CCP

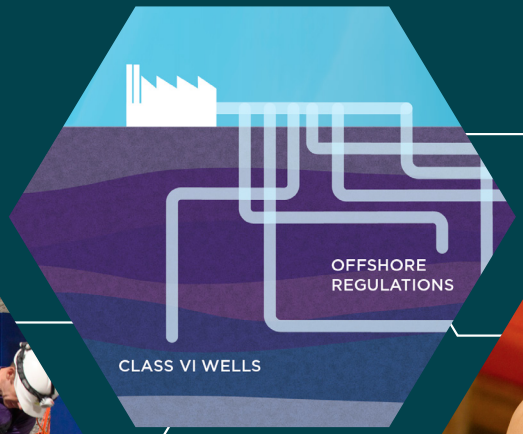
CO_2 CAPTURE PROJECT

2019 | ANNUAL REPORT

COMPLETING A TWO-DECADE JOURNEY TO MAKE CCS A TECHNICAL REALITY

CAPTURE

STORAGE, MONITORING & VERIFICATION



POLICY & INCENTIVES

COMMUNICATIONS

PARTICIPANT ORGANIZATIONS

bp Chevron BR PETROBRAS

ABOUT THE CCP

The CO_2 Capture Project (CCP) was formed in 2000. As an early pioneer in CCS development, it was set up to advance technologies for CO_2 capture and geological storage to help make CCS a viable option for CO_2 mitigation.

CCP is currently in its fourth phase of activity (CCP4), which began in late 2014. As a result of the disruption caused by the coronavirus, CCP4 has been extended to the end of 2021, in order to complete all ongoing projects.

The program is driven by three of the world's leading energy companies – BP, Chevron and Petrobras – supported by numerous experts. This group is focused on delivering further progress in CO_2 capture and geological storage technology through research, development and demonstration.

This 2019 Annual Report provides an update from the Teams that make up the CCP – Capture, Storage, Policy & Incentives, and Communications.

CCP AIMS:

- To drive down the cost of existing CO_2 capture technologies for future use by the oil, gas and power generation industries, through further technology R&D as well as demonstrations of next-generation technology
- Advancing knowledge of well integrity, natural site characteristics amenable to containment and subsurface processes governing CO_2 trapping
- Adapting subsurface monitoring technologies to track CO_2 underground and developing approaches to respond to out-of-zone migration of CO_2
- Providing technical and economic insights needed by a range of stakeholders, most notably governments and regulators, to inform the development of legal and policy frameworks.

CHAIRMAN'S INTRODUCTION

Tony Espie
BP, CCP Chairman

A warm welcome to the 2019 *CCP Annual Report.*

The publication of this report coincides with the outbreak of Covid-19 and we wish all of our readers and colleagues well at this time. As a result of the disruption caused by the virus, we have taken the decision to extend the CCP program by a year, to the end of 2021, in order to complete all ongoing projects. However, with the publication of the full CCP Results Book due later in 2021, this will be the final Annual Report that we produce. I hope that you find the contents interesting and insightful as we reflect, not just on the year's activities, but on the achievements of CCP as a whole.

> ***"The work of the last year maintained the impetus set in those earlier years and helps to bring our program to a fitting conclusion over this and next year."***

Since CCP began life back in 2000, much has changed in the world of climate change and carbon mitigation technologies. CCP was a true pioneer of CCUS two decades ago and has been one of the leaders in bringing it to technical maturity. Much of our work has had the aim of building knowledge to fill gaps in existing understanding in both capture and storage, as well as evaluating technologies that could reduce the cost of capture. We have gone through four CCP phases during that time, moving from screening of potential technologies to intensive development, demonstration and follow up of some of the most promising. Some of the highlights of this work are shown later in this Annual Report.

The work of the last year maintained the impetus set in those earlier years and helps to bring our program to a fitting conclusion over this and next year. Important projects were undertaken to bring the remaining capture and storage projects to (or close to) completion – including pilot testing of a piperazine solvent; evaluating a low-energy solvent for post-combustion capture; 3D printing of sorbent structures; and the testing of the final sealants to address behind casing wellbore seepage in the Mont Terri underground laboratory project. I extend my thanks to all members of the CCP technical teams, past and present, who have done so much to drive forward a broad range of initiatives since the founding of CCP.

It is worth reflecting upon the nature of collaboration as we embark upon the completion stage of CCP.

CHAIRMAN'S INTRODUCTION

> *"CCUS is both a practical and an effective means of reducing CO_2 emissions from the combustion of fossil fuels in the oil and gas sector."*

We could not have achieved anything like the results that we have on our own. Partners from the worlds of academia, industry, research and government have been instrumental in helping us meet our aims.

Whether that be through funding, sharing of expertise, supply of technologies and equipment or contributions in kind, this collaboration has been crucial, and I thank all for their contributions.

It is safe to say that the fortunes of CCUS have ebbed and flowed over the last two decades – but we are now in a good place. Initial interest in, and development of the technology, faced challenges and some cynicism regarding its technical feasibility early on. The financial crisis of 2008 put back development considerably as climate change fell down the international agenda. Now, we find ourselves with climate change front and centre of public and political attention, more so than ever before. CCUS as a technology has now been proven in a range of applications and at a range of scales and is well positioned to make a crucial contribution in delivering a low carbon world. However, much remains to be done to bring commercial-scale deployment of the technology to the level needed to make a material difference.

This is now where the main challenge lies. We are extremely proud of the role that CCP has played in demonstrating that, from a technical point of view, CCUS is both a practical and an effective means of reducing CO_2 emissions from the oil and gas sector.

The detailed results of our work over the last 20 years will remain a key foundation in the future of CCUS. As such, the results volumes and other content created during the lifetime of CCP will remain accessible to all – hosted on our website at **www.co2captureproject.org** (our final phase results volume will be available from late 2021 and will contain the results of all projects carried out in CCP4).

OVER THE LAST

20 YEARS

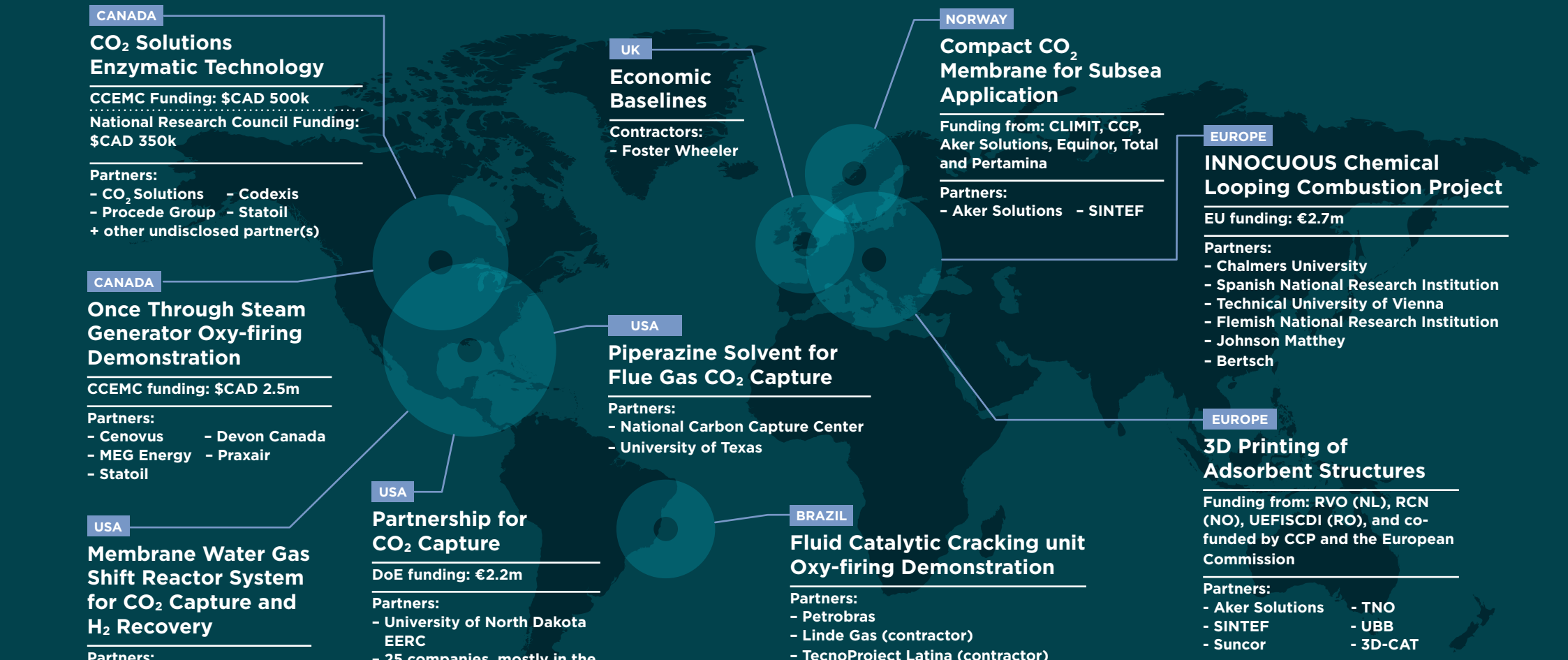
our work has produced results that will remain a key foundation in the future of CCUS

CCP PARTNERSHIPS AND COLLABORATIONS

CCP has been involved in many technical projects, studies and demonstrations conducted across the world over the last twenty years.

The CCP Capture and Storage teams have led many of these initiatives, frequently calling upon the support and collaboration from many within the broader CCS, academic, governmental and engineering worlds. This map is a summary of this truly international network of collaboration, showing a selection of the projects undertaken and the partners and contractors involved. CCP would like to thank all of those who have helped make these projects a success.

SEE STORAGE COLLABORATIONS ON NEXT PAGE ▶



CANADA

CO_2 Solutions Enzymatic Technology

CCEMC Funding: $CAD 500k

National Research Council Funding: $CAD 350k

Partners:
- CO_2 Solutions
- Codexis
- Procede Group
- Statoil
+ other undisclosed partner(s)

CANADA

Once Through Steam Generator Oxy-firing Demonstration

CCEMC funding: $CAD 2.5m

Partners:
- Cenovus
- Devon Canada
- MEG Energy
- Praxair
- Statoil

USA

Membrane Water Gas Shift Reactor System for CO_2 Capture and H_2 Recovery

Partners:
- Pall Corporation

USA

Partnership for CO_2 Capture

DoE funding: €2.2m

Partners:
- University of North Dakota EERC
- 25 companies, mostly in the power production business

UK

Economic Baselines

Contractors:
- Foster Wheeler

USA

Piperazine Solvent for Flue Gas CO_2 Capture

Partners:
- National Carbon Capture Center
- University of Texas

BRAZIL

Fluid Catalytic Cracking unit Oxy-firing Demonstration

Partners:
- Petrobras
- Linde Gas (contractor)
- TecnoProject Latina (contractor)

NORWAY

Compact CO_2 Membrane for Subsea Application

Funding from: CLIMIT, CCP, Aker Solutions, Equinor, Total and Pertamina

Partners:
- Aker Solutions
- SINTEF

EUROPE

INNOCUOUS Chemical Looping Combustion Project

EU funding: €2.7m

Partners:
- Chalmers University
- Spanish National Research Institution
- Technical University of Vienna
- Flemish National Research Institution
- Johnson Matthey
- Bertsch

EUROPE

3D Printing of Adsorbent Structures

Funding from: RVO (NL), RCN (NO), UEFISCDI (RO), and co-funded by CCP and the European Commission

Partners:
- Aker Solutions
- TNO
- SINTEF
- UBB
- Suncor
- 3D-CAT

CCP PARTNERSHIPS AND COLLABORATIONS

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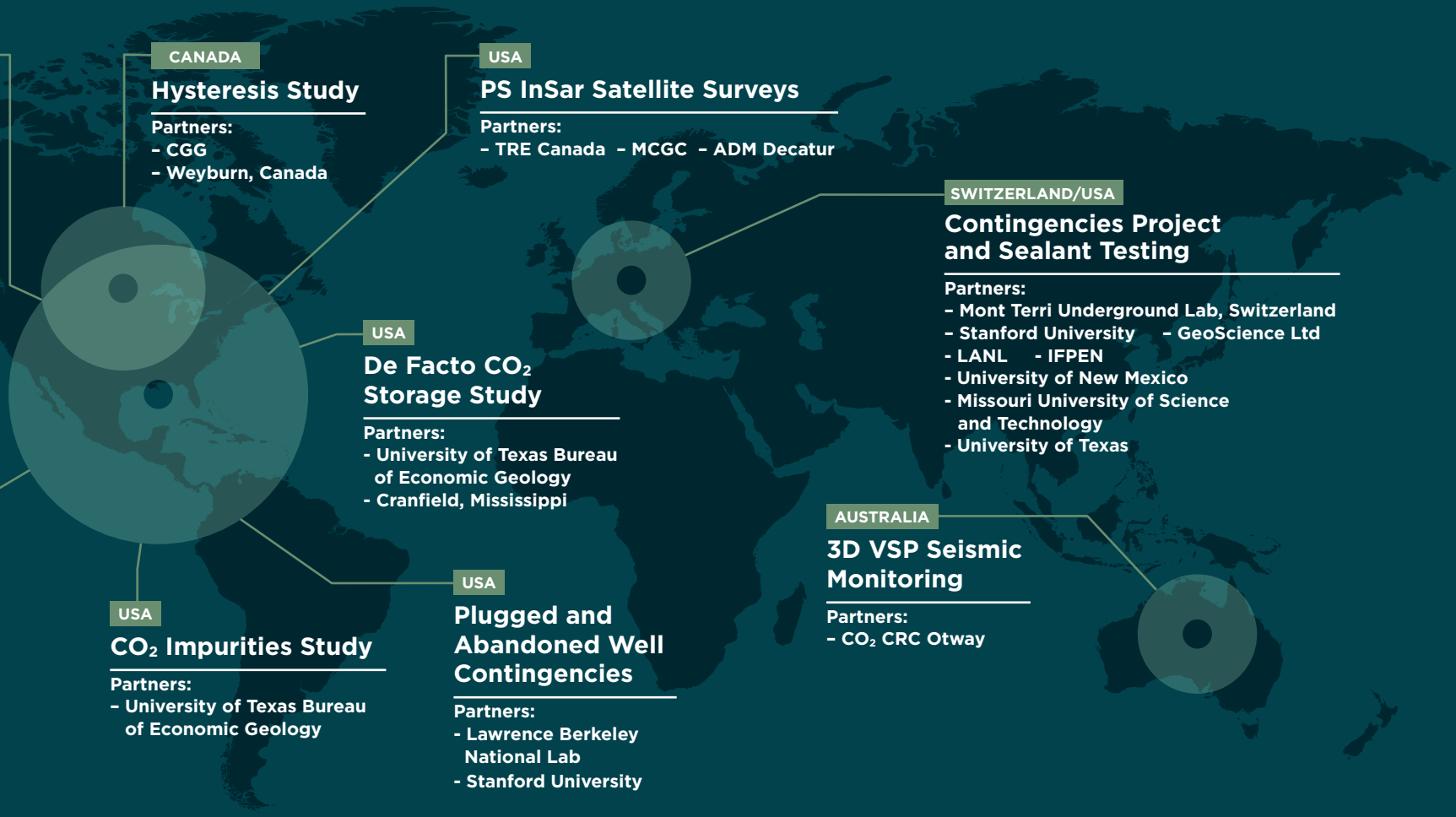
SEE CAPTURE COLLABORATIONS ON PREVIOUS PAGE ▸



CANADA/USA

Borehole Monitoring

Partners:
- PTRC/Aquistore
- Silicon Microgravity
- Computational Geosciences
- Ground Metrics
- LBNL (Lawrence Berkeley National Laboratories)
- Denbury Resources
- SECARB (Southeast Regional Carbon Sequestration Partnership)
- Advanced Resources International

CANADA

Hysteresis Study

Partners:
- CGG
- Weyburn, Canada

USA

PS InSar Satellite Surveys

Partners:
- TRE Canada
- MCGC
- ADM Decatur

SWITZERLAND/USA

Contingencies Project and Sealant Testing

Partners:
- Mont Terri Underground Lab, Switzerland
- Stanford University
- GeoScience Ltd
- LANL
- IFPEN
- University of New Mexico
- Missouri University of Science and Technology
- University of Texas

USA

De Facto CO_2 Storage Study

Partners:
- University of Texas Bureau of Economic Geology
- Cranfield, Mississippi

USA

Permeability Modifier Study

Partners:
- University of Texas at Austin

USA

CO_2 Impurities Study

Partners:
- University of Texas Bureau of Economic Geology

USA

Plugged and Abandoned Well Contingencies

Partners:
- Lawrence Berkeley National Lab
- Stanford University

AUSTRALIA

3D VSP Seismic Monitoring

Partners:
- CO_2 CRC Otway

CCP4
CAPTURE PROGRAM

2019 OVERVIEW

In 2019, the CCP4 Capture program has seen Raja Jadhav and his Capture Team completing and making continued progress on projects initiated earlier in CCP4, while also initiating a few new capture initiatives. A number of these projects are set for completion during 2020 and results will be made available in the CCP4 Results Book due for publication in 2021. A small number of projects are expected to be completed after 2020.

Pilot testing of novel solvents by CCP and its partners in 2019 has indicated potential capture cost reduction of up to 20–30% when applied to post-combustion NGCC flue gas. This included testing of a novel solvent (piperazine) which was completed during the past year – a summary of the results is contained in this Annual Report. Testing of a further novel solvent (non-amine) is currently undergoing pilot testing at a biomass-fired power plant in the UK.

A number of other projects were initiated, including piloting capture of CO_2 from cement production processes and small-scale gas engines, subsea removal of CO_2 from natural gas using membranes, as well as looking at novel alternatives to conventional CO_2 membranes for flue gas applications.

CCP4 SCENARIOS

The Capture program consists of four key scenarios. Much of the work has focused on applications in refining operations, heavy oil extraction, natural gas combined cycle (NGCC) power generation, and natural gas extraction.

Refinery
Identify and develop technologies for pre-combustion capture from steam methane reformer (SMR) H_2 plants

NGCC
Seek and develop breakthrough capture technologies with less than $50/tonne CO_2 avoided cost

Natural gas extraction
Understand landscape and potential for CO_2 capture from offshore gas production and support pilot testing of a promising technology

Heavy oil
Seek and develop breakthrough capture technologies with less than $50/tonne CO_2 avoided cost

CCP: 2000–2020
CAPTURE

The Capture Program began with the objective of identifying novel and next generation technologies that could significantly reduce the cost of capturing CO_2 from a number of oil and gas related processes – oil refineries, heavy oil extraction, natural gas-fired power generation and offshore natural gas extraction.

Initially, some 200 technologies were screened. The most promising of these were selected for further development, economic modelling, pilot testing and demonstration – including field demonstrations of FCC and OTSG oxy-firing capture technologies.

CCP4
CAPTURE PROGRAM

PROJECT:

PILOT-SCALE TESTING OF PZ SOLVENT

STATUS: **COMPLETED**

Aqueous piperazine is a second-generation solvent that has superior kinetics, favourable vapor-liquid characteristics, large operational CO_2 carrying capacity, and good resistance to thermal and oxidative degradation. When used with an advanced stripper configuration, it can be regenerated at elevated pressures with reduced energy consumption. Previous work funded by the U.S. Department of Energy (Award number DE-F0005654) established that Piperazine with the Advanced Stripper (PZAS) is a superior technology for CO_2 capture from flue gas with ~12 vol% CO_2. Modelling studies suggested that the PZAS technology may be uniquely suitable for application to low CO_2 concentration flue gases.

CCP was interested in PZAS application to lower concentration flue gases that are more prevalent in the oil and gas industry. CCP worked with the University of Texas at Austin and the National Carbon Capture Center, (NCCC), a U.S. Department of Energy-sponsored research facility in Wilsonville, Alabama to pilot the use of PZAS technology. The pilot-tested PZAS technology for capturing CO_2 from low CO_2 (4 vol%) flue gas, representative of flue gas from Natural Gas Combined Cycle (NGCC) power plants. Leveraging existing pilot facilities at NCCC, CCP sponsored a series of tests with 4% CO_2 flue gas. In July 2019, CCP deemed the pilot tests a success, providing significant data to scale up the PZAS technology for low CO_2 concentration applications such as flue gas from NGCC power plants.

The test campaign, including performance testing under different operating conditions and long-term tests for stability, lasted 2,100 hours and was completed in June 2019. New process configurations for absorber intercooling and process intensification concepts to combine direct contact cooler with absorber cooling were tested and confirmed. CO_2 removal rates of up to 96% were demonstrated and energy performance at 90% capture was around 2.35 GJ/tonne CO_2. Solvent degradation, emissions, corrosion and operation were generally similar to other applications. The pilot data used for model validation under a variety of operational conditions and model performance shows that the PZAS technology is ready for scale-up to large pilot (>100 tonne CO_2 captured/day) for this application.

PILOT-SCALE TESTING SITE OF THE PZ SOLVENT AT THE UNIVERSITY OF TEXAS, AUSTIN. IMAGE COURTESY OF UT

CCP4
CAPTURE PROGRAM

PROJECT:

DEVELOPMENT OF NOVEL C-CAPTURE SOLVENT AND PILOT TESTING

STATUS: **ONGOING**

Work continued in 2019 on the project being undertaken by CCP as part of a UK government-funded scheme under the Energy Entrepreneurs Fund Phase 5 (EEF5) program to develop and evaluate a novel low-energy solvent family for post-combustion CO_2 capture. Additional funding has been received through C-Capture and CLIMIT (Norwegian RD&D CCS program), and other partners involved in the additional project are SINTEF AS and Biobe AS.

C-Capture continues to optimize its solvent formulations to achieve high CO_2 capture rates. A 10-stage column has been constructed and is being commissioned at the Drax power station in the UK. Data from this 1 tonne per day (tpd) pilot plant as well as another 1 tpd pilot at Tiller (SINTEF) available for biomass-derived gas will be assessed by SINTEF/CLIMIT in late 2020.

A 10-COLUMN ABSORBER BEING INSTALLED AT DRAX
TO IMPROVE THE ABSORPTION RATE OF THE C-CAPTURE SOLVENT
IMAGE COURTESY OF C-CAPTURE

CCP4
CAPTURE PROGRAM

PROJECT:

SORBENT-BASED CAPTURE USING NOVEL 3D-PRINTING TECHNIQUE

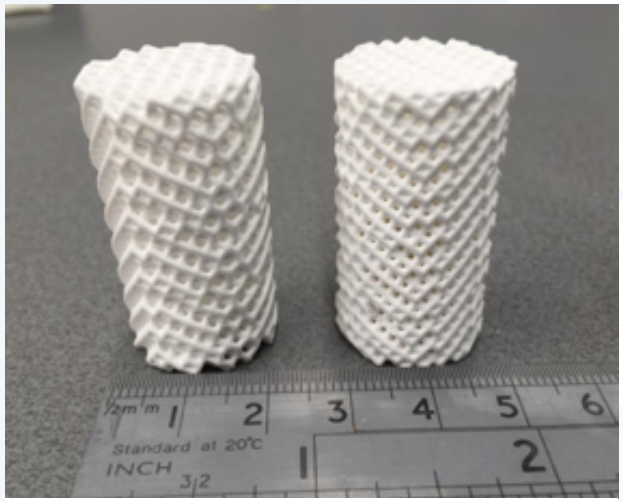
STATUS: **ONGOING**

Advances in 3D printing offer the potential for tailor-made capture solutions that could create the step-change in productivity and lower the costs needed to boost uptake in CCS applications. The project team is working towards developing 3D-printed sorbent structures for pre- and post-combustion applications.

The aims of the 3D-CAPS project are: to achieve a 10-fold productivity increase for two sorbent-based technologies in CCS; and to optimize sorbent shapes with Computational Fluid Dynamics (CFD) and other modelling tools, with direct realization in 3D-printed objects for testing under relevant conditions. Success in this project should also lead to a substantial decrease in overall equipment size and costs.

During 2019, the CCP Capture Team and its project partners progressed work on a number of fronts and the project is expected to be completed in late 2020.

ECN.TNO continued printing and evaluating small structures from silica and hydrotalcite pastes. Further work was undertaken to successfully increase crushing strength as well as looking at properties such as surface area, porosity, and cyclic CO_2 capacity. Degradation issues were solved by using a different photo initiator, while raised post-treatment temperatures (470–550°C) resulted in higher strength, albeit with lower surface area. New 3D-printing techniques are also being considered to improve the strength of the HTC structures still further.



3D-PRINTED FOAM STRUCTURE OF A SILICA ADSORBENT
IMAGE COURTESY OF ECN, PART OF TNO

The SINTEF team continued its focus on characterizing the pressure drop, adsorption kinetics and isotherms on the amine-grafted silica pellets as a reference case. Work on the functionalization of the ImmoAmmo structures led to higher capacity than the reference beads, but the structures showed quite a large pressure drop. Therefore, more open foams will be used.

The UBB (Babeș-Bolyai University) team progressed work on the CFD modelling of the HTC structures to be used for the Sorption-Enhanced Water-Gas Shift (SEWGS) process. Breakthrough modelling of several 2D geometries for different channel dimensions was carried out and work is in progress to carry out multi-cycle modelling of 3D-printed structures.

CCP4
CAPTURE PROGRAM

PROJECT:

CO_2MENT – CO2 CAPTURE FROM CEMENT FLUE GAS

STATUS: **ONGOING**

CCP is working alongside Inventys (now Svante) – and project partners Lafarge Canada, Total and the Canadian State of British Columbia – in the CO_2MENT project to address the removal of CO_2 from the cement production process, traditionally a significant emitter of the gas. The cement flue gas has a CO_2 concentration (~16 vol%) similar to the SMR hydrogen plant flue gas, a major source of CO_2 in refineries.

While Phase 1 of this 1 tpd pilot project addresses the removal of general contaminants from the flue gas of the cement plant, the CCP-funded Phase 2 is specifically concerned with the removal of CO_2. Amines deposited on a silica adsorbent are being tested for this purpose.

Work started in early 2019 and the Inventys team is working on design and construction of the pilot plant at a Lafarge site in Richmond, British Columbia. The PDU has been re-configured to test 16 vol% CO_2 flue gas and the latest adsorbents have been tested on flue gas.

The pilot operation is expected to start in the second half of 2020. Data from this will be collected, analysed and used to create economic models.

The PDU has been re-configured to test

16 vol% CO_2 flue gas

and the latest adsorbents have been tested on flue gas

CCP4
CAPTURE PROGRAM

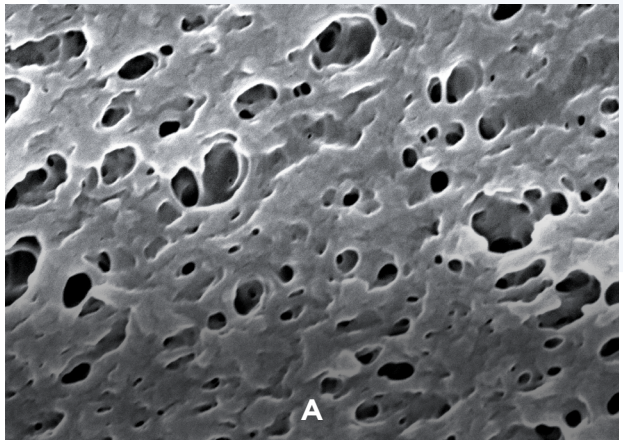
PROJECT:

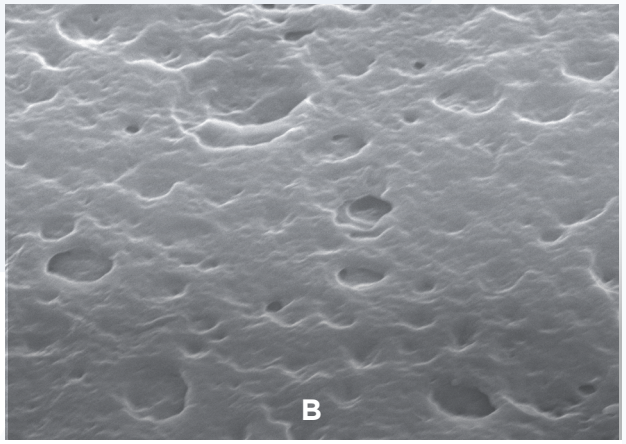
BENCH-SCALE DEVELOPMENT OF A TRANSFORMATIONAL GRAPHENE OXIDE-BASED MEMBRANE PROCESS

STATUS: **ONGOING**

A bench- and pilot-scale project involving the development of a novel graphene oxide (GO) membrane targeting flue gas streams from natural gas combustion was kicked off in 2019. Ultra-thin GO membranes have shown potential of much higher selectivity and permeance compared to the conventional membranes, enabling CO_2 separation when the concentration driving force is more limited. In the proposed process, NGCC flue gas is fed into a high-flux membrane, which concentrates the CO_2 in the permeate. Vacuum is used on the permeate side to create pressure driving force, while permeated water vapor acts as a diluent.

The permeate is recompressed and sent to a further, highly selective membrane. This produces a permeate which is mostly water vapor and CO_2 that results in a 95% pure CO_2 product upon drying. As the water has an important role in the performance of the membrane, its presence in the stream to be treated is not an issue for the process. As a consequence, this process may not demand a water removal system upstream to the membrane system.





INNER SURFACE OF A SUPPORT BEFORE **(A)** AND AFTER **(B)** GO DEPOSITION. AFTER GO DEPOSITION, ALL THE PORES WERE COVERED BY GO FLAKES WITHOUT ANY PINHOLES. IMAGES COURTESY OF RENSSELAER POLYTECHNIC INSTITUTE (RPI)

CCP4
CAPTURE PROGRAM

OTHER PROJECTS:

STATUS: **ONGOING**

COMPMEM – QUALIFICATION OF COMPACT CO_2 MEMBRANE

Testing began in 2019 on CO_2 separation membranes for use in sub-sea applications, as part of the COMPMEM project. Screening and performance tests of four membranes, material compatibility tests and pilot tests of industrial scale membrane samples will all be undertaken with the project due to complete in 2022.

MODULAR CO_2 CAPTURE

A pilot project to capture CO_2 from small-scale gas engines was kicked off in 2019 in the U.S. The novel process is based on a turbo-expander concept, coupled with CO_2 removal using membranes.

CCP4
STORAGE, MONITORING & VERIFICATION PROGRAM

2019 OVERVIEW

The main projects comprising the CCP4 Storage, Monitoring & Verification (SMV) program achieved major milestones during 2019.

The long-standing assurance and contingencies work at the Mont Terri underground laboratory in Switzerland has proved immensely valuable and 2019 saw the completion of all the sealant testing.

Field trialling programmes also continued at the Aquistore reservoir facility in Canada, with the Borehole microgravity tests and the repeat electro-magnetic (EM) survey both completed during the course of the year.

CCP4 THEMES

The SMV Team's CCP4 work has the overarching objective of ensuring the long-term security of geologic CO_2 storage approached through the following themes:

Storage assurance

- Subsurface processes: clarification and understanding of complex processes impacting storage security
- *Well integrity:* solutions to identify and mitigate CO_2 leakage
- *Monitoring & Verification:* modeling the cost-effectiveness of emerging and integrated sensors

Contingencies

Models for detection, characterization and mitigation of out-of-zone fluid migration (CO_2, brine) through wells and natural or induced geologic conduits

Field trialing

Deployment and integrated assessment of emerging monitoring technologies at third-party sites with research and operator partners

CCP: 2000–2020

SMV

The CCP SMV Program began with the pioneering of a risk-based approach for geological site selection, operation and closure, and identified promising storage monitoring tools for further development. During the course of the four phases of CCP, R&D knowledge about CO_2 storage and behaviour was systematically built up and a range of monitoring tools developed for testing, including breakthroughs in borehole gravity and use of fibre optic cable as an acoustic sensor. Key publications during the lifetime of CCP have included a definitive book on CO_2 storage; a Certification Framework; and a landmark CO_2-exposed well study.

CCP4
STORAGE, MONITORING & VERIFICATION PROGRAM

PROJECT:

WELL SEALING EXPERIMENT AT MONT TERRI UNDERGROUND LABORATORY (MT-UGL)

STATUS: **ONGOING**

The SMV Team continued its multi-faceted work with the Mont Terri underground rock laboratory in Switzerland during 2019.

The well system leakage remediation experiment looking at novel sealant performance concluded its second phase. Four sealants were tested to assess capability in restoring pressure containment in the cased and cemented intervals, which had previously been exposed to heating-cooling cycles over a six-month period to create micro-annuli. Sealant performance was analysed using a step-rate pressure protocol – final assessment will be performed after over-coring of the entire injection well installation, slated for mid-2020.

A series of sealants were tested via an experimental-scale well installed at the test site that mimics CO_2 containment loss through various conduits (which were deliberately induced in this well) that occur in various well system interfaces, e.g. cement/casing, cement/rock and fractures within the cement and caprock systems.

During 2019, results were published from the second sealant test; while a third and fourth sealant test were completed prior to over-coring:

CS-A EXPERIMENT SITE AT MONT TERRI UNDERGROUND LABORATORY. IMAGE COURTESY OF FEDERAL OFFICE OF TOPOGRAPHY SWISSTOPO

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CCP4
STORAGE, MONITORING & VERIFICATION PROGRAM

PROJECT:

WELL SEALING EXPERIMENT AT MONT TERRI UNDERGROUND LABORATORY (MT-UGL)

STATUS: **ONGOING**

- The first sealant trial (a nanoparticle hydrogel) had achieved sealing to 30 bar/m in the low perm interval but proved temporary in a (much) higher perm interval. The success in the low perm test shows promise for providing a successful seal in a reservoir environment.
- The second sealant was a polymer gel and the trial significantly reduced leakage rates – although not to zero, with flow was reduced to c. 3 ml/min at applied differential pressures of less than 30 bar.
- The third sealant tested was silicate based – this showed initial sealing but degraded over time.
- A fourth, epoxy-based sealant underwent testing towards the end of 2019. Observations indicate an excellent sealing performance directly after injection but a noticeable decrease of sealing capacity after about one week. This may be due to hardening of the sealant between the performance tests, possibly allowing new flow-paths at the higher step rate injection pressure range. This sealant is also being used to flood the entire well system and stabilize it prior to over-coring (exhumation of the core).

Over-coring will take place in 2020, followed by imaging and rock/fluid analysis to characterize induced defects and corresponding sealant emplacements.

Meanwhile, the CS-D experiment, supported by CCP, which entails flowing carbonated water through the main fault at Mont Terri, completed drilling and instrumenting wells. Pressure testing revealed the fault showing activation and different pressure behaviours after pulsing. Analysis suggests no breakthrough to the observation well and further technical analysis is presently underway to understand the complex behaviour being exhibited.

A further project – FS-B, supported by CCP and led by Mont Terri and other participants – aims to induce fault slippage on a highly instrumented fault. This should reveal permeability changes that might allow fluid migration. Drilling and instrumenting are due in early 2020.

CCP4
STORAGE, MONITORING & VERIFICATION PROGRAM

PROJECT:

PERMEABILITY MODIFIERS FOR SEAL ENHANCEMENT, WELL MITIGATION & FLOOD CONFORMANCE

STATUS: **ONGOING**

This project addresses well and top seal integrity, which can be difficult to assess prior to CO_2 injection. Working with the University of Texas, CCP aims to identify possible enhancement solutions as well as looking at changes to barrier status from geo-mechanical stress changes and chemical reactions over the course of a CO_2 storage project.

After the initial R&D phase, work in 2019 involved continued bench-scale core flood tests (gel time vs. gel concentration, salinity & acid content) of selected sealants in a CO_2-rich environment – followed by modelling and history matching of the most interesting modifiers. The programme has shown reductions in permeability with silica gels but possible breakdown after further injections. This behaviour is being investigated further.

BENCH-SCALE CORE FLOOD TEST. IMAGE COURTESY OF UT

CCP4
STORAGE, MONITORING & VERIFICATION PROGRAM

PROJECT:

AQUISTORE CO_2 STORAGE PROJECT COLLABORATION

STATUS: **ONGOING**

Good progress was seen in 2019 on a number of monitoring projects at the Aquistore storage site in Saskatchewan, Canada, following delays to the project in the previous year. The aim is to assess non-seismic geophysical techniques for their potential to offer cost savings with sufficient resolution and/or to enhance surface seismic.

The EM survey was completed in July and repeat data has successfully been obtained with casing and down-well detectors. Trial reports have been received and time data supplied for data integration.

SETTING UP FOR FIELD TRIAL.
IMAGE COURTESY OF SILICON MICROGRAVITY

BOREHOLE MICROGRAVITY TOOL.
IMAGE COURTESY OF SILICON MICROGRAVITY

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CCP4
STORAGE, MONITORING & VERIFICATION PROGRAM

PROJECT:

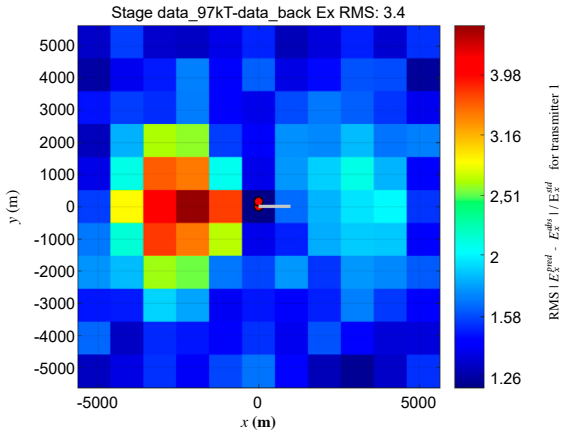
AQUISTORE CO_2 STORAGE PROJECT COLLABORATION

STATUS: **ONGOING**

The Borehole Microgravity project to quantify CO_2 saturation also saw significant advances during 2019. The new 3-axis sensor was successfully field tested in the UK and then trialled at Aquistore. Gravity was successfully measured down to ~2000ft but temperatures below that point were higher than in the earlier UK test and the temperature compensation did not fully perform as expected. Tool thermal upgrades have since been completed and will be implemented in a second trial in Q2 2020. This partnership between Silicon Microgravity Ltd, CCP, PTRC and Eclipse E line services marks an important first step in characterizing this emerging technology for storage CO_2 plume surveillance.

Finally, the Aquistore Data Integration Project, comprised of joint inversions of available surveillance data using a common reservoir flow model, is underway.

The scope of work covers synthetics modelling and inversion; jointly inverting gravity and single-phase flow for velocity and initial saturation; jointly inverting EM, gravity and single-phase flow for velocity and initial saturation; and adding seismic travel time tomography from VSP to update the model.



MODELLED TIME LAPSE CHANGE IN TRANSIENT RESPONSE
IMAGE COURTESY OF CHEVRON ENERGY TECHNOLOGY COMPANY ETC

2019 OVERVIEW

In 2019, the Policy & Incentives Team led by Arthur Lee published a new report looking at selected recent developments in regulations for CO_2 storage projects globally – with particular emphasis on key developments, outstanding issues and gaps that might help or hinder the commercial success of CCS.

The report, entitled *Survey of CO_2 Storage Regulations*, reviewed regulations from the USA, Canada, the EU, the UK, the Netherlands, Norway, Indonesia, Japan and Australia. These included regulations for permitting and for qualifying CO_2 storage projects for incentives. The focus was on CO_2 storage projects relevant to oil & gas as well as other industries. Increased CCS policy confidence and a growth in regulatory regimes for CO_2 storage worldwide were among the key findings of the report.

A detailed comparison was undertaken of five different regulatory frameworks that best address the key regulatory issues:

- EPA UIC Class VI Well Permits
- California LCFS
- Alberta CCS Regulatory Framework Assessment recommendations
- EU CCS Directive
- Australian Offshore Petroleum Amendment

The regulations for CO_2 storage were found to be inconsistent, with various disparities in the treatment of long-term liability and post-injection monitoring requirements. Despite this, there are some areas – such as the need for proof of financial ability to cover potential liabilities and public engagement – which are, on the whole, being approached in a similar way.

Overall growth in CCS policy confidence is reflected in the development of new regulatory frameworks – such as for tax incentives provided by the Internal Revenue Service's 45Q provisions in the United States and California's LCFS provisions. Also, certain countries, such as the United Kingdom, has expressed growing ambition by creating the CCS Council and CCUS Cost Challenge Taskforce with the aim of making CCS economically feasible.

CCP: 2000–2020

POLICY & INCENTIVES

Increasing CCS regulations across the world is an indicator of how stakeholders view the importance of CO_2 storage and in turn, validates the progress of CCS deployment. The objective of the P&I Team over the past 20 years has been to provide the technical and economic insights needed by a range of these stakeholders, most notably governments and regulators. The Team's significant work has included a first-ever study on Funding mechanisms for CO_2 pipeline networks; studies on Regulatory issues and challenges; Stakeholder analysis; Local community benefit sharing; Transitioning EOR to storage and Energy transition. To actively share their findings, the Team has been regular participants of the UNFCCC COP conferences.

CCP4
COMMUNICATIONS PROGRAM

2019 OVERVIEW

The Communications team continued its activity to publicise the work of the CCP Technical teams to the CCS world, wider industry, government and academia. It did this by extending its range of project technical factsheets, providing updates to the CCP website and providing news alerts to CCS influencers and media.

A range of collateral was produced during the year. This included a technical factsheet published on the 3D-CAPS project in the early part of 2019, which highlighted how CCP and a number of partners are developing new adsorbents through 3D printing technology. This was uploaded to **www.co2captureproject.org**, as were CCP's Annual Report and Survey of Storage Regulations. Alerts on each were sent to over 4,000 influencers and press releases were issued enabling a wider audience to read about progress in CCS media.

CCP: 2000–2020

COMMUNICATIONS

One of the founding principles of CCP when it was set up was that the results of its work should be made widely available to support the development of CCS. Since then, communications technology has developed in such a way as to make this aim much easier to achieve than might otherwise have been the case. During the course of CCP, a range of communications materials has been produced – initially in print, then increasingly digitally, to support the work of the Technical and Policy teams – including Results Books, Technical Factsheets; Policy Reports; Annual Reports; Conference Presentations; Brochures/Leaflets; and Posters.

Apart from being made available at conferences, these materials have also been centrally accessible via the CCP website – **www.co2captureproject.org.** CCP also launched an innovative digital educational platform – **www.ccsbrowser.com** – to bring clearer understanding of CCS to the wider public.

STRUCTURE: CCP TEAMS 2019

The CCP is made up of four Teams – Capture; Storage, Monitoring & Verification; Policy & Incentives; and Communications.

The Teams consist of experts drawn from each of the member organizations.

Each participating member is represented on a CCP Executive Board that comes together quarterly.

The CCP is also supported by a Technical Advisory Board (TAB) responsible for conducting independent peer reviews on the activities of the CCP Teams and their respective programs. The TAB comprises independent assessors from industry and academia.

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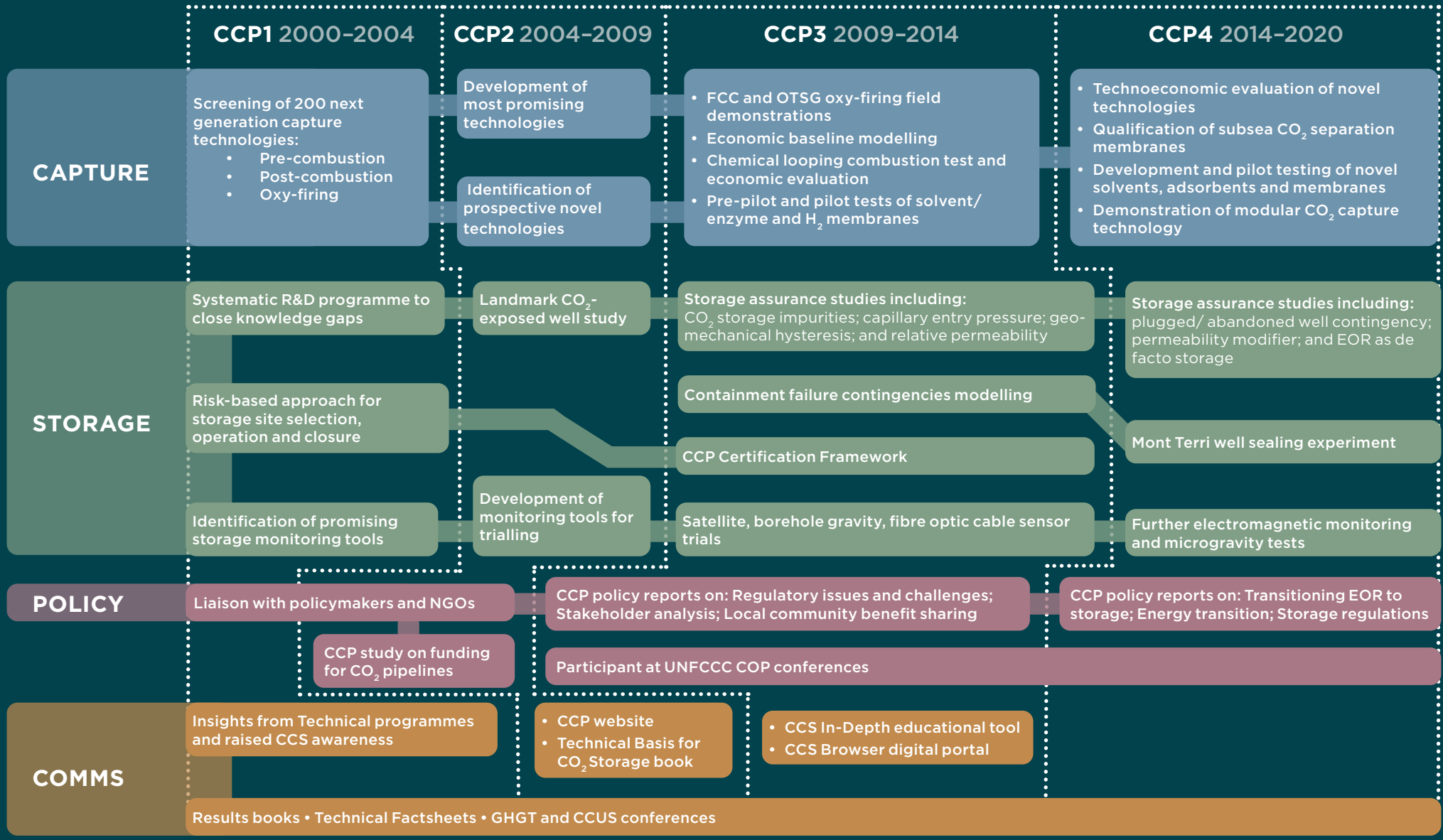
A PIONEERING TWO-DECADE JOURNEY

Some of the key milestones in CCP's history are outlined below, covering all four CCP workstreams.



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