should be able to capture, pack, transport and store 10 million metric tons of CO2 a year and should be operational by the year 2035. This cluster will be backed up by the packing and transport infrastructures for storing CO2 in the North Sea developed by other projects such as the Northern Lights project 1that Total is already involved in.

The "3D" project's ambition is to validate replicable technical solutions and to achieve industrial deployment of Capture & Storage technology around the world. It should play a major role in enabling industries with high energy consumption and CO2 emissions, such as the steel industry, to reduce their emissions. This project is an essential lever for meeting the targets of the Paris Agreement on global warming.

Inventys partners with Total and Lafarge to demonstrate cement CCUS

inventysinc.com

Project CO2MENT will demonstrate and evaluate Inventys' CO2 Capture System and a selection of CO2 utilization technologies at Lafarge's Richmond cement plant in Canada over the next four years.

Inventys has partnered to develop and demonstrate the first full-cycle solution to capture and reuse CO2 from a cement plant. The project is led by Inventys in partnership with Lafarge Canada Inc., a member of the global building materials group, LafargeHolcim, and Total, a major energy company.

It also received financial support from CCP (CO2 Capture Project), the Province of B.C., and Canada's federal government through the National Research Council of Canada Industrial Research Assistance Program (NRC IRAP).

The project provides an opportunity to evaluate the potential for a new business model for supplying post-combustion CO2 to the existing CO2 market as well as assessing the economic feasibility of newly developed CO2 utilization technologies.

"Using the CO2 as a raw material, especially when coupled with BC's renewable energy, could potentially generate profits to subsidize the costs of CO2 capture and enable a use in a region where storage can't exist," said Inventys Co-Founder and VP of Strategic Accounts, Brett Henkel.

"Our objective is to see if a commercial scale project can provide a business case for up to 3,000 tons of CO2 per day, preventing those emissions from going to the atmosphere."

The objectives of Project CO2MENT are as follows:

PHASE I - The Contaminant Program : Reduce harmful organic and inorganic substances, such as sulphur dioxide, dust and soot, as well as nitrogen oxides, from cement flue gas;

PHASE II - The CO2 Capture Program: Separate the CO2 from flue gas using a customized-for-cement version of Inventys' carbon capture technology at pilot scale;

PHASE III - The CO2 Reuse Program: Prepare post-combustion CO2 for reuse and support the economical assessment and demonstration of CO2 conversion technologies onsite, such as CO2-injected concrete and fly ash.

Funding for the first two phases is complete and development of Phase I is underway. Phase I will begin operation in 2019; followed by Phase II & III in 2020.

ExxonMobil partners with Global Thermostat CO2 removal tech

globalthermostat.com

www.exxonmobil.com

ExxonMobil and Global Thermostat have signed a joint development agreement to advance breakthrough technology that can capture and concentrate carbon dioxide emissions from industrial sources, including power plants, and the atmosphere.

The companies will evaluate the potential scalability of Global Thermostat's carbon capture technology for large industrial use. If technical readiness and scalability is established, pilot projects at ExxonMobil facilities could follow.

"Advancing technologies to capture and concentrate carbon dioxide for storage and potential industrial use is among a suite of ExxonMobil research programs focused on developing lower-emissions solutions to mitigate the risks of climate change," said Vijay Swarup, vice president of research and development for ExxonMobil Research and Engineering Company.

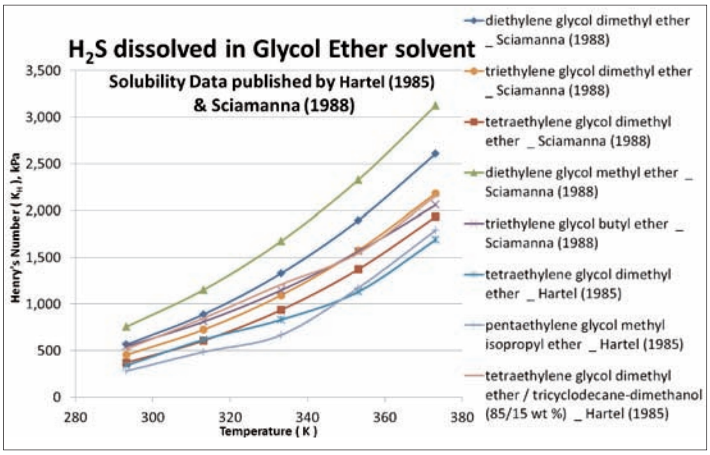
"Our scientists see potential in this exciting technology that could lead to more affordable methods to reduce emissions in power generation and manufacturing, along with removing carbon dioxide from the atmosphere."

ExxonMobil and Global Thermostat are also exploring opportunities to identify economic uses for captured carbon dioxide.

Optimising physical solvents

A process configuration for Acid Gas Recovery (AGR) for H2S capture and CO2 capture has been designed and techno-economically analysed at Ulster University.

Dr. Ashok Dave, past researcher at Ulster University, NI, UK. ashokddave@yahoo.com



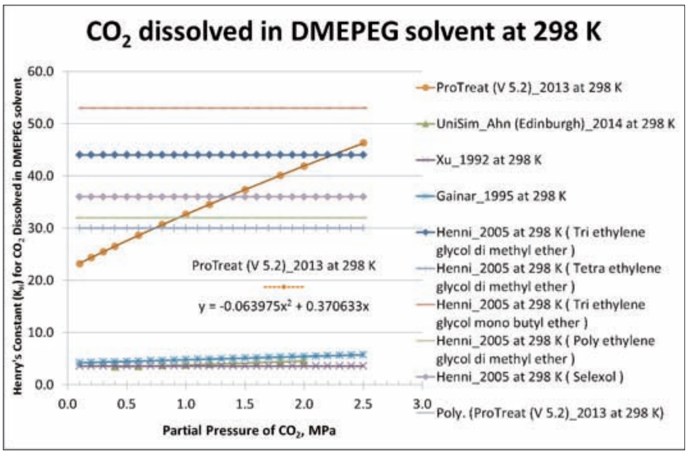


Figure 2 - Solubility of CO2 and H2S in various DMEPEG polymers

Pre-combustion IGCC is one of the leading technologies having potential for effective control of green-house gas emissions (to prevent global warming and the resulting climate change effects). Syngas production and utilization at high pressure (in a pre-combustion IGCC power plant) may facilitate the utilization of earth abundant coal and the capture of CO2 by physical solvents like DMEPEG. Capacity of physical solvent to absorb GHG gas such as CO2 is in direct proportion of the partial pressure of the individual GHG (such as CO2). Subsequently, the absorbed CO2 is desorbed by depressurization (or heating or both) of the solvent.

The general formula of DMEPEG is CH3O-[C2H4O]n-CH3. The generic name DMEPEG (Di Methyl Ether of Poly Ethylene Gly-col) is assigned to a blend of various polymer chain lengths (n) of glycol ethers which is commercially known as Genosorb® or Coastal AGR®. Certain specific blends of DMEPEG solvent are prominently used by SELEXOLTM process licensed by UOP® to capture the acid gas compounds such as H2S and CO2. The solubility of CO2 or H2S for their binary solution in DMEPEG solvent as modelled by ProTreatTM software is compared with the published data in Figure 1.

A process configuration for Acid Gas Recovery (AGR) (for H2S capture and CO2 capture) has been designed and Techno-Economically analysed at Ulster University, UK. Out of the 10800 TPD syngas fed to AGR plant, this process configuration captures 99.5 % H2S by expending 30.7 GJ heat / Ton H2S capture and 88 % CO2 (7888.32 TPD) by consuming 50.7 kW-Hr electric power / Ton CO2 capture. The pre-combustion IGCC power plant is generating 390 MWe net at 46.5% net efficiency. This extraordinarily high efficiency is realised thanks to the specially designed energy efficient Acid Gas Recovery unit consuming 14.385 MWe power for AGR process and allied utilities including CO2 compression.

A single diameter tower is proposed to check the cost of the packed tower. CO2 is absorbed from syngas feed in bulk at nearly 70 % flood condition throughout the height of the packed tower by stacking various internals of nominal size being incrementally lowered with the height of the packed tower.

The CO2 rich solvent coming out of the packed tower is warmed up to 70 – 75 °C to facilitate the recovery of more than 55 % of the co-absorbed H2 which is equivalent to 3.267 MW power generation. After the recovery of H2, the solvent is further heated before depressurizing the solvent in several stages. The desorbing CO2 is cooled and compressed from their individual desorption pressure for CO2 transport (to 120 bar), thus controlling the power consumption for CO2 compression (to 14.1 MWe).

The CO2 capture plant include a train of reverse rotating pump allowing the solvent to successively depressurize, thus generating 3.8887 MW in total. The desorbed CO2 is compressed by a train of centrifugal impellors driven together by a central bull gear in an integrally geared compressor consuming 14.1 MWe to compress the 7888.32 TPD captured CO2 up to 120 bar.

The project location is considered as UK. The currency exchange rate is considered to be 1.12 € / £. The H2S capture plan is expected to cost 15.2 million € whereas the CO2 capture plant is expected to cost 55 million € including 30 % cost for the CO2 compressor.

The overall CO2 Capture plant is expected to cost 46 Million £. Considering the specific investment of 2514 € / kWe net for the whole IGCC power plant, the avoidance of carbon dioxide emission is expected to cost 20 € for the generation of each of the MW-hr considering 8 % interest rate.

The process design and the equipment design developed within this work are largely based on the information available within open literature and the available resources.

IOGP report - the potential for CCS and CCU in Europe

A report coordinated by the International Association of Oil & Gas Producers (IOGP) to the thirty second meeting of the European Gas Regulatory Forum 5-6 June 2019.

The 31st Madrid Forum invited IOGP to coordinate a report on the potential of Carbon Capture and Storage (CCS) and Carbon Capture and Utilisation (CCU) technologies, including technical, economic and public acceptance considerations, working with all interested stakeholders.

A Taskforce composed of interested stakeholders was subsequently established, and this group began regular discussions, including on current regulatory barriers and incentives. Two workshops were held to facilitate in-depth discussions on CCS and CCU.

The Taskforce agreed on the importance of separating out the CCS and CCU value chains into their component parts, in order to identify the barriers, incentives and public financial support that could apply to individual segments of the chain (capture, transportation, and utilisation or storage).

When the CCS and CCU value chain is disaggregated, it becomes easier to design targeted incentives which facilitate the deployment of capture, transport, use and storage as individual business cases, thereby creating an overall CCS and CCU system, which in turn encourages scale.

Public financial support is, however, necessary to facilitate early deployment of the CCS and CCU infrastructure, since the business case for large-scale deployment in Europe requires a supportive ETS price in combination with an enabling regulatory framework.

Once the required capture, transport, storage and utilisation infrastructure has been deployed, and economies of scale emerge, CCS and CCU unit costs will decline and public financial support, e.g. infrastructure funding or tax credits, may be reduced.

For systemic deployment of CCS and CCU in Europe, a regulatory framework is needed that both incentivises investment and maintains flexibility to accommodate new CCS and CCU approaches and technologies across the value chain.

Key policy recommendations

Market uptake

• Promote a market framework for decarbonised products and services, including Guarantees of Origin and/or other accreditation schemes, to incentivise new business models for CCS and CCU technologies.

• Support Member State initiatives to promote early deployment of CCS and CCU infrastructure, such as:

- Contracts for Difference in the power sector;

- Tax incentives for CO2 storage;

- Funding of exploration and appraisal of potential CO2 storages;

- Absorbing early value chain risk by providing guarantees for CO2 supply and/or off-take.

Capture

• Enable the economic incentives available under the EU ETS to recognise and reward CCU, subject to a lifecycle analysis and clear carbon accounting rules.

• Ensure CO2 transport by ship and other modes of transport in addition to pipeline for the purposes of storage is recognised and rewarded under the ETS.

Transport

• Enable gas infrastructure or other companies, where Member States so decide, to transport CO2 as a commercial or regulated activity, including in an offshore environment towards the storage, overseen by NRAs with appropriate mandates.

• Encourage Member States and other parties to the London Protocol to prioritise ratification of the 2009 amendment of Article 6, which allows for the cross-border transport of CO2 for the purpose of offshore storage and support proposed temporary solutions including preliminary entry into force among the current ratifying parties.

• Encourage studies which appraise offshore transport infrastructure to identify infrastructure suitable for re-use. Storage

• Clarify the liabilities of CO2 storage facility operators, whether state-entities, gas infrastructure companies, or exploration and production companies.

• Encourage Member States to develop CO2 storage atlases of suitable storage complexes, as well as promote relevant geological and infrastructure information sharing.

Public support

• Ensure CCS and CCU technologies and projects are eligible for available public support schemes across the various stages of development, including R&D, demonstration projects, and early roll-out of infrastructure.

• Ensure CCS and CCU are recognised as economic activities contributing to climate change mitigation in the taxonomy developed in the context of the action plan on sustainable finance.

• Ensure Member States consider concrete deployment strategies and supportive policies for CCS and CCU nationally and in the NECPs, in order to achieve the EU 2050 climate ambitions.

More information

www.iogp.org

Oil companies talk carbon at EAGE

The June 2019 London event of the European Association of Geophysicists and Engineers (EAGE) featured a "Forum Session" discussing how the oil and gas industry could "deliver the world's low carbon energy needs", including speakers from Wood Mackenzie, ENI, and the Carbon Capture and Storage Association. Equinor Chairman Jon Erik Reinhardsen spoke at the opening session.

"The energy transition is happening today and moving very quickly," said Neal Anderson, CEO of energy research firm WoodMackenzie, at a EAGE "Forum Session" in June 2019, "Delivering the World's Low Carbon Energy Needs". But "there seems to be a 'them and us' [situation] that does no-one any good at all."

"Oil and gas business has a critical role to play. I would like to see us as a business be much more proactive and involved in this debate."

Mr Anderson said that the industry needs to get much better at communicating how it can contribute positively to climate problems. But "we're really good at solving complex problems. I've never heard anyone make that argument."

And the low public opinion of the oil and gas industry can cause real problems, as we saw with fraccing, which in the UK was "effectively shut down by public opinion".

"The perception is we're dragged kicking and screaming by investors."

Mr Anderson said that he has worked in the US for the past 14 years, "continually talking to clients about 'energy transition', and got very little traction until about 6 months ago". But here (UK) "everyone wants to talk about it. Companies understand there's a potential about revocating license to operate."

In the future we will see companies competing to get access to oil and gas resources with the lowest carbon footprint. In his view, new development in the Arctic and Canadian Oil Sands is "highly unlikely". But there is definitely a continued need for more exploration. "My real worry is in the medium term we will have a supply crunch."

"The industry is putting its hopes on tight oil, I'm not sure that's an endless resource. We still need low cost resources like Exxon in Guyana."

More focus on climate could help companies attract younger people. "Young people care passionately about this. Everyone who comes to WoodMac asks me, 'what's your position on the energy transition,'" he said.

Mr Anderson said that carbon prices can put a disadvantage to companies in the EU, if they are uncompetitive with suppliers which don't have carbon prices. One answer could be "something like a carbon tariff applied on imports to the EU".

"People say it's a 'WTO issue' – but look at the Trump Administration," he said.

Luke Warren, CCSA

Luke Warren, chief executive of the Carbon Capture and Storage Association (CCSA), said he thought the future of the oil and gas industry will be tied intimately with the CCUS (carbon capture, utilisation and storage) sector.

Today there are 23 large industrial carbon capture projects, operating or under construction. The challenge is to do to CCS what happened with renewables, with costs coming down as the business grew, he said.

However, the oil and gas industry is not yet "wholeheartedly getting behind CCUS," he said.

Mr Warren believes that one way or another, the energy transition "will happen" – and there will be restrictions on CO2 emissions – although there are doubts about whether the Paris agreement will be adhered to.

Carbon capture initially focussed on the coal power sector. But now, "in a lot of markets [coal has] lost its future," with governments withdrawing support for coal power stations due to carbon concerns, he said. The same could happen to the oil and gas industry now if it does not take measures to manage carbon. And "It is oil and gas industry which has the capacity to develop this technology."

In terms of the cost of storing carbon, this depends largely on how expensive it is to obtain the carbon. "There's pure CO2 being vented to the atmosphere in Teesside," he said. "Sequestering it is very cheap."

Hydrogen has "gone up on everyone's radar," and could be supplied from natural gas with CCS. It can be stored. It can be used in applications which require high heat (industry, domestic), and used to power heavier vehicles such as ships and trucks, where batteries are challenging, he said. "The question is how to create some early markets."

Mr Warren said he did not envisage that a carbon price will drive investment in carbon capture "this side of 2030".

It is perhaps a bad idea for oil and gas companies to be too fixated the carbon price as a way to make carbon capture commercially viable, he said. "I think we need a price on carbon to send a signal to the market. But we can't rely on carbon pricing – when it requires bringing technology costs down."

Instead, we are likely to see a range of regulatory and funding policies focussing on supporting carbon capture, focused on different sectors, just as we saw with wind and solar, he said.

ENI

ENI has had "energy transition" on its list of priorities since 2017, said ENI's Luca Bertelli, Chief Exploration Officer. It joined the Oil and Gas Climate Initiative (OGCI), and is following its targets for reducing fugitive emissions of methane.

There are 3 pillars to ENI's model – improving operational efficiency, decarbonising its activities, and being "carbon neutral" in its operations, such as from investing in deforestation to offset CO2 emissions from its operations it cannot eliminate. It covers the emissions from downstream and chemical activities. It also plans to increase investment in renewables, up to 1.6 GW by 2022 and 5gW by 2025. "Renewables is becoming an important part of our business," he said.

Mr Bertelli noted that "the level of climate debate" is different in different countries. Europe is at the "top level", "US is less concerned. Developing countries are [mainly] concerned about supporting people."

"I believe a single global carbon pricing will be very difficult to achieve," he said. "Look at global trade wars. Local solutions will be the ones which prevail.

ENI has set a target of emissions reductions it wants to achieve from its own operations, and is measuring against them. It also has a program to get to zero flaring, he said.

OMV

Gary Ingram, VP Exploration & Appraisal, OMV, noted that New Zealand has banned oil and gas exploration for carbon reasons. "They are trying to be a front runner, putting pressure on the world to see how they can solve it."

Mr Ingram said companies are sometimes not pushing hard enough to make a change to their own emissions, such as when they see benchmarking data from companies like Wood Mackenzie and see they are in the average.

There are ways they can reduce emissions which are not thought about much. For example, the cost of having a dynamically positioned rig vs an anchored rig – with a dynamically positioned rig continually burning fuel.

Equinor

Jon Erik Reinhardsen, Chairman, Equinor spoke during the opening session on the company's change of emphasis.

Equinor changed its name in summer 2018, after being Statoil for 45 years. The Statoil name "represented certainty the world needed oil and gas and Statoil provided it as safely and efficiently as possible," he said.

The name change reflects the fact that this is no longer the case, he said.

Factors weighing into the decision included that Equinor "accepts climate change is real and it will make an impact on how we do business," he said. "We support Paris agreement – we want to be part of the solution for a cleaner energy supply to the world. Under the new strategy we are becoming a broad energy company."

The Equinor name also represents equity, quality, equilibrium and the Norwegian heritage. "The new name communicates our new approach to new generatios of talent and we already see effects of this coming through," he said.

Equinor "has ambitions" to invest 15 to 20 per ecnt of its capital int renewable energy from 2030 (although the remainder will still be oil and gas).

Mr Reinhardsen said he sees a carbon tax as a very important measure to drive change in emissions. "From an international persetive we don't have a legislative framework. But we do have Paris agreement and UN sustainable devloopment goals," he said. "Both accords have become widely accepted among soceities, investors and companies as targets to strive for improve climate."

"Investors are now having signiciant influence on aligning oil companies with Paris agreement". One group called "Climate Action 100+" includes investors with $33tn under management, and its activities "has had a material impact on oil companies".

"We believe demand for oil and gas will eventually start flattening out – first for oil and later for gas. That is a necessary thing to happen to meet Paris agreement goals," he said.

Equinor sees the changes happening on 3 major themes.

Companies will increasingly compete based on their carbon efficiency, so will look for 'low carbon' resources and energy efficient solutions. Carbon taxes "will play an important role driving this development."

There will be increased focus on how to mitigate carbon emissions, which can be from natural carbon sinks (such as forestation), CCUS, and generating hydrogen from natural gas (with CCS).

There will be increasing expectations and demands from society and investors with climate and sustainability.

Equinor's name change reflects the fact that the company "accepts climate change is real and it will make an impact on how we do business" - Jon Erik Reinhardsen, Chairman, Equinor

Equinor's new Johannes Sverdrup development will produce 660,000 bopd at maximum production, with CO2 emissions from operations at under 1kg CO2 per barrel, a 20th of industry average. This is possible because the hydrocarbons are of high quality, and because the field will be powered by electricity generated by hydroelectric power onshore.

Mr Reinhardsen was asked how CO2 emissions could be incentivised, after we have seen the carbon tax system not really functioning properly in Europe.

"I think we have to keep working on this," he said. "One of the elements that come into play - is the degree we are successful with CCS. That could create space for some of these industries."

"It is always about technology, developing new solutions."

"We should go out of this room with some pride saying we come from an [oil and gas] industry which supplies affordable energy to the world – which is stabilising the whole world these days. Even though energy prices are volatile it is better than the alternative.

"We have to realise climate change is for real and we have to work towards zero carbon profile and put the effort in to find out how we're going to get there. We need to get together much broader than just this industry."

More information

www.eage.org

Rotterdam – when CCS combines innovative engineering, investment and public support

The CATO "CCUS developments in the North Sea region" event in Rotterdam on June 26 showed how innovative engineering, investment and public support might be combined to make carbon capture and storage viable.
By Karl Jeffery

John Browne, former CEO of BP, has said that the way to make carbon and capture and storage commercially viable is to get "the right combination of innovative engineering, private investment and public support", which also proved to be transformational for wind and solar power. Mr Browne is largely credited with turning BP from a small civil service type company into an oil major, and so has a track record building enormous businesses.

At the CATO event in Rotterdam on June 26, "CCUS developments in the North Sea region", we saw what it might look like when these elements come together. CATO is the Dutch national R&D programme for CO2 capture, transport and storage.

For "public support" (government financial support), the Dutch government is developing a scheme called "SDE++", which will enable companies investing in CO2 capture to receive a guaranteed return, based around the carbon price plus a top-up where necessary (like the UK's "Contract for Difference" scheme). Conversely, if they emit to the atmosphere, they may need to pay an additional tax on top of the carbon price, until the carbon price reaches a certain level.

To get "private investment", the companies emitting the most CO2 in the Port of Rotterdam are being invited to join PORTHOS, a scheme to build a CO2 pipeline along the length of the port, leading to capture offshore. The members will need to pay for their own capture and pay PORTHOS for transport and storage. The Dutch government is developing a subsidy / support scheme called SDE++ (see below)

For "innovative engineering", engineers and academics are carefully modelling the pressures and temperatures the pipeline can safely operate under and how to achieve them. One concern is the cooling the CO2 will undergo as it reduces pressure from the pipeline to the reservoir, and whether this might lead to hydrates (CO2 and water freezing) or damage to the materials. This might be mitigated by having CO2 at low pressure (in pipelines and ships) to begin with, and then increasing the delivery pressure as the reservoir pressure increases.

Public support

The Dutch government is one of the proactive in the world on carbon issues, but also shows a willingness to listen to environmental groups, who have not been much in favour of carbon capture in the past seeing it as way to lock in use of fossil fuels.

But environmental groups are showing more support to the SDE++ subsidy scheme for carbon capture, planned for 2020, pacified by promises that it will be applied only to industrial emissions, because there is an expectation that all power will come from renewables. There may also be a cap on the maximum amount of subsidy for carbon capture which the Netherlands will ever do. (Proposals for a cap are not yet definite but a figure of 7 MT/y CO2 was quoted). The first SDE scheme was for renewables only.

The Dutch government also has a subsidy scheme for carbon capture, utilisation and storage feasibility studies.

According to Keith Whiriskey of environmental group Bellona, which has always been in favour of carbon capture, perhaps some of the credit in the change of stance of other environmental groups could be credited to 16 year old Greta Thunberg, and her message that something needs to be done urgently about climate. People increasingly recognise that waiting for renewables to supply all energy may take too long, he said.

Private investment - PORTHOS

The PORTHOS project, is a scheme to build a CO2 pipeline along the Port of Rotterdam, which roughly follows the Maas River, with a compressor site at the coast, then a pipeline to offshore storage. It is operated by 3 companies, the Port of Rotterdam, EBN, an organisation owned by the Dutch government which takes a non-operating ownership in oil and gas projects, and Gasunie, the national gas transport system operator. The name stands for "Port Of Rotterdam Transport Hub and Offshore Storage."

PORTHOS is planning to make its final investment decision in late 2020 / early 2021. The plan is to store 2 MT/year CO2 from 2023, climbing to 4MT / year.

Mark Driessen from the Port of Rotterdam Authority pointed out that Rotterdam is the ideal location for a CCUS hub, with enormous CO2 emissions (16 per cent of total CO2 emissions for the country), a large industrial cluster in a relatively small area, the potential for storage in nearby empty gas fields offshore. It is hard to think of a better place in the world to do CCUS.

95 per cent of the emissions in the port come from 15 emitters, of which 3 are power plants, expecting to be phased out due to the move to renewable power. Of the remaining 12, five have been "very supportive" of PORTHOS. But the contracts have not yet been signed and negotiations continue, Mr Driessen said.

For the project to get a final investment decision, at least three of the large emitters in the port must at the same time commit to working with the project. And there is a chicken-and-egg reluctance to do detailed technical studies before the project is fully confirmed, he said.

But as a shared project, the contribution required from individual companies is much lower than if they were building their own scheme with a single emitter and single injection source. There is both pressure and support from the Dutch government. There are also plans to bring in CO2 from other industrial sites nearby, growing the scheme into a major CO2 hub.

Technical details

The pipeline will be 90cm or 108cm in diameter, running the length of the port, with a compressor station on the Maasvlaakte in the western end. The project team have 'booked' the one remaining slot on an existing pipeline corridor. The pipeline will be able to take up to 5MT / year of CO2, but this is envisaged as a maximum flowrate not steady state flowrate.

The compressor station will take 6 hectares of space, and require electricity and cooling.

The pipeline will then go beneath the Maas river, and then under the seabed out under the North Sea. It will use existing offshore platforms and wells, taking the CO2 to storage in depleted gas fields at around 3.3km depth.

A longer term plan could be to bring in CO2 from other industrial sites – including the Chemelot industrial cluster in South East Netherlands, the Zeeland cluster in South West Netherlands, and Antwerp (Belgium), together providing up to 10 MT/y CO2.

There are "ten thousand" challenges to work through, because "it has never been done before the way we want to do it". In particular with flow assurance, he says.

It may make more financial sense to use shipping rather than a pipeline initially to take CO2 to the offshore location – some financial models show that pipelines are only viable at flowrates of above 5 MT/y. The operational and energy costs of operating a pipeline are lower than shipping, but the capital costs of a pipeline are much bigger. But the project team has decided that for the Rotterdam area it definitely wants to build a pipeline, he said.

Innovative engineering

Filip Neele, senior project manager CO2 storage with TNO discussed how engineers are identifying and resolving storage challenges with CO2 associated with the rapid depressurisation and cooling.

The CO2 is planned to be stored in depleted gas reservoirs, typically at 20 bar or lower, but with temperatures above 100 degrees C, at 2.5 to 5km depth. But the CO2 transport is planned to carry 80 to 100 bar pressure, at seawater temperatures of 5 to 10 degrees C.

The CO2 pressure would normally be reduced with a choke valve at the well head. But a 1 bar pressure decrease will typically lead to a 1 degree temperature drop. Meanwhile CO2 has the possibility of forming (frozen) hydrates at anything below 15 degrees C, which would block the well and cause a shut down in flow.

Also, the wells were designed to carry hot gas from oil reservoirs, not cold CO2.

So the engineering is based ensuring the bottomhole temperature is never below 15 degrees.

Achieving this is easier with a higher injection rate, which also means a lower pressure drop at the choke. The minimum injection rate may be as much as 2 MT / year. But it depends on the tubing and the reservoir properties.

It could be possible to heat the CO2 and avoid it being so cold at the bottom of the well, but this would require a lot of energy. Another option would be to only use higher pressure reservoirs (e.g. above 50 bar), or have a CO2 pipeline at lower pressure.

Perhaps there would be an initial low pressure pipeline phase, and then increase pressure or switch to liquid injection as the reservoir pressurises, he said.

Port of Rotterdam plans

Overall, the Port of Rotterdam to decarbonise along three directions – carbon capture, synthetic fuels, and recovering plastics and power from waste, said Ruud Melieste, corporate strategist with the Port of Rotterdam Authority.

The port has 5 refineries, 36 chemical companies, 6 power plants and 12 'cogens' generating heat and power, altogether amounting to 16 per cent of the total CO2 emissions of the Netherlands, he said.

Mark Driessen from the Port of Rotterdam Authority pointed out that Rotterdam is the ideal location for a CCUS hub - "It is hard to think of a better place in the world to do CCUS"

Its current strategy is to expand its heating grid, steam grid and CO2 grid, sharing heat, steam and CO2 around the port between sources and users of it. Its current CO2 grid connects the Shell Pernis refinery (a CO2 source) with industrial greenhouses which pump it into their air so it acts as fertiliser.

From 2020 to 2030 it anticipates building a hydrogen grid, carrying both "blue" hydrogen (made from natural gas) and "green" hydrogen (from renewables). From 2030 to 2050, it plans developing chemicals which utilise carbon, and to convert waste to chemicals.

Seagoing vessels could switch to synthetic fuels and biofuels, and later move to hydrogen power, perhaps electricity.

Dutch Ministry plans

The Netherlands government has a target to reduce CO2 by 49 per cent by 2030, said Joëlle Rekers, senior policy advisor with the Dutch Ministry of Economic Affairs and Climate Policy (EZK). Over 100 different organisations have committed to reduce their own emissions by 49 per cent by 2030, she said.

To get there, it wants to establish a minimum (floor) price for CO2 emission credits, phase out coal power by 2030, and build 10 GW more offshore wind.

There are detailed plans for allocating the Dutch area of the North Sea to different uses, including a NATO practise flying zone, shipping lanes, cables, wind farms and space for helicopters to land safely on offshore platforms.

Carbon capture and storage is seen as a cost effective way to reduce emissions from industry, although the expectation is that all power will be generated with renewables, so CCS will not be required for power generation. Electricity usage by industry will also be expected to be supplied by renewables.

If it proves impossible for private companies to develop CCS infrastructure, perhaps there is a role for the government to step in.

Offshore system integration

Joris Koornneef with Dutch research organisation TNO, has been looking for useful ways that offshore systems could be integrated.

The Netherlands could have 60 GW of offshore wind by 2050, and run into problems 'landing' the power into the country's domestic grid.

But instead, compressors on offshore gas production platforms could run on electricity from wind rather than their own gas generators. Currently 6 per cent of offshore gas production is used to power offshore compressors and process equipment, he said. The carbon value works out at 75 to 100 euro per tonne of CO2 mitigated, maybe less for some cases.

Another option is to use excess wind power to electrolyse water and make hydrogen. But this would need a lot of wind power - 4GW - to roughly make the same hydrogen as is currently used in the port of Rotterdam, around 0.3 MT/y. To illustrate how much this is, consider that an average offshore wind farm is 480 MW and total offshore European wind power as of June 2019 was 18.5 GW.

Equipment to generate hydrogen using wind power offshore at large scale takes more space than would be available on an offshore platform, so there might be a need to build entire offshore islands.

"We think gas, CCS and electricity can work together," he said. Further information about the research is at **www.North-sea-energy.eu**

UK developments

Jon Gibbins, director of the UK Carbon Capture and Storage Research Centre (UKCCSRC), said that the UK is still struggling to develop business models for carbon capture. One obstacle is that people take the price of offshore wind power and compare it with the price of coal + CCS, without taking into account the intermittency of wind. So people are focussing on the price rather than the value.

But modelling projects for the UK's planned "net zero" by 2050 show that it will require between 75 and 175 MT CO2 of storage per year, including CO2 from industry, power generation, hydrogen generation, bio-energy CCS, and air capture.

Plans have been developed to build five CO2 clusters around the UK, in Scotland, Teesside, Humberside, South Wales and Merseyside. The South East of England / London is yet to see any CO2 planning – although it could involve CO2 carried to a storage site by ship.

The Humber project is based around the Drax biomass power station and nearby offshore storage. The Merseyside project is based on storage in gas fields offshore North West England, and this works out "one of the least cost projects", with a total development cost of £1bn, he reported.

South Wales has the "highest concentration of heavy industry in the UK" as a fraction of regional emissions, but would require shipping to take CO2 to a storage site. Meanwhile Scotland has about half the storage capacity of the entire European Union, but relatively little CO2 emission, mainly from the Grangemouth industrial cluster.

The Teesside project is based around a potential project by the Oil and Gas Climate Initiative (OGCI), a gas power station with post combustion capture, generating 5m tonnes of CO2 a year. There are also ideas to generate 125 GW of hydrogen fuel, with an estimated £22.7bn capital cost, feeding hydrogen into industry and the domestic gas grid. The CO2 transport and storage component of this project is a relatively small amount, £1.34bn.

The UK government recently announced £170m funding for CCUS projects, which should lay the groundwork to put together clusters, with an aspiration to have at least one cluster running by 2030. There would be larger amounts of money anticipated from the overall UK government spending on low carbon.

There is still no financial mechanism to reward doing BECCS (bio energy carbon capture and storage), he said. But perhaps after UK leaves the EU, agricultural subsidy schemes could be reconfigured to reward companies which produce energy crops and guarantee them a long term market.

Norway

Michael Drescher, principal researcher CO2 transport with Equinor, gave an update on the "Northern Lights CCS Project", involving Equinor, Total and Shell. The project is part of the Norway's national CO2 capture and storage project and contains the transport and storage part of the value chain.

The plan is to collect CO2 from two sites, Fortum's waste to energy plant in Oslo and Norcem's cement factory in Brevik. The CO2 is carried by ship to a receiving terminal near Bergen, where it would be further transported by pipeline to offshore storage.

The project would scale up gradually, with initially CO2 from one or two sources from Fortum and Brevik with a volume of approximately 0.4 M tonnes/year each but seeking to add additional third-party volumes in the future. The project plans to install a pipeline with a maximum capacity of 5M tonnes/year.

The project is partly funded by the Norwegian State, which plans a final investment decision later in 2020. The project team is currently mid-way through FEED (front end engineering and design), planning to finish at the end of 2019, with drilling a confirmation well in Q1 of 2020.

Mr Drescher is confident it can go ahead. "We don't see any technical showstoppers for the facilities, but the well is needed to confirm acceptable subsurface storage," he said. Injection of the first CO2 is planned to be in Q1 of 2024.

The initial design is taking into account existing operational experience and latest technology. However, the included safety margins for the design could be further challenged in future projects being able to bring down the costs in later projects.

For example, Equinor is investigating the possibility of using lower pressures for CO2 ship transport at later stages to enable larger CO2 carriers.

In addition, Equinor is looking into the practice of establishing cost-effective CO2-specifications for CO2 value chains. Necessary CO2-specifications will vary from chain to chain. For example, a cost-effective CO2-

specification will be very different if it would be a ship-based chain, like the Norwegian CCS value chain project (very pure) or a pipeline-based chain, like the Porthos CCS project, where higher amounts of impurities could be tolerated. In addition, there are other important factors which influence a cost-effective CO_2-specification such as the CO_2 source, capture and purification technology, safety and thermodynamic considerations, material integrity, etc.

Furthermore, Equinor is evaluation more radical cost cutting concepts such as injecting CO_2 directly offshore, omitting a necessary receiving terminal in the future. However, this could bring other types of challenges.

If the CO_2 would be injected directly by each CO_2 carrier, it would likely be batch-wise injection which would lead to strain on the equipment and reservoir. Another solution could be to have a floating CO_2 receiving ship at the wellhead, providing a buffer and thus enabling continuous CO_2 injection.

Carbon capture mistakes

Earl Goetheer, principal scientist with TNO, said that some mistakes made in schemes over the years, in his view, were too much focussed on OPEX rather than CAPEX in carbon capture, and pursuing unviable air capture and CO_2 utilisation schemes.

The focus on operational expenditure (OPEX) in carbon capture led to a chase for a solvent which had the best performance, in terms of energy required to recover the solvent after it had captured the CO_2.

But it turned out that project developers were more interested in reducing capital expenditure (CAPEX) rather than OPEX, so choosing the cheapest, most easily available solvent. This is MEA, which has been in use since the 1930s. If you buy a proprietary solvent from a chemical company, you are locked in to using it, he said.

But there are downsides to MEA which are not apparent in energy figures. The solvent loss rates of MEA is high, 1.5 to 2.5kg per tonne CO_2. This is not expensive in financial terms, but damages the overall carbon performance, because a lot of CO_2 is emitted in its manufacture, he said.

The emission rates to air can also be high, in the range of grams (of MEA) per m3 of CO_2. This could be due to amines condensing onto tiny (sub-micron) particles present in the flue gas of a typical coal power plant or refinery. These particles are too small to separate with a typical water wash or demister.

This problem was not observed in the first CO_2 capture projects, because they were mainly on removing CO_2 from natural gas fired combustion, which did not contain such tiny particles and the focus was on the CO_2 as a product, he said.

On the subject of CO_2 air capture, Mr Goetheer said he was sceptical that it could work at costs he has seen quoted of $80 per tonne. It costs at least $40 to capture CO_2 from flue gas, which can be up to 25 per cent C02 in case of cement production. But air is just 400 parts per million of CO_2. To illustrate the difficulty of this separation, he suggested an analogy of trying to find the 400 people who have one leg in a city of a million people.

On CO_2 utilisation, Mr Goetheer asserted that "96 per cent of it is nonsense, regarding applicability". It is possible to create the molecules technically, but the cost of energy to make the molecule is more than the product is worth. For example, if you make methane from CO_2, you use an enormous amount of energy to create a very low value molecule.

Many people talk about making formic acid in this way, since this product has a high (but fluctuating) value, but it also has very small market volumes.

Mr Goetheer said that using CO_2 to make algae may be overrated, when you consider that algae contains 1 to 2 g of solid per litre of water. So sequestering a small amount of carbon would require a massive quantity of water.

Some areas which may make sense are using electricity to make hydrogen and using this hydrogen for CO_2 activation towards methanol or methane. . "Methanol makes a bit more sense, it has a higher mass, higher value and is a liquid," he said. "You can use methanol to make ethylene, propylene and gasoline."

Other interesting options could be converting CO_2 into polymers and permanently storing CO_2 in minerals, perhaps to make cement. Electrochemistry could as well be a mean to produce value added chemicals such as formaldehyde or CO from CO_2. TNO has already seen it would be possible to integrate an electrochemical conversion process with CO_2 capture in an integrated process.

Transport and storage projects

The EU is providing funding for CO_2 transport projects provided they involve more than one country, under its scheme "Projects of Common Interest in cross-border carbon dioxide transport infrastructure," said Filip Neele, senior project manager CO_2 storage with TNO.

Funding in the first round (2017) was awarded to Norway's "Northern Lights" (involving UK and Norway), the UK's Acorn project, which has funding under the label "Sapling", a project labelled "Rotterdam Nucleus" linked to the Netherlands PORTHOS project (also involving the UK), and the UK's Teesside project, also involving Norway.

In the second round (2019), the Netherlands and Ireland jointly supported "Northern Lights", and Belgium joined Porthos. There was a new project Ervia, storing CO_2 off Cork, also involving the Netherlands, UK and Norway, and a Dutch project "Athos" also involving Ireland. To illustrate the size of funding, a representative of PORTHOS said its grant was Eur 6.5m.

There are multiple storage projects in the Netherlands. As well as PORTHOS, "ATHOS", in the northern Netherlands is based around a Tata steel plant, planning first injection in 2027. The "Aramis" project in Den Helder, North of Amsterdam, plans CO_2 transport by ship and pipeline and storage offshore the Netherlands.

The "H-Vision" project in Rotterdam plans to make hydrogen from gas and do CO_2 storage, with 2MT/year by 2025. A project "H2M" in Eemshaven plans to make "blue hydrogen" from Norwegian gas, and take CO_2 by ship back to Norway.

A project in the south of the country involves companies from the Chemelot cluster targeting 0.5mt/year storage by 2025, with liquid CO_2 sent by barge to, for example, the PORTHOS project. "Barge transport is very cheap," he said.

The "Zeeland" project plans to ship 1.7mt a year CO_2 from an inland steel plant to a North Sea port, including to 3.1 MT/year by 2040.

More information

www.co2-cato.org

Capture and utilisation news

Results of study into Enzymatic Technology for CO2 capture in industry

co2solutions.com

The technology appears to have significant environmental and operational advantages over alternative post-combustion capture technologies, such as advanced amine technology.

CO2 Solutions and COAL21, funded by the Australian black coal industry for the demonstration of low emission coal technologies, such as CCS, have announced the results of a study examining the performance of the Corporation's enzymatic technology when applied to coal-fired power plants for post-combustion carbon capture. The study was conducted over the past 18 months by PROCOM Consultants (Brisbane, Australia) and funded by the COAL21 Fund.

The enzymatic technology appears well suited to coal-based industrial plants (e.g. iron and steel, cement) in particular for its tolerance to the oxides in flue gas and appears to have significant environmental and operational advantages over alternative post-combustion capture technologies, such as advanced amine technology.

Richard Surprenant, CO2 Solutions' Chief Technology Officer, commented, "The detailed report prepared by Procom Consultants highlights the low-cost and environmentally friendly qualities of our process. It further confirms the major paradigm shift that the enzymatic technology represents for the carbon capture industry."

New electrochemical process shortens the path to capturing and recycling CO2

www.engineering.utoronto.ca

A research team from University of Toronto Engineering has developed a new electrochemical path to transform carbon dioxide into valuable products such as jet fuel or plastics.

"Today, it is technically possible to capture CO2 from air and, through a number of steps, convert it to commercial products," says Professor Ted Sargent (ECE) who led the research team. "The challenge is that it takes a lot of energy to do so, which raises the cost and lowers the incentive. Our strategy increases the overall energy efficiency by avoiding some of the more energy-intensive losses."

In order to be fully recycled, the dissolved carbonate is normally turned back into CO2 gas, and then into chemical building blocks that form the basis of fuels and plastics. One way to do this is to add chemicals that convert the carbonate into a solid salt. This salt powder is then heated at temperatures above 900 C to produce CO2 gas that can undergo further transformations. The energy required for this heating drives up the cost of the resulting products.

The U of T Engineering team's alternative method applies an electrolyzer, a device that uses electricity to drive a chemical reaction. Having previously used electrolyzers to produce hydrogen from water, they realized that they could also be used to convert dissolved carbonate directly back into CO2, skipping the intermediate heating step entirely.

"We used a bipolar membrane, a new electrolyzer design that is great at generating protons," says Geonhui Lee, who along with postdoctoral fellow Y. Chris Li is among the lead authors of a new paper in ACS Energy Letters which describes the technique. "These protons were exactly what we needed to convert the carbonate back into CO2 gas."

Their electrolyzer also contains a silver-based catalyst that immediately converts the CO2 produced into a gas mixture known as syngas. Syngas is a common chemical feedstock for the well-established Fischer-Tropsch process, and can be readily turned into a wide variety of products, including jet fuel and plastic precursors.

"This is the first known process that can go all the way from carbonate to syngas in a single step," says Sargent.

While many types of electrolyzers have been used to convert CO2 into chemical building blocks, none of them can deal effectively with carbonate. Furthermore, the fact that CO2 dissolved in liquid turns into carbonate so readily is a major problem for existing technologies.

"Once the CO2 turns into carbonate, it becomes inaccessible to traditional electrolyzers," says Li. "That's part of the reason why they have low yields and low efficiencies. Our system is unique in that it achieves 100% carbon utilization: no carbon is wasted. It also generates syngas as a single product at the outlet, minimizing the cost of product purification."

In the lab, the team demonstrated the ability to convert carbonate to syngas at an overall energy efficiency of 35%, and the electrolyzer remained stable for more than six days of operation.

Sargent says that more work will be needed to scale up the process to the levels needed for industrial application, but that the proof-of-concept study demonstrates a viable alternative path for direct-air carbon capture and utilization.

"It goes a long way toward answering the question of whether it will ever be possible to use air-captured CO2 in a commercially compelling way," he says.

Lackner's carbon-capture technology moves to commercialization

cnce.engineering.asu.edu

Arizona State University and Silicon Kingdom Holdings (SKH) have agreed to deploy carbon-capture technology developed by Professor Klaus Lackner, director of ASU's Center for Negative Carbon Emissions.

The proprietary technology acts like a tree that is thousands of times more efficient at removing CO2 from the air. The "mechanical trees" allow the captured gas to be sequestered or sold for re-use in a variety of applications, such as synthetic fuels, enhanced oil recovery or in food, beverage and agriculture industries.

Unlike other carbon-capture technologies, SKH's technology can remove CO2 from the atmosphere without the need to draw air through the system mechanically using energy-intensive devices. Instead, the technology uses the wind to blow air through the system. This makes it a passive, relatively low-cost and scalable solution that is commercially viable. If deployed at scale, the technology could lead to significant reductions in the levels of CO2 in Earth's atmosphere.

Nano-bugs eat CO2 and make eco-friendly fuel

University of Boulder researchers have developed nanobio-hybrid organisms capable of using airborne carbon dioxide and nitrogen to produce a variety of plastics and fuels, a promising first step toward low-cost carbon sequestration and eco-friendly manufacturing for chemicals.

By using light-activated quantum dots to fire particular enzymes within microbial cells, the researchers were able to create "living factories" that eat harmful CO2 and convert it into useful products such as biodegradable plastic, gasoline, ammonia and biodiesel.

"The innovation is a testament to the power of biochemical processes," said Prashant Nagpal, lead author of the research and an assistant professor in CU Boulder's Department of Chemical and Biological Engineering. "We're looking at a technique that could improve CO2 capture to combat climate change and one day even potentially replace carbon-intensive manufacturing for plastics and fuels."

"Each cell is making millions of these chemicals and we showed they could exceed their natural yield by close to 200%," – Assistant Professor Prashant Nagpal (Photo: Casey A. Cass / University of Colorado Boulder)

The project began in 2013, when Nagpal and his colleagues began exploring the broad potential of nanoscopic quantum dots, which are tiny semiconductors similar to those used in television sets. Quantum dots can be injected into cells passively and are designed to attach and self-assemble to desired enzymes and then activate these enzymes on command using specific wavelengths of light.

Nagpal wanted to see if quantum dots could act as a spark plug to fire particular enzymes within microbial cells that have the means to convert airborne CO2 and nitrogen, but do not do so naturally due to a lack of photosynthesis.

By diffusing the specially-tailored dots into the cells of common microbial species found in soil, Nagpal and his colleagues bridged the gap. Now, exposure to even small amounts of indirect sunlight would activate the microbes' CO2 appetite, without a need for any source of energy or food to carry out the energy-intensive biochemical conversions.

"Each cell is making millions of these chemicals and we showed they could exceed their natural yield by close to 200%," Nagpal said.

The microbes, which lie dormant in water, release their resulting product to the surface, where it can be skimmed off and harvested for manufacturing. Different combinations of dots and light produce different products: Green wavelengths cause the bacteria to consume nitrogen and produce ammonia while redder wavelengths make the microbes feast on CO2 to produce plastic instead.

The process also shows promising signs of being able to operate at scale. The study found that even when the microbial factories were activated consistently for hours at a time, they showed few signs of exhaustion or depletion, indicating that the cells can regenerate and thus limit the need for rotation.

"We were very surprised that it worked as elegantly as it did," Nagpal said. "We're just getting started with the synthetic applications."

The ideal futuristic scenario, Nagpal said, would be to have single-family homes and businesses pipe their CO2 emissions directly to a nearby holding pond, where microbes would convert them to a bioplastic. The owners would be able to sell the resulting product for a small profit while essentially offsetting their own carbon footprint.

"Even if the margins are low and it can't compete with petrochemicals on a pure cost basis, there is still societal benefit to doing this," Nagpal said. "If we could convert even a small fraction of local ditch ponds, it would have a sizeable impact on the carbon output of towns. It wouldn't be asking much for people to implement. Many already make beer at home, for example, and this is no more complicated."

The focus now, he said, will shift to optimizing the conversion process and bringing on new undergraduate students. Nagpal is looking to convert the project into an undergraduate lab experiment in the fall semester, funded by a CU Boulder Engineering Excellence Fund grant. Nagpal credits his current students with sticking with the project over the course of many years.

The new study was recently published in the Journal of the American Chemical Society.

More information

www.colorado.edu/chbe

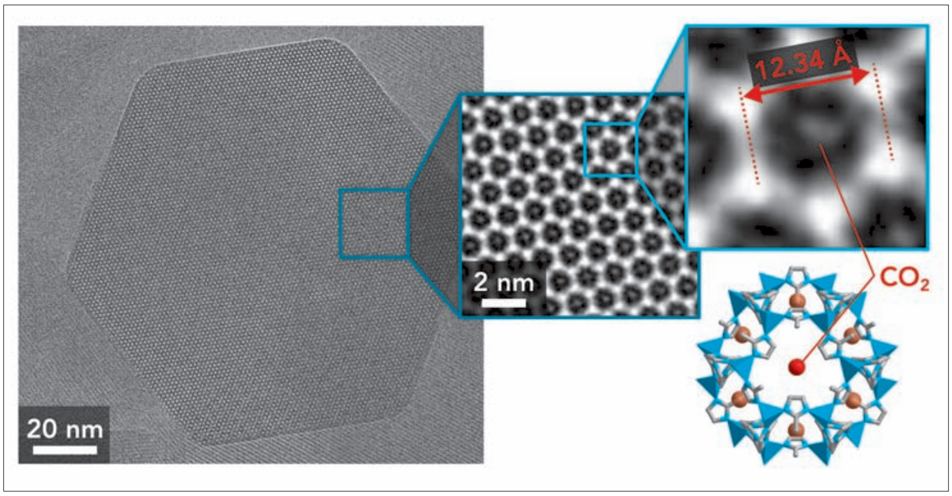
First snapshots of trapped CO2 molecules captured

Scientists from the Department of Energy's SLAC National Accelerator Laboratory and Stanford University have taken the first images of carbon dioxide molecules within a molecular cage.

The CO2 is trapped in a highly porous nanoparticle known as a MOF, or metal-organic framework, with great potential for separating and storing gases and liquids.

The images, made at the Stanford-SLAC Cryo-EM Facilities, show two configurations of the CO2 molecule in its cage, in what scientists call a guest-host relationship; reveal that the cage expands slightly as the CO2 enters; and zoom in on jagged edges where MOF particles may grow by adding more cages.

"This is a groundbreaking achievement that is sure to bring unprecedented insights into how these highly porous structures carry out their exceptional functions, and it demonstrates the power of cryo-EM for solving a particularly difficult problem in MOF chemistry," said Omar Yaghi, a professor at the University of California, Berkeley, who was not involved in the study.



Cryo-EM images show a slice through a single MOF particle in atomic detail (left), revealing cage-like molecules (center) that can trap other molecules inside. The image at right shows carbon dioxide molecules trapped in one of the cages – the first time this has ever been observed. Bottom right, a drawing of the molecular structure of the cage and the trapped carbon dioxide. (Li et al., Matter, 26 June 2019)

MOFs have the largest surface areas of any known material. A single gram, or three hundredths of an ounce, can have a surface area nearly the size of two football fields, offering plenty of space for guest molecules to enter millions of host cages.

Despite their enormous commercial potential and two decades of intense, accelerating research, MOFs are just now starting to reach the market. Scientists across the globe engineer more than 6,000 new types of MOF particles per year, looking for the right combinations of structure and chemistry for particular tasks, such as increasing the storage capacity of gas tanks or capturing and burying CO2 from smokestacks to combat climate change.

“Yuzhang Li, a Stanford postdoctoral researcher and lead author of the report, said "These materials have the potential to capture large quantities of CO2, and understanding where the CO2 is bound inside these porous frameworks is really important in designing materials that do that more cheaply and efficiently."

One of the most powerful methods for observing materials is transmission electron microscopy, or TEM, which can make images in atom-by-atom detail. But many MOFs, and the bonds that hold guest molecules inside them, melt into blobs when exposed to the intense electron beams needed for this type of imaging.

A few years ago, Cui and Li adopted a method that's been used for many years to study biological samples: Freeze samples so they hold up better under electron bombardment. They used an advanced TEM instrument at the Stanford Nano Shared Facilities to examine flash-frozen samples containing dendrites—finger-like growths of lithium metal that can pierce and damage lithium-ion batteries—in atomic detail for the first time.

For this latest study, Cui and Li used instruments at the Stanford-SLAC Cryo-EM Facilities, which have much more sensitive detectors that can pick up signals from individual electrons passing through a sample. This allowed the scientists to make images in atomic detail while minimizing the electron beam exposure.

The MOF they studied is called ZIF-8. It came in particles just 100 billionths of a meter in diameter; you'd need to line about 900 of them up to match the width of a human hair. "It has high commercial potential because it's very cheap and easy to synthesize," said Stanford postdoctoral researcher Kecheng Wang, who played a key role in the experiments. "It's already being used to capture and store toxic gases."

Cryo-EM not only let them make super-sharp images with minimal damage to the particles, but it also kept the CO2 gas from escaping while its picture was being taken. By imaging the sample from two angles, the investigators were able to confirm the positions of two of the four sites where CO2 is thought to be weakly held in place inside its cage.

More information

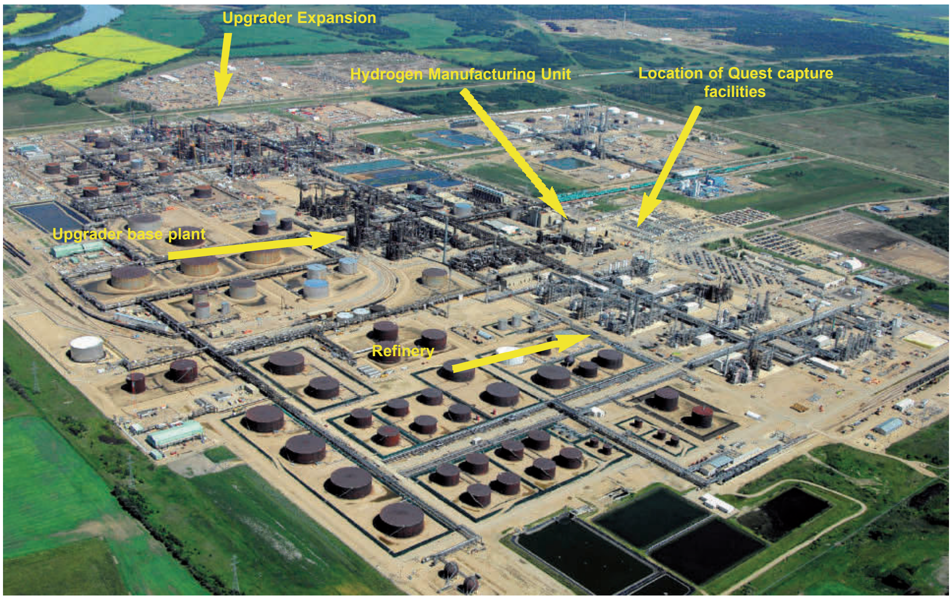
www.slac.stanford.edu

Shell QUEST project captures and stores 4m tonnes of CO2

In less than four years, the Quest carbon capture and storage facility has captured and safely stored four million tonnes of CO2, ahead of schedule and at a lower cost than anticipated.

The Quest CCS facility captures and stores about one third of the CO2 emissions from the Shell-operated Scotford Upgrader near Fort Saskatchewan, Alberta, which turns oil sands bitumen into synthetic crude that can be refined into fuel and other products. The CO2 is transported through a 65-kilometre pipeline and injected more than two kilometres underground below multiple layers of impermeable rock formations.

Since its start up in late 2015, the capture process at Quest has also worked better than anticipated, helping the facility exceed its target of capturing one million tonnes of CO2 per year. The facility is also safely storing the CO2 deep underground better than expected. The geological formation used for storage, which is prevalent across much of Western Canada, is demonstrating incredible capacity for CO2 injection.



Aerial photo of the Quest site

Quest has a robust measurement, monitoring and verification program verified by a third party (Det Norske Veritas (DNV)) to ensure the CO2 is permanently stored.

“Quest continues to show the world that carbon capture and storage (CCS) is working, its costs are coming down and that Canadians are leaders in CCS,” said Michael Crothers, Shell Canada President and Country Chair. “If Quest were to be built today, we estimate it would cost about 20-30% less to construct and operate. With our know-how, strong regulatory frameworks and ideal geology, Canada is uniquely positioned to capitalize on CCS technology.”

“Canada's oil and natural gas sector recognized the need to reduce CO2 emissions and by leveraging technology and Canadian ingenuity, we are delivering impressive results,” said Tim McKay, President, Canadian Natural Resources Limited. “Quest’s achievement reinforces the significant opportunity that CCS projects have in the ongoing responsible development of Canada’s energy resources as part of a lower carbon emissions future.”

Quest is operating at a lower cost thanks to a variety of factors including lower variable costs, capture reliability and reduced storage costs. To help encourage wider use of CCS technology around the world and bring down future costs of building CCS facilities, the designs, certain intellectual property and data from Quest are publicly available. This is due to Quest’s government funding arrangement, which is tied to knowledge sharing commitments to benefit future CCS projects.

“While Quest has benefited from significant government funding, the rapid learning curve and cost reductions are making CCS increasingly self-sufficient,” added Crothers.

“Industry is looking at carbon capture utilization and storage (CCUS), which could provide the ability for projects to be self-funded if they are able to generate revenues from CO2. Currently, CCUS for enhanced oil recovery (EOR) is the most commercially viable option to progress self-funded carbon capture.”

Quest received $865 million from the governments of Canada and Alberta to build and operate the facility.

Quest is world’s first commercial-scale CCS facility applied to oil sands operations and is operated by Shell on behalf of the Athabasca Oil Sands Project (AOSP). The respective ownership interests of AOSP assets in aggregate, directly and indirectly, are 70% Canadian Natural Resources Limited and an affiliate, 20% Chevron Canada Limited and 10% Shell Canada Limited through certain subsidiaries.

More information

www.shell.ca

Petra Nova CO_2 Capture Facility (Thompsons, Texas)

CO_2 CAPTURE FOR A BRIGHTER HORIZON

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MHI's knowledge and experience is unparalleled. With nearly three decades of R&D and operational experience, applications on various combustion exhaust, and capacities ranging from 220 to 5,200 stpd, MHI has acquired invaluable knowledge which ensures that our projects and technology continue to move the world forward.

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