Project acronym and title:

SECURe – Subsurface Evaluation of Carbon capture and storage and Unconventional risks

INNOVATION IN THE SECURE PROJECT

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Disclaimer

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Public introduction

Subsurface Evaluation of CCS and Unconventional Risks (SECURe) is gathering unbiased, impartial scientific evidence for risk mitigation and monitoring for environmental protection to underpin subsurface geoenergy development. The main outputs of SECURe comprise recommendations for best practice for unconventional hydrocarbon production and geological CO2 storage. The project is funded from June 2018–May 2021.

The project is developing monitoring and mitigation strategies for the full geoenergy project lifecycle; by assessing plausible hazards and monitoring associated environmental risks. This is achieved through a program of experimental research and advanced technology development that includes demonstration at commercial and research facilities to formulate best practice. We will meet stakeholder needs; from the design of monitoring and mitigation strategies relevant to operators and regulators, to developing communication strategies to provide a greater level of understanding of the potential impacts.

The SECURe partnership comprises major research and commercial organisations from countries that host shale gas and CCS industries at different stages of operation (from permitted to closed). We are forming a durable international partnership with non-European groups; providing international access to study sites, creating links between projects and increasing our collective capability through exchange of scientific staff.

Executive report summary

In this document we present the innovations that were advanced as part of the H2020 project Subsurface Evaluation of CCS and Unconventional Risks (SECURe). It serves as a source of information for the public, a reference for the SECURe consortium partners and as supporting documentation to Milestone 9 to the European Commission. We document the innovation management, the advancement of TRL and the exploitation potential of ten innovations: three in WP3 (Environmental baseline and monitoring strategies), five in WP4 (Advanced monitoring and sensor technologies) and two in WP5 (Impact Mitigation and Remediation).

The information contained in this document was mostly captured during two series of interviews with the WP leads supervising innovation in their WP and the involved researchers. The first series of interviews took place at the start of the project to establish the starting TRL. The second phase was concluded after the Mid-Project Review in the Spring of 2020 with the aim of tracking progress and document the anticipated TRL at the end of the project.

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1 Introduction

One of the main aims of the SECURe (Subsurface Evaluation of CCS and Unconventional Risks) project is to better understand the potential environmental impacts of shale gas and CCS technologies. To achieve that goal, SECURe's Project Management Plan lists seven specific objectives (D7.7, p. 6–7) two of which specifically target innovation within the project:

1. To develop new technologies to improve the detection and monitoring of environmental impacts related to geoenergy projects.
2. To investigate new methods for remediating potential environmental impacts of geoenergy projects, specifically to reduce leakage from wells or naturally occurring permeable pathways.

This report focuses on these objectives and will be kept on file and made available to the European Commission to provide evidence of reaching Milestone 9. We first present how technology exploitation and innovation were handled within SECURe including intellectual property management and an exploitation framework.

Then, we present an overview of the ten identified innovations in the SECURe project structured as follows:

- Summary of the technology
- Current TRL
- Development within SECURe

The paragraph on development within SECURe contains a projected TRL for the end of the project (May 2021) and includes a summary of the interviews conducted by Rhian Kendall, Jan Hennissen and Ed Hough in the Spring of 2020. Work package leads and scientists responsible for the respective innovations were asked four questions:

1. What has been achieved over the course of the SECURE project?
2. How have these achievements impacted TRL?
3. When will the technology have been advanced as far as it goes within the SECURe time frame?
4. What is next for these technologies? Development through other grant proposals? Industrial exploitation?

The conclusions section includes a table which illustrates the TRL's that are anticipated by the end of the SECURe project in May 2021.

2 Technology exploitation and innovation

At the start of SECURe in 2018, both the unconventional hydrocarbons and CCS industries were at an early stage of large-scale uptake by Member States of the EU. This gave significant potential for the development of innovative technologies, and a joined-up approach to good practice for some common aspects of CCS and unconventional hydrocarbons technologies, in some instances resulting from transfers of technologies/methodologies between Unconventional Gas and CCS industries.

SECURe allows the progression of moderately advanced technologies through to system development, proving concepts with field studies. It also fosters the development of novel technologies from research concepts through to feasibility studies and early-stage technology development.

A UKRI (BGS) Innovation Manager was appointed to facilitate by undertaking the following tasks:

Through consultation with the subtask leaders, identify and collate information on potential innovative technologies both identified to at proposal stage (Table 1) and any new ideas which may evolve through the course of the project.

- Following each Work Package meeting, obtain progress update from the Work Package leaders in order to monitor progress and identify any risks to completion. This information will be compiled and be made available for the Management Board Meetings.
- Following discussion about innovation at Management Board meetings, evaluate any comments and advice and feedback to Work Package leaders.
- Identify potential partnerships across the consortium and facilitate their development.
- Identify potential uses and markets for new technologies, through consultation with the Work Package Leaders.
- Identify any potential IPR issues and work with the SECURe IPR expert and Work Package leaders to resolve these.
- Consult with UKRI (BGS) Innovation Panel for guidance where necessary.
- Assist partner's plans for commercialisation and exploitation.
- Provide information on innovative technologies to the SECURe communications team for use in their products and public engagement activities.
- Provide SECURe communications team with assistance in understanding and interpreting the innovative technologies if necessary.

Table 1 Summary of monitoring technologies that will be developed in SECURe (modified from the SECURe project proposal document).

Del. #	Technology	TRL Start	TRL End	Description	Who	Pathway to innovation
D3.3	Synergies of environmental baseline strategies (UK & Canada sites)	6	8	Integration of techniques to provide baseline methodologies. Individually the techniques used are probably at currently at TRL 9 but if integrated they are currently at TRL 6	BRGM, UKRI (BGS), PGI, U. Calgary	Analysis of results from, and development of, integrated testing and monitoring tasks
D3.6	Integrated multi-tracer fingerprinting of gas and fluid migration	6	7	Isotope methods applied to gas storage and exploration monitoring	UKRI (BGS), BRGM, U. Calgary	Field testing of a method and lab validation
D3.6	Methodology optimisation for methane and higher hydrocarbons concentrations/isotopic ratio measurements in groundwater and soil gas	5	8	Optimization of sampling and analytical approach to CO_2/methane and higher hydrocarbons concentrations/isotopic ratio measurements in groundwater and soil gas	PGI- NRI	Field testing of a method and lab validation
D4.6	UAV-based CO_2 sensor	3	5	CH_4-based platform to be extended to CO_2. UAV will be test at the GTB, UK.	UKRI (BGS), UNOTT, GEUS, BRGM	Field testing of prototype
D4.4	Gas source based monitoring sensors	2	5	Use the MMO genes of high and low affinity methane oxidizing bacteria collected from wells and possibly streams to monitor the occurrence of stray methane	GEUS, UKRI (BGS) & UNOTT	Field testing of a method and lab validation
D4.5	A tool for the detection of potential leakage (rate) of high heavy metal concentrations	2	4	Development and quantitative framework for detection of soil contamination related to exploitation of	SINTEF	Software optimization and method development

				unconventional resources		
D4.5	Fracture leak rate prediction to validate flow sensors	2	4	Fracture flow prediction to inform about spatial and temporal propagation	SINTEF	Field testing of a method
D4.6	Noble gas downhole sensor	6	8/9	Samples taken under representative downhole conditions allowing calculation of natural chemical inert tracer mass balances	TNO, IFPEN	Field testing of a prototype
D5.1	Study possible failures of well cement	1	4	Mitigate and remediate poor cement completions during CO_2 storage or extraction of unconventional hydrocarbons	SINTEF	Lab validation
D5.2	Remediation of leakage using silicate gels	3	4	Testing and ranking of various squeeze sealant materials with respect to ease of placement	SINTEF	Lab validation

2.1 IPR MANAGEMENT

“This IPR management plan “the Plan” is intended to supplement the provisions already agreed upon in the SECURe Consortium Agreement “the CA” and Grant Agreement “the GA”. If there is any conflict between the Plan and the CA or the GA, the terms of that agreement will prevail over this plan.

The Plan may be updated throughout the Project if it is deemed that further management is needed for specific IPR issues, or new issues are identified. The Project Management plan which incorporates this Plan will be revised in November 2019.

This Plan aims to summarise existing IPR obligations and provide suggestions for management of data in relation to key areas where it can be anticipated that IPR issues may arise.”

“Parties’ management of IP should therefore ensure that Results are not only protected, but available in a way which allows exploitation of such Results, in order to comply with the GA.
Ownership and sharing of IP in Results must be clear, as well as the rights of Parties and third parties to use/exploit the Results, and the associated sharing of revenue. This may be achieved by specific IP arrangements on a case by case basis.

Parties are responsible for identifying and protecting their own IP. Jointly owned IP will be governed by specific IP arrangements as agreed separately between the relevant Parties. “

“As stated in the SECURe work plan in the proposal annexed to the GA, it is anticipated that the provisions of both the GA and the CA will be implemented by specific IP arrangements agreed throughout the project, between specific partners, as appropriate.

Individual, specific agreements covering allocation of ownership and exploitation of jointly generated Results will be necessary due to the range of Results and outputs anticipated, with varying levels of commercial and academic value. “

2.2 EXPLOITATION FRAMEWORK

Avenues to support exploitation of innovations

The exploitation and dissemination of innovative developments within the SECURe project will be supported by communications activities targeted towards a range of stakeholder communities. To date, this has included explaining innovations that are being developed in SECURe to the Advisory Board which includes representatives from industry, regulatory, legislator and academic communities. This has taken place at the bi-annual Advisory Board meeting (January 2020) and at the June 2020 General Assembly.

Future dissemination activities are planned within the project that will support the exploitation of the innovations will include (dates tentative):

- Publicity associated with open access papers, conference abstracts, presentations and posters- this is an ongoing activity that will extend beyond the funded period of the SECURe project;
- Description of new methods and procedures at 3 project webinars (focussed on work packages 2/5 and 3/4 January, March 2021 and WP6, May 2021);
- Inclusion in project newsletters (December 2020 and May 2021);
- Presentations and dedicated section on the virtual project meetings with Australian stakeholders (September 2020);
- Dedicated talks at the SECURe December 2020 research conference;
- Highlighted at the launch of the International Platform for Environmental Monitoring, allowing dissemination to a wider stakeholder audience including research groupings in South East Asia and South America;
- Publicised through the SECURe website and online data feeds.

Collectively, these activities will promote the innovations, and along with the exploitation plans (and in some cases, dedicated business development plans used by individual project partners and their contractors), these will maximise the development and potential for exploitation of the particular innovations.

3 Synergies of environmental baseline strategies (UK & Canada sites) (linked to D3.3)

3.1 SUMMARY OF TECHNOLOGY

Technologies for establishing the ranges of natural baseline environmental conditions at CCS or shale gas exploration sites are generally well established, although transfer of good practice/know-how between these technologies is not commonly undertaken. Technologies include groundwater, soil gas, atmospheric and seismic monitoring. Within SECURe, groundwater monitoring and atmospheric monitoring by drone will be advanced.

3.2 TECHNOLOGY REDINESS LEVEL (TRL)

Individual technologies are likely to be already fully developed and at TRL 9. Integration of these technologies is novel but is not as advanced, and likely to be at TRL ~6.

3.3 DEVELOPMENT WITHIN SECURE

A drone-based campaign on a natural gas analogue site near Grenoble, France, and an as yet to be identified CCS site, would push this technology beyond TRL 7 (see also Section 5).

Isotope work can be extended to quantify and analyse samples from CCS and methane sites- e.g., to analyse alkanes and natural isotopes (this may be achieved at the natural gas analogue site near Grenoble, France).

A review of how baselines are established for CCS sites will be completed in WP3. This will outline what could be transferred to shale gas exploration sites, including a synthesis of what has been completed for shale gas exploration sites, using examples form the UK and US.

Groundwater monitoring has been ongoing since 2015/6 at one proposed (Vale of Pickering) and one active (Preston New Road) shale gas site in the UK. This has included real-time monitoring of total dissolved gases, pH, conductivity, temperature. This dataset would be suitable for comparison to candidate CCS sites (although the environmental and geological setting of these would differ from the shale gas sites). Results from the sites are posted on the web (e.g. http://www.bgs.ac.uk/research/groundwater/shaleGas/monitoring/home.html). Presently, this does not include measurement of dissolved methane specifically, although attempts have been made to do this.

Depending on site availability and access, downhole methods can be tested on ‘deep’ boreholes (e.g., down to over 250 m in depth), which would be a notable technical advance (also, see Section 10).

By the end of SECURe, the drone and isotope technologies are likely to be at TRL8, following development and adoption of some methods and improvements between shale gas and CCS technologies. The acquisition and analysis of data from the natural gas analogues in the French Subalpine Chains site has been successfully conducted in Oct. 2019 and the results on the possibility of airborne identification of gas seeps under natural conditions (geogenic baseline) are encouraging. The review of potential learning between shale gas and CCS technologies will be completed by August 2020.

WP3 Innovation review meeting: May 20th 2020, 09.00 GMT; remote

Present Wolfram Kloppmann (BRGM), Pauline Smedley, Ed Hough and Rhian Kendall (BGS)

Q1) What has been achieved over the course of the project

A field campaign has been completed (Grenoble, France, October 2019), allowing a suite of monitoring techniques to be trialled and tested. Samples for testing and analysis of clumped isotopes have been taken for a bacteriological study (GEUS, BGS). These will allow recommendations for how the use of several techniques can be optimised to be developed.

Access to the GOWN databases (Canada) has been granted, and data will be used to assess anomalies (trying to answer the 'what is an anomaly' question).

Q2) How have these achievements impacted TRL?

The recommendations stemming from the project are still anticipated to bring the TRL level to 9, by recommending an integrated approach to using several monitoring techniques at a single site.

Q3) When will it have been taken as far as it goes?

The availability of further samples (if possible) will allow fine-tuning of recommendations and a local signature of fluids. The stalling of the shale gas industry in Europe will restrict available data and slow development of these types of innovations. One next step is to study methane concentrations at different levels, and also to benchmark and compare laboratory results using different methodologies/sampling protocols.

Q4) What is next for these technologies? Other grants? Industrial exploitation

See response to Q3 above. For baseline monitoring, techniques can be developed for more cost-effective ways of establishing baseline environmental conditions and anomalies. We can look at a global framework of capabilities of techniques (what for, and where suitable to be deployed, where applicable). Research can look to identifying where elevated salinities are (or are not) linked to subsurface activities.

4 Integrated multi-tracer fingerprinting of gas and fluid migration (linked to D3.6)

4.1 SUMMARY OF TECHNOLOGY

Integrated multi-tracer fingerprinting of gas and fluid migration technologies whilst used at shale gas exploration sites in north America and Denmark, they are only poorly established in the UK. Within the SECURe project, a much broader range of isotopes will be analysed, especially in saline groundwaters or flowback. It should be possible to distinguish between thermogenic and biogenic methane based on these combined techniques. This task also aims to review the absolute method measurement of methane in groundwaters.

4.2 TECHNOLOGY REDINESS LEVEL (TRL)

Although some of these technologies are well established in some regions (e.g. via BRGM in France at TRL9) they are less well in others so aim to move from TRL6 to 9 within the SECURe project.

4.3 DEVELOPMENT WITHIN SECURE

SECURe aims to analyse samples of groundwater from shale gas exploration sites in the UK. Importantly, the project will allow a broader choice of isotopes (e.g., B, Li) to be analysed (these have rarely been applied to saline fluids). Suitable samples for advanced isotope fingerprinting of gases have be obtained from the joint WP3-WP4 Fontaine Ardente sampling campaign Autumn 2019 (French Subalpine chains study site). The SECURe project will demonstrate the combined techniques that are currently applied independently to established CCS/shale gas exploration analytical programmes. It will be possible to distinguish between thermogenic methane and biogenic sources. Specifically, secondary processes that can alter these isotope signatures and produce false positives or negatives when tracing thermogenic alkanes will be investigated. A model developed for Alberta (Humez *et al.*, 2019) will allow for the prediction of isotopic signatures for shale gas exploration sites in the UK.

In the Vale of Pickering shale gas exploration site, Li and B isotopes can be analysed and interpreted from groundwater samples for the first time- this will be a major scientific advancement of the SECURe project. The combination of a large set of gas (C, H and O isotopes on alkanes and CO_2) and groundwater isotope fingerprints (O, H, C, S, Sr, B, Li isotopes) for local Environmental Baseline Assessment (EBA) around shale gas exploration/exploitation boreholes will be investigated for the Danish Vendsyssel site (subtask 3.1.4). This case study will demonstrate the potential of multi-isotope studies in areas of complex and multiple gas and salinity sources where less comprehensive approaches will lead to ambiguous conclusions. Another innovative approach of this study is the use of multi-isotopic data from mud gas upon drilling down to 3600 m depth to be able to identify the depth at which eventual surface-near stray gas originates.

Additionally within the SECURe project, there is the potential to review the absolute measurement of methane in groundwaters. Experience suggests that the results obtained from different laboratories differ due to differences in sampling and analytical methods employed by different laboratories and organisations. Research carried out within SECURe will compare the results obtained from different analytical methods and establish why results differ, using a standardised suite of groundwaters collected especially for the project.

WP3 Innovation review meeting: May 20th 2020, 09.00 GMT; remote

Present Wolfram Kloppmann (BRGM), Pauline Smedley, Ed Hough and Rhian Kendall (BGS)

Q1) What has been achieved over the course of the project

Fieldwork and sampling from Fontaine Ardente complete. UK fieldwork planned for Autumn 2019 delayed due to inclement weather; UK fieldwork planned for spring-summer 2020 delayed due to the COVID-19 crisis. Samples and analysis of flowback fluids is underway. Analysis of samples for Li-B underway in BRGM laboratories.

Q2) How have these achievements impacted TRL?

In some areas, the TRL remains at 6 due to issues with sample collection. Sample analysis is not complete, but when complete and interpreted, TRL levels will be reviewed

Q3) When will it have been taken as far as it goes?

In SECURe, there are sufficient resources to carry out the analytical campaign as originally envisaged, but acquiring samples remains a risk due to restrictions on field access due to the COVID-19 crisis.

Q4) What is next for these technologies? Other grants? Industrial exploitation

In some circumstances, isotopic analysis may be useful as a monitoring tool (but probably not routine). Cost effective salinity and conductivity measurements will be useful in some scenarios.

5 Methodology optimisation for methane and higher hydrocarbons concentrations/isotopic ratio measurements in groundwater and soil gas (linked to D3.6)

5.1 SUMMARY OF TECHNOLOGY

The use of isotopic ratios for the discrimination of hydrocarbon source (e.g., biogenic or thermogenic) is well established and has been employed at numerous hydrocarbons exploration sites (e.g., Vale of Pickering, Preston New Road, both UK). A relatively large volume of groundwater is required to enable the molar amount of $\delta^{13}C$ necessary for successful discrimination of hydrocarbons, and analysis is currently expensive using IRMS mass spectrometry. Methods for soil gas have been patented but represent a cost both in terms of time taken to gain approval to use the technique, and an unknown financial cost to any monitoring activities. However, currently there are no agreed or defined sampling protocols and it is believed that differences in sampling procedures may account for a greater degree of error than the analysis itself.

5.2 TECHNOLOGY REDINESS LEVEL (TRL)

Although an established technique and commercially deployed, the method for sample collection is not established, and is currently considered at TRL~5. Once established, a groundwater monitoring method would be at TRL ~8. A groundwater monitoring method may be at a similar TRL level by the end of the SECURe project.

5.3 DEVELOPMENT WITHIN SECURE

A method for groundwater and soil gas sampling will be developed within SECURe. Samples will be collected using different sample collection protocols and methods refined following the first series of sample collection. It is anticipated that samples of groundwater will be collected from multiple levels in boreholes (e.g., 20 – 25 m and 60 – 65 m depth ranges). Following analysis, a review of the results will establish which sampling technique gives the optimal results at a reasonable cost.

Given the need for sample collection and analysis before further information is known regarding which sampling technique gives optimal results, a review of the technique and innovation is suggested in 4-6 months following a sampling campaign (planned first part of October 2019- e.g., February – March 2020).

We could add the following technique (relevant also for D 3.6)

Summary of technology: The measurement of shale gas baseline fingerprints by direct degassing of solid samples collected at outcrop was so far never tested at a larger scale in the frame of EBA. This technique needs a specific sampling protocol under controlled conditions (He as protective gas, specifically developed glass jars, Lerouge *et al.*, 2015,Lerouge *et al.*, 2019) and a degassing protocol still to be tested and refined (influence of relative humidity, evolution over time, notably of isotope fingerprints).

Current level: degassing of cores and cuttings in exploration/observation boreholes (e.g. Cheung *et al.*, 2017) has been applied at a TRL of 5-6 (benchmarking with complementary techniques as mud gas sampling) but gas measurements in shales at outcrop are still in an experimental state. Acquisition of new field data within SECURe and the thorough assessment of secondary processes occurring in the critical zone might allow for establishing standard protocols for degassing techniques within shale gas EBA (TRL 6-7).

Development within Secure: Samples collected in the French Subalpine Chain site gas seeps (Oct. 2019 campaign) are currently under analysis (Lerouge *et al.*, 2020). The conservation of thermogenic gases in surface-near, partially weathered claystones suggest that these measurements might provide access to shale gas fingerprints, provided that secondary processes, e.g. alkane oxidation can be measured and, ideally, corrected. Direct outgassing, upon weathering, of thermogenic methane will also be taken into account when assessing the environmental baseline in areas where the shale-gas bearing formations outcrop directly as contribution to the geogenic gas background values. The technology will be demonstrated on the French SE sedimentary basin shale gas play (currently under moratorium) as a relevant environment.

WP3 Innovation review meeting: May 19th 2020, 09:00 GMT (10:00 CET); remove
Present: Monika Konieczyńska (PGI), Wojciech Wołkowicz (PGI), Ed Hough (BGS), Rhian Kendall (BGS)

Methodology optimisation for methane and higher hydrocarbons concentrations/isotopic ratio measurements in groundwater and soil gas

Q1) What has been achieved over the course of the project

A series of sampling tests has been conducted at soil gas and groundwater sites as well as on post shale gas sites. These have been followed up by laboratory observations. On these results, statistical analysis has been carried out (methane concentrations mainly) and a scheme prepared for final method evaluation sampling and lab tests (Methodology for method evaluation).

During the field work, it appeared that a sampler designed by PGI did not work as intended and so a new prototype is needed and will be tested in forth coming field tests campaign.

Q2) How have these achievements impacted TRL?

Work done so far has not impacted the TRL yet. The main achievement proven so far is that the simplest rubber hand pump is the most practical (cheap and reliable) for soil gas sampling. But the pump is not the focal point of the method.

Q3) When will it have been taken as far as it goes?

It is planned to conduct the planned test sampling and lab analysis in June till July (samples storage time effect tests).

Q4) What is next for these technologies? Other grants? Industrial exploitation

We do intend to implement the methodology for measurements in standard tasks of geological and hydrogeological survey in Poland as well for other projects undertaken by the PGI.

6 UAV-based CO2 sensor (linked to D4.1)

6.1 SUMMARY OF TECHNOLOGY

The development of a drone-mounted monitor to detect CO2 follows on from other projects (e.g., InnovateUK, BGS Innovation fund). This work package is essentially a feasibility study to prove UAV use for a new atmospheric CO_2 sensor. Although other CO_2 sensors have been developed this will be much more sensitive, being able to capture data at ppm in ms time intervals. The UAV was developed by Quest and the sensor is being developed by BGS. BGS has already developed a sensor for atmospheric methane Drones provide a cost-effective method of monitoring soil gas at facilities, in contrast to helicopters or satellite-based technology, to ppm levels.

6.2 TECHNOLOGY REDINESS LEVEL (TRL)

The current status is that:

- The drone is functional;
- The hyperspectral sensor is functional;
- The monitor can be carried by the drone;

This indicates that the current TRL level is approximately level 3 (at the lower stages of technology development)

6.3 DEVELOPMENT WITHIN SECURE

Within SECURe, the drone will be flown, with the monitor, through a plume of CO2 (either a leaking site- natural analogue, or a controlled release of CO2). The test site should ideally be independently monitored to enable comparisons to be made across the site. Flight is likely to be summer 2019, with reporting by May 2020. By the end of SECURe, the technology will progress to TRL 4 (“Laboratory testing of prototype component or process”) or 5 (“Laboratory testing of integrated system”)

WP6 Innovation review meeting: XXXXX 2020, XX:XX GMT (10:00 CET); remove
Present: Colm Jordan, Ed Hough (BGS)

Q1) What has been achieved over the course of the project

The BGS fixed wing drone with CO2 sensor was flown at a test site in the UK in June and August 2019. The sensor successfully recorded background CO2 levels. The main purpose of the outing was to test operation of the prototype system in flight and to determine baseline levels at the site; there was no controlled gas release.

In October 2019 we undertook test flights of the TOTAL rotary drone with the CO2 and CH4 sensors at natural gas seeps in the French Alps (Figure 1). Data are not yet fully processed (due to COVID-19 causing restricted access to offices) but on-site telemetry suggests that the UAV sensors successfully recorded gas emissions.

Figure 2 October 2019 fieldwork at French Alps natural gas seeps. Left: Walkover survey with the TOTAL gas sensor. Right: Gas sensor flown on a rotary drone

Q2) How have these achievements impacted TRL?

We plan to modify the fixed-wing BGS CO2 sensor so that it will operate on a rotary drone. We hope that injection will take place at the GTB UK site (October 2020?) and we plan test flights of the sensor. We are planning to have simultaneous ground measurements for validation and calibration. This would constitute a test of a prototype system at an operational environment, which would equate to TRL 6 on the published EC scale (https://ec.europa.eu/research/industrial_technologies/pdf/workshop-innovation-report_en.pdf).

Q3) When will it have been taken as far as it goes?

Next steps in development include processing data retrieved from the October 2019 fieldwork which will give confidence that CO2 and CH4 can be successfully monitored by drone. Following that, sensors could be developed to monitor other gasses or modified to optimise concentrations of gasses that can be identified.

Q4) What is next for these technologies? Other grants? Industrial exploitation

At current stages, the drone technology is still in the development phase. There is obvious potential for industrial interest in this technology, partly dependant on how the Shale Gas and CCS industries (the latter particularly in Europe) develop.

7 Gas source based microbial sensors (linked to D4.6)

7.1 SUMMARY OF TECHNOLOGY

Microbial methods will be used for monitoring shale gas (methane) leakage via groundwater. Methods used in hydrocarbon exploration (microbial prospecting for oil and gas) indicate that the changes in the proportion/number of microorganisms that can oxidise methane in soils and those that can oxidise larger alkanes can indicate the presence of microseeps from underlying hydrocarbon reservoirs, and therefore can distinguish biological sources of methane from thermogenic sources. We will be adapting and optimising culture-based methods to identify whether this method can be used to identify whether methane detected around shale gas operations is a result of leakage from extraction, or whether it is naturally occurring biological methanogenesis. The culture based-methods will be paired with a more detailed DNA based analysis to identify whether these methods can refine and improve the technique.

7.2 TECHNOLOGY REDINESS LEVEL (TRL)

The current TRL is estimated at TRL level of TRL2 and is anticipated to reach TRL3 by the end of the project.

7.3 DEVELOPMENT WITHIN SECURE

A useful application of microbiology would be to combine culture based- and molecular biology-based techniques to determine the source (thermogenic/biogenic) of methane. This would be particularly useful in those instances where wet gas: dry gas ratios and isotope work give confusing results. The advantage of a microbial approach would be that it would be possible to detect microbial methanotrophs at the time of sampling ground water, which may be able to indicate intermittent leakage in the recent past, but which are not leaking at present.

To date, optimisation of methods for field sampling, sample preparation, testing of carbon sources for best diagnostics and data analysis have been carried out. The conditions under which this test needs to be run have been refined allowing us to start to test the robustness of this with various field samples.

During the project,

- The experimental methods will be optimised;
- Analysis will be run on groundwater samples;
- Results will be interpreted

By the end of the SECURe project, the technology will have progressed to TRL3 - The conditions under which this test needs to be run have been refined allowing us to test this with various field samples.

WP4 Innovation review meeting: April 9th 2020, 14:00 GMT; remote

Present Simon Gregory and Rhian Kendall (both BGS)

Q1) What has been achieved over the course of the project to date?

Optimisation of methods for field sampling and preparation methods, testing of carbon sources for best diagnostics, data analysis.

Q2) How have these achievements impacted TRL?

The conditions under which this test needs to be run have been refined allowing us to test the robustness of this with various field samples

Q3) When will it have been taken as far as it goes?

By the end of the project the proof of concept and initial field testing will be demonstrated. This concept could be applied to monitoring other industries (e.g., monitoring subsurface hydrogen storage sites; monitoring geothermal sites).

Q4) What is next for these technologies? Other grants? Industrial exploitation

There is additional improvement that can be done within this project (linking genetic identities to this test to see if accuracy can be improved). Beyond this project, technology could be further developed through other grants, if industry is sufficiently interested in these results.

8 A tool for the detection of potential leakage (rate) of high heavy metal concentrations (linked to D4.7)

8.1 SUMMARY OF TECHNOLOGY

Laboratory experiments to assess the impact of changes in chemical parameters of fluids on fluid-rock interaction (pH, temperature, oxidant level, fluid/rock ratio, salinity, etc), and thus on the elemental concentrations in fluids. Geochemical reactions will be evaluated. Shale samples will be characterised mineralogically and chemically. Fluids from fluid-rock interaction experiments will be chemically characterised (by inductively coupled plasma mass spectrometry and ion chromatography for changes in heavy metal and other element concentrations) at multiple stages during on-going experiments. A fundamental understanding of groundwater quality linked to interaction of rocks with fracturing fluids is needed for assessment of risks and impacts of leakage..This will result in a tool for the detection of potential leakage (rate) of high heavy metal concentrations providing quantification of kinetics and extent of element leaching from water-rock interaction under a set of water conditions(parameters of pH, salinity, temperature, fluid/rock ratio, redox state) that are typical of fracturing fluid conditions; and improved understanding of element mobility and hazards linked to leakage.

8.2 TECHNOLOGY REDINESS LEVEL (TRL)

The current TRL is estimated at TRL2 and is anticipated to reach TRL4 by the end of the project

8.3 DEVELOPMENT WITHIN SECURE

SECURe aims to analyse elemental mobilisation during interaction of Bowland shale with simulated fracturing fluids, through quantitative determination of geochemical fluid compositions from batch reactor experiments. Development of the innovation can be demonstrated by:

- This research identifies chemical reaction pathways of geochemical elements (including contaminants) in fracturing fluids over a range of fluid chemistries and environmental conditions.
- Fluid pH buffering favours immobilisation of some metal ions by adsorption and precipitation (e.g. Al, Mn, Fe, Pb, Ba).
- The surface topography of different minerals in polished shale sample sections after fluid-rock interaction indicates that mineralogical compositions may play an important role in determining the pore structure.

Update WP4 innovation progress meeting on May 20, 2020
Present: Jan Hennissen (BGS), Matteo Icardi, Federico Municchi and Yukun Ji (all UNOTT)

Q1) What has been achieved over the course of the project?

Chemical pathways in subsurface following introduction of fluids: regulated mainly by pH and temperature. This mobilizes potentially harmful contaminants. Bench top batch experiments combined with thin section elemental mapping was undertaken. Manuscripts being written up for publication.

Q2) How have these achievements impacted TRL?
Start TRL: 2; projected end TRL: 5.
At the moment, the technology is at TRL4: real world samples from end members of the Bowland Shale have been tested in a laboratory setting. TRL 5 may not be achieved because of current restrictions on the use of hydraulic fracturing.

Q3) When will the technology have been taken as far as it goes within the scope of the SECURe project?
The technology could be further enhanced by investigating a larger diversity of shale sample compositions, by conducting flow through experiments, and by testing with real hydraulic fracturing fluids. However, this falls beyond what is possible within the timeframe (and facilities and manpower) of the SECURe project.

Q4) What is next for this technology? Other grants? Industrial exploitation?
The next step for this technology will involve establishing predictive rules for contaminant transport based on shale rock composition and hydraulic fracturing composition.

9 Fracture leak rate prediction to validate flow sensors (linked to D4.4)

9.1 SUMMARY OF TECHNOLOGY

Computational software to predict flow and transport using the opensource C++ library OpenFOAM, with field-size applications and integration of geomechanical models.

9.2 TECHNOLOGY REDINESS LEVEL (TRL)

The current status of the technology is that an existing general purpose open source flow solver has to be modified to suit a particular flow scenario. This is a labour-intensive process that, although possible, can require specialist IT hardware in terms of computing size and speed. Because of this, the current TRL level for these predictive models is considered TRL 2.

9.3 DEVELOPMENT WITHIN SECURE

Within SECURe, development of the predictive method will progress by:

- Developing models for fractured media. Code will be available by about November 2019.
- Application of model to fracture evolution and geomechanical data from WP partners INiG and possibly SINTEF (via D3.9).
- Review of developments and identification of resulting TRL level. Progression of the method to TRL 4/5 will be demonstrated by improved computational efficiency that are applicable to near-real-time analysis of fracture propagation.

Update following the WP4 progress meeting on May 20, 2020:
Present: Jan Hennissen (BGS), Matteo Icardi, Federico Municchi and Yukun Ji (all UNOTT)

Q1: What has been achieved over the course of the project?

This technology takes the shape of open source libraries for the OpenFoam software environment. These packages are online and publicly available First year development went very quickly (Federico and Matteo) Work resulted in two publications already (second publication appeared May 2020).

Q2 How have these achievements impacted TRL?
Start TRL: 2; projected end TRL: 4. Currently, TRL 4 (technology validated in laboratory) has been reached. Evidence is the use of lab datasets to develop the software modules. Next step will be the use of real-world data sets based on laboratory results in collaboration with PGI.

Q3) When will the technology will have been taken as far as it goes within the scope of SECURe?
This technology could still be advanced in the scope of the SECURe project. As of now, it has been tested with local datasets; next step is the use of other user's data which is the real test. Links with WP3 could advance the TRL beyond the projected TRL 4.

Q4) What is next for these technologies? Other grants? Industrial exploitation?

Matteo Icardi already liaised with Philippa Parmiter regarding further development. Porous electrode modelling problems are very similar to problems addressed in the current research. Potential collaboration with IMFT (Toulouse, France) for further development. Industrial exploitation is difficult at the moment because of open source status of the technology.

10 Noble gas downhole sensor (linked to D4.8)

10.1 SUMMARY OF TECHNOLOGY

The prototype downhole sampler that is used in Subtask 4.1.3 is the result of a collaboration between IFPEN and our industrial partner SEMM LOGGING. The sampler which has been patented by IFPEN and SEMM LOGGING was designed after a careful market analysis and a precise concept specification. The manufacturing of the sampler was done by a German Sub-contractor, according to a clearly described specifications/ concept drafted by IFPEN and SEMM LOGGING. Our prototype monitoring tool, consists of a downhole sampler, a mobile PVT cell and a gas chromatograph. It allows us sampling of gas and liquid in temperature up to 125°C and pressures up to 35 MPa. The tool is compatible for sampling of hydrocarbons, CO_2, N_2, nobles gases and water (aqueous solutions). The quantity of the dissolved gas (GWR/ GOR) and the composition of the vapor phase is analyzed by gas chromatography. With the help of a thermodynamic calculation tool we can then calculate the quantity of the dissolved gas at different (p, T, x). In comparison with the common commercial downhole samplers, it covers a higher range of temperature and pressure and it provides a representative sample without any contamination or composition modification.

10.2 TECHNOLOGY REDINESS LEVEL (TRL)

The current technology is considered TRL6 (the technology is at an advanced stage of development but requires testing in in-situ environments to prove viability as a commercial entity).

10.3 DEVELOPMENT WITHIN SECURE

SECURe will allow a suitable test site to be identified, and for the in-situ testing of the sensor at in-situ temperatures and pressures. The first validation test has been carried out in March 2019. This is was a lab test in a special oven which permitted us to simulate the extreme sampling conditions (35 MPa and 125°C). With our industrial partner, we are planning to perform an on-site validation test in a gas storage site in south of France this summer. In parallel, all the specifications and user manuals are being drafted for one-end user operations. A business model is under development which presents our target applications and time scales for reaching TRL8.

Review- once subcontracts have been agreed/field test sites have been identified and arranged.

WP4 Innovation review meeting: June 3rd 2020, 09:00 GMT (10:00CET); remote

Present: Pascal Ricroh (IFPEN), Ed Hough (BGS)

Q1) What has been achieved over the course of the project?

During February 2020, field testing at SIG Geo-1 borehole (Switzerland) of the downhole sensor and surface cabin and related infrastructure (including chromatographs). Field tests included obtaining full capacity and part-capacity samples from ~400 m below ground level; these samples allow for the analysis and estimation of gas-water ratios and volumes of inert gas. For some samples, the composition of dissolved gasses has been verified. Preliminary results have been discussed with the subcontract partner.

Q2) How have these achievements impacted TRL?

The tool was at TRL 6 in 2018 (level- a prototype system). The tool currently stands at TRL 7 following the successful field campaign (level- operating at a pre-commercial scale). This is demonstrated by the tool being capable of achieving objectives during the field test. It is anticipated that the tool should achieve TRL 8 by the end of the project (level- first of a kind commercial system), once methods have been improved to eliminate potential errors in sampling (e.g., atmospheric contamination).

Q3) When will it have been taken as far as it goes?

Next field campaign (planned for October/November 2020 at SIG Geo-2) will aim to optimise the surface analytical instrumentation and improve the methods to obtain higher gas-water ratios. The down-hole sensor is on track to becoming a fully commercial product in the next few years.

Q4) What is next for these technologies? Other grants? Industrial exploitation

There is an existing business plan developed by IFPEN/SEMM logging. Design of the sampler is on schedule. There have been some delays related to the Coronavirus crisis that have led to short delays in tool fabrication and delays in the second phase of tool testing. Development of the tool (in terms of data analysis) could be a viable next step for development of the technology. Marketing of the tool has also been slightly delayed, but presentations and articles are planned to publicise the tool and capabilities. The tool will be highlighted during the SECURe general assembly (June 17 2020), and also an opportunity to showcase the tool at the SECURe December 2020 conference.

11 Study possible failures of well cement (linked to D5.1)

11.1 SUMMARY OF TECHNOLOGY

Assessment of causes of well cement failure are at a very early stage, with some work believed to have been completed by service companies, but very little in the public domain (this may have been considered by the CO2Geonet project). There is little research focussing on how cements may fracture under pressure during CO2 injection, or how to conduct realistic testing in-situ.

11.2 TECHNOLOGY REDINESS LEVEL (TRL)

Given the current level of understanding of the factors contributing to well cement failure, the technology is presently (April 2019) considered to be TRL2.

11.3 DEVELOPMENT WITHIN SECURE

This innovation will develop a methodology, based on laboratory-scale experiments, for how to produce realistic fractures propagated through the cement sheath of a borehole for testing small sections of borehole cores. Development of the innovation can be demonstrated by:

1. Development of a method to generate realistic fractures in cement (Sintef);
2. Generate fractures in cement samples;
3. Propagate fractures through cement samples (at this stage, not considering the cement/steel borehole casing interface), including understanding of the permeability of the fractured sample;
4. Injection of remediation fluids and testing for permeability reduction;
5. Publicize/develop further with partner organisations.

By the end of the SECURe project, it is anticipated that this technology will be approaching or at TRL4-research proving feasibility of technology.

Results from WP5 Innovation progress meeting on April 17, 2020
Present: Jan Hennissen (BGS), Pierre Cerasi (SINTEF)

Q1) What has been achieved over the course of the project?

- Main research question: are we able to fracture cement in a field relevant way?
- Trying to mimic what would happen in a field setting when cement fails. Main issue in the field: cement cannot be reached
- Mini wellbore simulator used to fracture cement and surrounding rock by pressurizing casing. Recipe for sealant distributed among partners

Q2) How have these achievements impacted the TRL?

- Deliverable was 31/07/2019
- TRL start: 1 basic principles observed
- TRL projected: 4 technology validated in the lab

Current TRL: 3: experimental proof of concept has been reached.

Q3) When will it have been taken as far as it goes?

Recipes for sealant developed at BGS will now be tested in the mini wellbore simulator at SINTEF. This could still be tested as part of the SECURe project.

Q4) What is next step for these technologies? Other grants? Industrial exploitation?

Expanding the applicability into the field of hydraulic fracturing- this has relevance to geothermal systems that require bedrock stimulation..

12 Remediation of leakage using silicate gels (linked to D5.2)

12.1 SUMMARY OF TECHNOLOGY

Silicate gels have been developed and it is thought that these may be suitable sealants to reduce the permeability of damaged (fractured) cements. The gels are commercially available, but have not been specifically targeted at addressing well cement failure.

12.2 TECHNOLOGY REDINESS LEVEL (TRL)

Presently the technology is at TRL3; the performance of these sealants has not been tested on cements or compared to other potential sealants, as far as we know.

12.3 DEVELOPMENT WITHIN SECURE

The behavior of silicate gel will be compared to alkaline fluids being used in experiments in D5.2. The following steps will demonstrate the development of the technology:

1. Define the chemistry of carbonate fluids; small-scale testing in the laboratory;
2. Assess the permeability of samples post-placement;
3. Compare performance of silicate gel and carbonate fluids.

Following these steps, the TRL level of this technology is anticipated to be TRL4: Technology in development.

This work is subject to the successful completion of the innovations linked to D5.1 (Section 11).

Review- will be appropriate in Winter 2019 – Spring 2020.

Results from WP5 Innovation progress meeting on April 17, 2020
Present: Jan Hennissen (BGS), Pierre Cerasi (SINTEF)

Q1) What has been achieved over the course of the project?

- Literature study showed concept was only tested in sandstone setting where slow/weak remediation was possible
- Quicker reaction required for SECURe for large fractures; this requires high concentration of silicate gels
- High concentration and quick solidification may present practical problems on well site, in order to get the gel into the fractures without solidifying before reaching optimal placement.
- In lab mini wellbore simulator was used (described in D5.2)
- At the moment: stage where a large fracture in the middle of a cement core is tested, at a concentration low enough for the gel to be fluid. Currently, slowly upping the concentration

Q2) How have these achievements impacted TRL

- Deliverable was 30/09/2019
- TRL start: 3 experimental proof of concept
- TRL projected: 4 technology validated in the lab
- TRL 04/2019: 3 experimental proof of concept
- TRL 4: technology validated in the lab has been reached.

Q3) When will it have been taken as far as it goes?

This technology will have been taken as far as it can go over the lifetime of the SECURe project.

Q4) What is next for these technologies? Other grants? Industrial exploitation

Next steps will include the testing of more recipes and expanding the setup for hydraulic fracturing applications. This will include tri-axial pressure testing.

13 Conclusions

This Milestone 9 report presents the advancement of ten innovations in the SECURe project. For each innovation we presented a summary of the technology, the current TRL and an overview of the development as part of SECURe to date. In some cases this includes a revision of the anticipated TRLs for the end of the project. Table 2 reflects these changes.

Table 2 Summary of new estimated TRLs for the end of the SECURe project

Del. #	Technology	TRL Start	TRL End
D3.3	Synergies of environmental baseline strategies (UK & Canada sites)	6	9
D3.6	Integrated multi-tracer fingerprinting of gas and fluid migration	6	9
D3.6	Methodology optimisation for methane and higher hydrocarbons concentrations/isotopic ratio measurements in groundwater and soil gas	5	8
D4.6	UAV-based CO2 sensor	3	5
D4.4	Gas source based monitoring sensors	2	3
D4.5	A tool for the detection of potential leakage (rate) of high heavy metal concentrations	2	4
D4.5	Fracture leak rate prediction to validate flow sensors	2	4
D4.6	Noble gas downhole sensor	6	8
D5.1	Study possible failures of well cement	1	4
D5.2	Remediation of leakage using silicate gels	3	4

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