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Web-based tool of corrective measures – summary report

Definitive version

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Public abstract

This report is part of the research project MiReCOL (Mitigation and Remediation of CO_2 leakage) funded by the EU FP7 program[1]. Research activities aim at developing a handbook of corrective measures that can be considered in the event of undesired migration of CO_2 in the deep subsurface reservoirs. MiReCOL results support CO_2 storage project operators in assessing the value of specific corrective measures if the CO_2 in the storage reservoir does not behave as expected. MiReCOL focuses on corrective measures that can be taken while the CO_2 is in the deep subsurface. The general scenarios considered in MiReCOL are 1) loss of conformance in the reservoir (undesired migration of CO_2 within the reservoir), 2) natural barrier breach (CO_2 migration through faults or fractures), and 3) well barrier breach (CO_2 migration along the well bore).

The work conducted throughout the MiReCOL project consisted of studying and simulating many remediation techniques for CO_2 storage. The final aspect was developing an online web app to host a web tool and online handbook to present the findings from the project, for the use of CO_2 operators, regulators, decision makers, and the public. This deliverable details the work done to create the MiReCOL web app, as well as presents a reading guide, or manual, to use the web tool and handbook. Within the web tool, the guide explains the source of information and the functionality of the site analysis, the well remediation analysis, and the technique analysis. Regarding the handbook, the guide explains the organization and sources of information.

[1] More information on the MiReCOL project can be found at www.mirecol-co2.eu.

Public introduction (*)
CO_2 capture and storage (CCS) has the potential to reduce significantly the carbon emission that follows from the use of fossil fuels in power production and industry. Integrated demo-scale projects are currently being developed to demonstrate the feasibility of CCS and the first such projects are expected to start operating in Europe under the Storage Directive in the period 2015 – 2020. For the license applications of these projects a corrective measures plan is mandatory, describing the measures to be taken in the unlikely event of CO_2 leakage. This project will support the creation of such corrective measures plans and help to build confidence in the safety of deep subsurface CO_2 storage, by laying out a toolbox of techniques available to mitigate and/or remediate undesired migration or leakage of CO_2. The project is particularly aimed at (new) operators and relevant authorities. The MiReCOL project investigates various techniques for control of CO_2 migration including: i) injection strategy, ii) gel or foam injection, iii) water or brine injection and iv) injection of chemicals which react with CO_2 and precipitate it as a solid. The results of this work will contribute to later activities that will assess the effectiveness and consequences of all leakage mitigation measures, leading to the production of a Corrective Measures Handbook.

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1 INTRODUCTION

Carbon dioxide capture and storage [CCS] is a technology that has promising capabilities for emission reduction in the energy generation fields, as well as the materials industry (IEA, 2013) (IPCC, 2014). Already, there are projects underway that exhibit the functionality of this technology (Global CCS Institute, 2015). To support the growth of this field, stakeholders must be informed of the process itself as well as the risks and implications involved.

Several tools have been developed to help promote this knowledge sharing, including GERICO: management of risks for CO_2 storage (Le Guénan et al., 2011)[2]; the monitoring selection tool on the IEAGHG website (BGS, 2010)[3]; and the National Risk Assessment Partnership's tool on quantifying risks of CO_2 storage (Pawar et al., 2016). To accompany these existing tools and fill in the gap of knowledge about remediation techniques, MiReCOL provides studies and information on new and existing methodologies to mitigate and remediation a CO_2 storage site. The result of this project is a web app[4] which hosts a web tool to assess the various remediation techniques, as well as a handbook which offers literature on these techniques

This web app is meant to serve as a reference for CO_2 storage operators, regulators, authorities, decision makers, and the public to learn more about remediation measures available in the case of undesired CO_2 migration. The tool is intended to aid the research process and does not replace creating a remediation or contingency plan. Within the project, some practices are quite well established, while many are still in the beginning phases, which has been noted by using technology readiness levels [TRL] (TRLs, 2014). This is to give a perspective of how practical the remediation techniques are.

The following section details how to use the web app, regarding both the web tool and the handbook, while the sections thereafter explain more of the background knowledge used to formulate the web tool and handbook. The way the tool was developed is described in Section 3, including the calculations behind the tool. Section 4 contains the source of the data and information used in the web app and the conclusion wraps up the deliverable and concerns the applications where this web app can be used.

[2] http://gerico.brgm.fr/
[3] http://ieaghg.org/ccs-resources/monitoring-selection-tool1
[4] http://tool.mirecol-co2.eu

2 WEB APP MANUAL

This section is meant to serve as a reading guide for the use of the web app, which includes two main sections: the web tool and the handbook. Both of these features are intended to offer guidance and information for CO_2 storage operators, CO_2 storage regulators, competent authorities, and the public on different remediation techniques and their impacts.

The MiReCOL web app is located online at http://tool.mirecol-co2.eu. This web app is best viewed using the web browser Mozilla Firefox or Google Chrome. It functions using Internet Explorer and Microsoft Edge, except some features are limited. Once on the site, there are options to view the two parts of the web app (the web tool and the handbook), as well as an option to learn more about the web app and MiReCOL project (Figure 1).

Figure 1. Screenshot of the MiReCOL web app home page.

On the "About" page, you will find a brief description of the MiReCOL web app, information about the project in general, partners involved, and contact information. There is a link to the MiReCOL website as well (http://mirecol-co2.eu), which provides more information about the project, the scientific blog, events and relevant sites, publications, and a listing of the partners (Figure 2).

Figure 2. The original MiReCOL project website.

2.1 Using the web tool

Once selecting the web tool option, two selections are provided: "Site Remediation" and "Well Remediation". The former offers two functions (explained in Section 2.1.1):

1. Compare the leakage reduction potential from all the investigated remediation techniques based on their overall performance (Technique analysis).
2. Enter your site details, and find the closest scientific simulations for each remediation technique to determine their effectiveness (Site analysis).

The "Well Remediation" selection will take you to the assessment of a leakage via a well barrier failure, described in Section 2.1.2.

Important to note is that the web tool assumes the user has already detected an irregularity in monitoring, suggesting migration of the CO_2 plume.

2.1.1 Site Remediation

The following sub-sections describe the options once navigating to the "Site Remediation" page. At the bottom of the page is a button that reads "Back to remediation selection", which will take you back to the page which displays the options of site remediation or well remediation.

2.1.1.1 Technique analysis

This part of the tool displays several dropdown options, as well as a graph titled "Probability of success for remediation techniques". Upon loading the webpage, each remediation technique investigated in the MiReCOL "Report on individual remediation techniques scoring method and classification/ranking results" (Korre, 2017, link) is depicted in the plot. The name of the remediation technique is on the x-axis, and the probability of success (in percent) is on the y-axis.

To narrow down the options shown, you can select values for each of the dropdown menus (which are spatial extent, cost efficiency, response time, longevity, and TRL), and the plot will be dynamically updated with the remediation techniques that fit that selection (see Figure 3). For example, if you would only like to view remediation options that are low cost, then you would go to the "Cost efficiency" dropdown, and select "High (0-1 M€)". If you selected "Medium (1-10 M€)", then remediation techniques with both medium and high cost efficiencies would be displayed. To reset the choices you have made, click the "Reset selections" to see all the remediation techniques again.

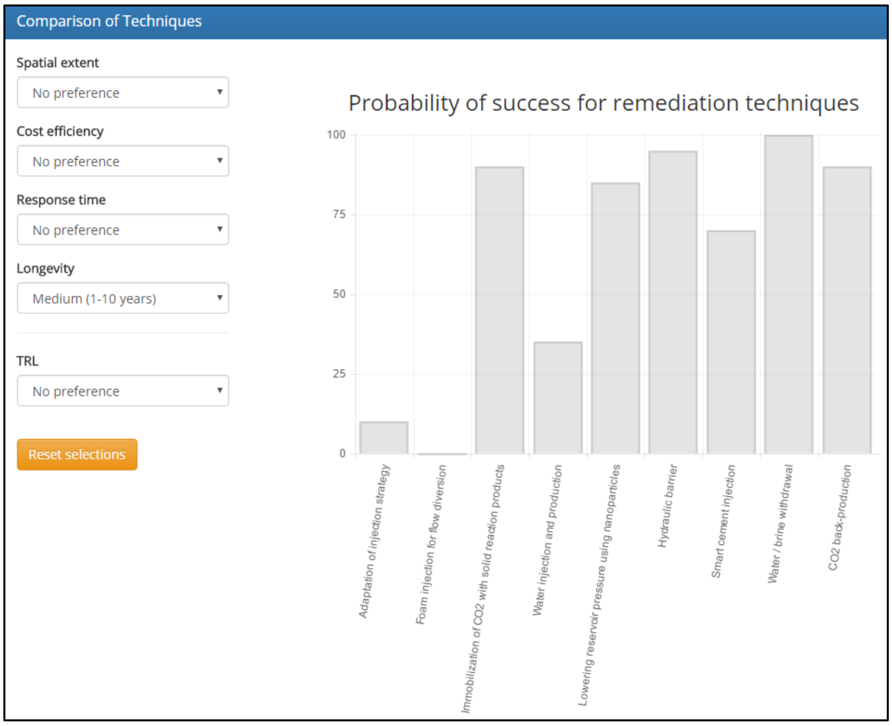

Figure 3. Selection options and output bar chart from the "Technique analysis" page, displaying probability of success for those techniques that meet the selected criteria.

Below the bar chart is a list of the remediation techniques that meet the user's selected criteria. Clicking one of the techniques displays the TRL and a radar chart, which illustrates how the technique performs on a 3-point scale in regards to likelihood of success, spatial extent, longevity, response time, and cost efficiency. The farther from the centre of the chart, the better the metric is. An overview of the technique and associated MiReCOL deliverables are listed (Figure 4), as well as a description of the ranking of the radar chart (Figure 5). At the bottom of the page are links to the two MiReCOL studies from which this information is pulled, "Report on individual remediation techniques scoring method and classification/ranking results" (Korre, 2017, link) and “Report on methodology for the CO_2 storage remediation portfolio optimisation and the results of the scenario analysis” (Govindan et al., 2017, link).

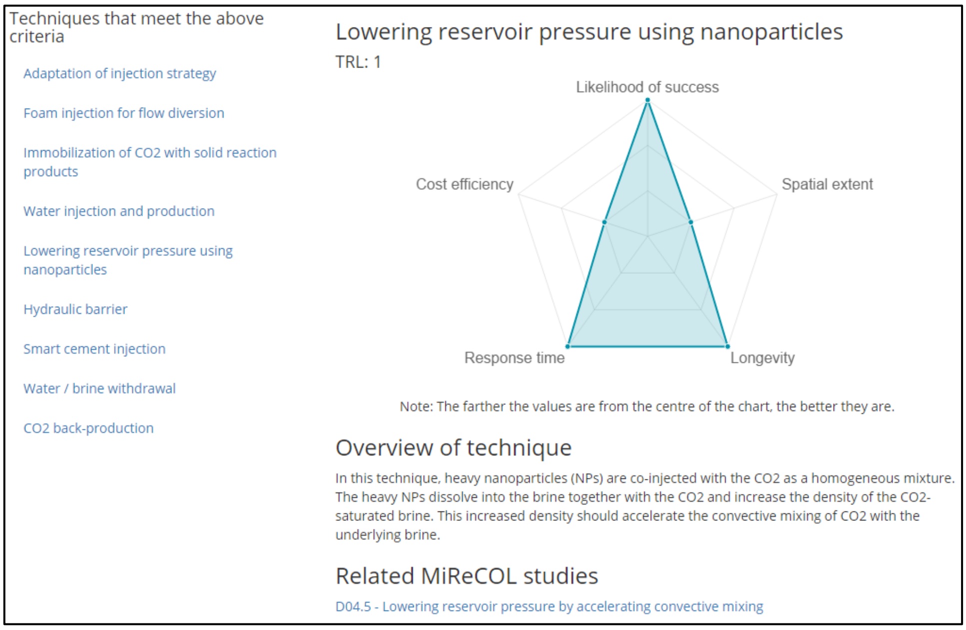

Figure 4. Output techniques listed on the “Technique analysis” page based on user selection, along with the selected technique TRL, radar chart, overview of the technique, and related deliverables.

Description of ranking for the radar chart

The following table details what each rank means for each of the five criteria displayed on the chart. Despite being a qualitative output, the resulting spider chart outputs represent the best efforts that were made to standardise the scales in different dimensions in order to ensure that it is indicative of the overall merit of a given technique, and also facilitate comparison between techniques.

Rank	Likelihood of success (%)	Spatial extent (km2)	Longevity (years)	Response time (years)	Cost efficiency (M€)
Low [1]	0 - 33	0 - 1	0 - 1	> 1	> 10
Medium [2]	34 - 66	1 - 5	1 - 10	0.1 - 1	1 - 10
High [3]	67 - 100	> 5	> 10	0 - 0.1	0 - 1

Figure 5. Table clarifying the ranking system of the radar chart found on the “Technique analysis” page.

2.1.1.2 Site analysis

This aspect is intended to learn more about the user’s site and provide an idea of how different remediation techniques would work. Though this tool does not assess the user’s actual site, it attempts to find the closest scenario that was simulated for each remediation technique. This allows reuse of the simulations run during the MiReCOL project, without requiring intensive calculation and modelling while using the web tool.

Upon loading the page, the user is to answer the questions (to the best of their knowledge) about the site they would like to investigate, as shown in Figure 6. For the tool to function, all the questions must be submitted. Once answering the questions on the first screen, press “Next” to go to the following questions. The questions deal with the user's reservoir, the CO_2 stored in the reservoir, the user's idea of the CO_2 migration, and questions on mitigation options. Once answering the questions, select the "Submit" button to go to the "Output" page and see the results of your site input.

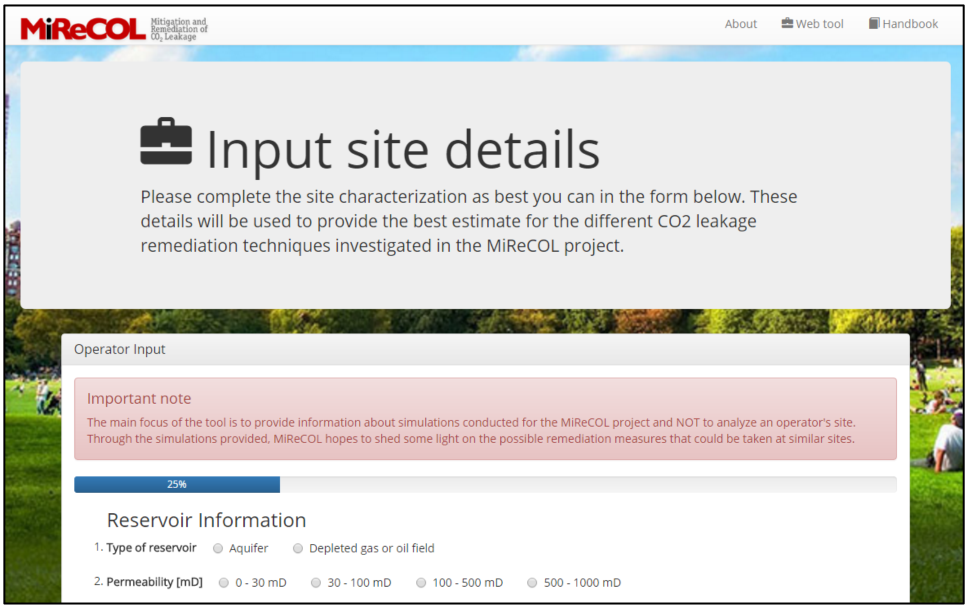

Figure 6. Screenshot of the "Site analysis" page in the MiReCOL web tool.

On the "Output" page, there is a radar chart next to two dropdown menus (see Figure 7). This section allows you to visually compare output criteria of the closest scenario (to the user's input) from two remediation techniques. Selecting a technique under "First Technique" will display one set of data on the radar chart in orange, the overall score for that technique, and the technology readiness level of that technique. Selecting a technique under "Second Technique" will display the same type of data for another technique, this time in blue. The radar chart shows five output criteria, likelihood of success, spatial extent, materials/cost, response time, and longevity.

- The likelihood of success is the interpretation of the scientist who ran the simulations, but the main idea is the likelihood that this technique halts CO_2 migrations. Below the radar chart, in the list of the remediation techniques under the heading "Other Notes", some scientists have further specified their definition of this criterion.
- The spatial extent relates to the distance over which this remediation technique will function. As a base notion, this value is the distance simulated in the experiments.
- The materials and cost values are to give an idea of what is required for this remediation technique. As it can be difficult to know costs of a remediation without performing a full-site analysis, the ranking in the radar chart serves as an estimation. This value is different from the "Technique analysis" section, in that it is simply cost and not cost efficiency.
- The response time can be thought of as the time it takes for the remediation to be set up and to start preventing CO_2 migration.

- Longevity is the time that the remediation will stay in place. Similar to spatial extent, this criterion is based on the simulations that the scientists ran, while some include the point that once in place, these remediation techniques would be permanent.

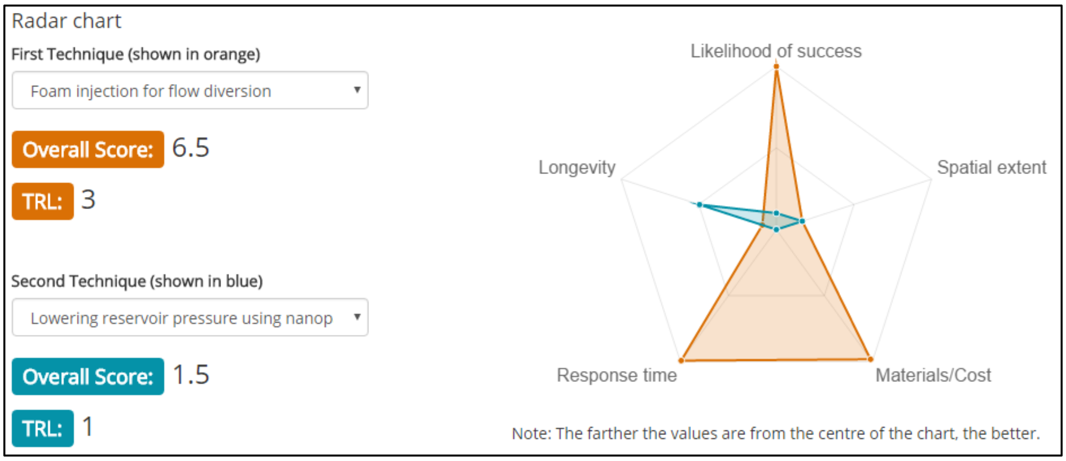

Figure 7. Screenshot of the radar chart on the site analysis output page.

Directly below the radar chart is a table with user input and the closest scientific scenarios. What this contains in the second column is a list of the input parameters from the user. The following columns are the scientific simulations that are closest to the user's input values. For example, the third column shows the technique of "foam injection for flow diversion" (Wessel-Berg et al., 2015, link), which had several simulations run. The user's input is compared to each scenario, and the closest one is selected and displayed in this table.

Further down on the page are the outputs of each remediation technique. They are divided into two categories: appropriate and inappropriate. A method would be deemed inappropriate if the user input a feature that is not compatible with the remediation technique. To demonstrate, if the user had noted that his site had no neighbouring reservoir, then the remediation technique "flow diversion to nearby compartment" (Orlic et al., 2016, link) would be placed under the "Inappropriate methods" section. Within each remediation technique are displayed the output criteria, as described above for the radar chart, as well as other notes which are further comments about the terminology from the scientists who performed the simulations. Finally, associated risks to the remediation technique and associated MiReCOL deliverables are listed.

2.1.2 Well remediation

If the well remediation option is selected, the initial screen shows a list of primary (in blue) and secondary (in red) barriers found in a typical well (Figure 8). These barriers are possible failure locations if a leak is in the well. To better illustrate this, the image to the right of the barrier list has colour-coded lines and numbers which correspond to the numbers in the barrier list. Thus, if the failure location is at the blue number 4, then the user can see in the list that the blue number 4 is the “completion packer and polished bore receptacle”.

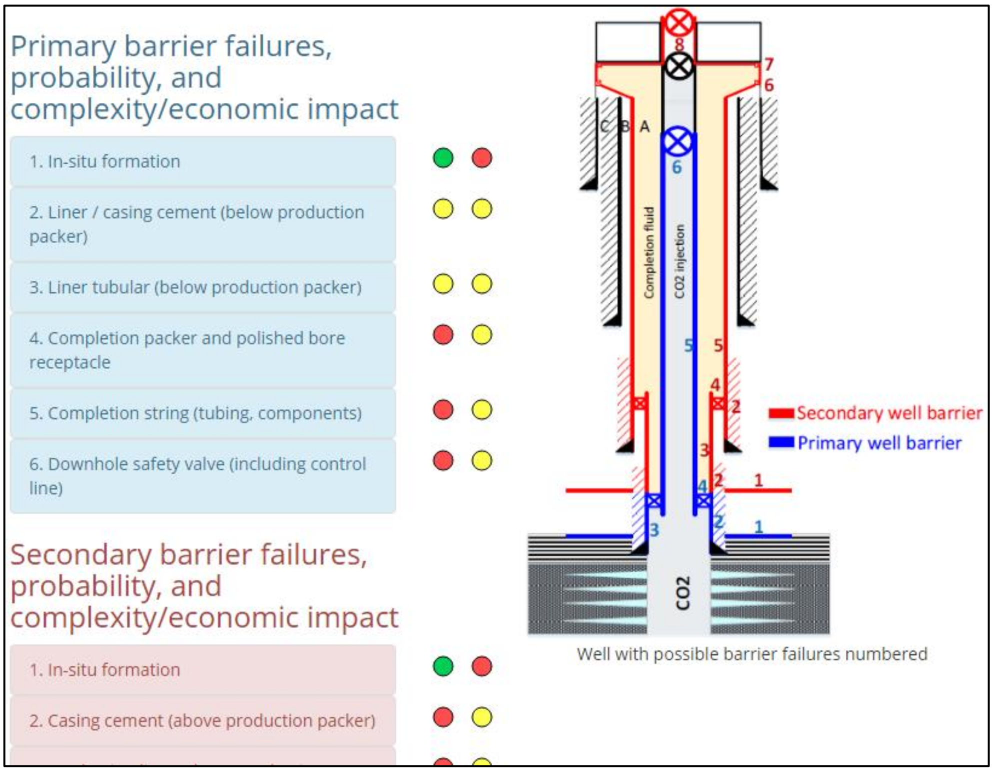

Figure 8. Screenshot of the initial page of the well remediation tool.

The two dots next to each barrier display the “probability” and “complexity/economic impact” of that barrier. Hovering over each dot will show these labels. The first dot, represents the probability of that barrier failing, while the second dot represents the difficulty or cost of replacing that barrier. The colour key lower on the page explains what these traffic light colours mean in the context of well barriers, as shown in Figure 9.

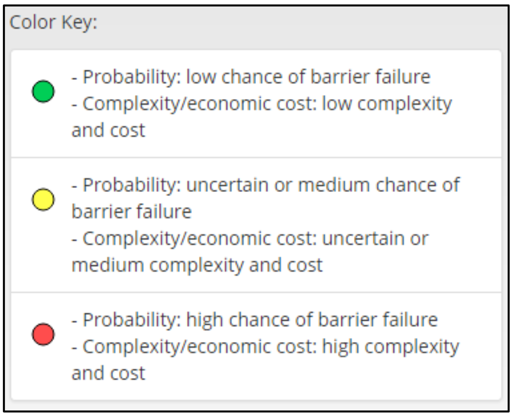

Figure 9. The colour key for the two dots next to each well barrier on the well remediation page.

Once deciding on a barrier to investigate, clicking on that option will display a window within the page that describes the well barrier further (Figure 10). This window displays a short description of the barrier, the probability and complexity/economic cost dots again, possible causes of the barrier failing, and an image to show the barrier.

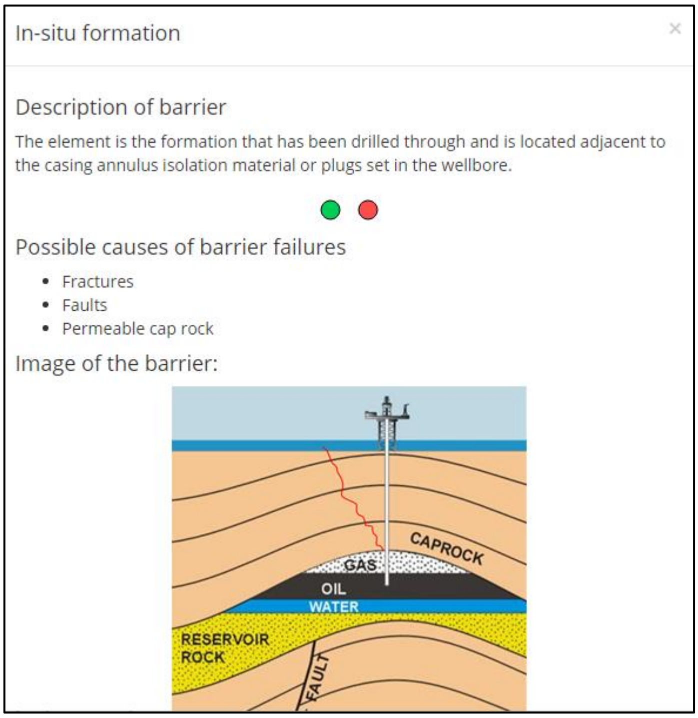

Figure 10. Description shown once clicking on a well barrier on the well remediation page.

If this is the barrier you desire to remediate, then you can click on the button “Select this barrier” to continue onto the next page. If you would like to go back to select a different barrier from the lists, then you can either click outside of the popup window or select “Close”. After selecting a barrier, suggested remediation practices are listed first on the page (see Figure 11). Below this are listed technical and economic risks, which are colour-coded with a traffic light colour to display the overall risk for these two risk categories. Green signifies low risk, yellow signifies medium risk, and red signifies high risk. Once finished with this page, you are able to either investigate more well barrier failures, by clicking on the “Back to all barriers” button, or go back to the menu with the options of site or well remediation, by clicking on the “Back to remediation selection” button.

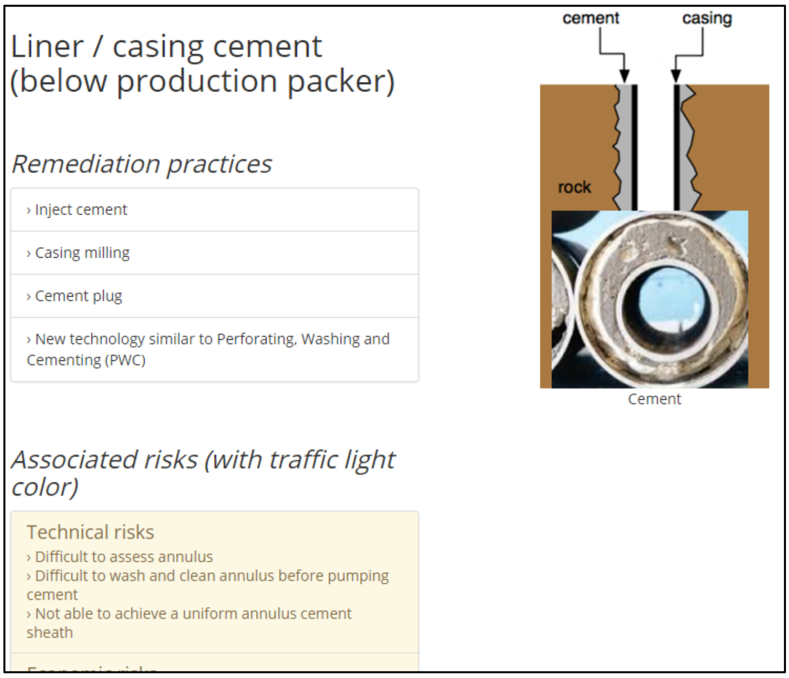

Figure 11. Screenshot of the well remediation page, once a barrier has been selected as that which needs to be remediated.

2.2 Using the handbook

The MiReCOL online handbook groups together the remediation techniques, deliverables, publications and other literature from the project. This is organized in three tabs (Figure 12):

- Remediation techniques
- MiReCOL reports
- Downloadable literature

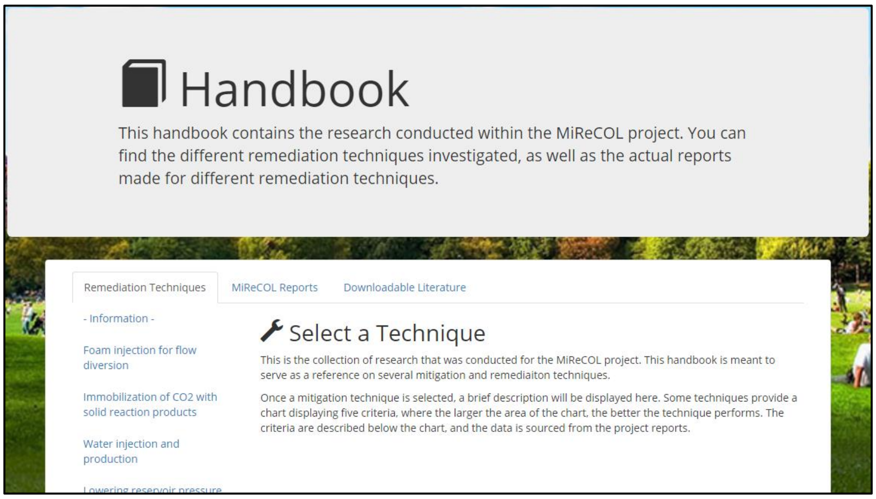

Figure 12. Screenshot of the initial page of the online handbook, showing the three tab options: remediation techniques, MiReCOL reports, and downloadable literature.

2.2.1 Remediation techniques

The default screen shows this tab. In the column to the left, you can see listed the different remediation techniques that were investigated in MiReCOL. Upon clicking one of the techniques, the middle content of the page changes to display that technique name along with the TRL and a brief overview of the technique. If the technique was analysed in Deliverable 11.2 (Korre, 2017, link), then a radar chart (and table explaining the chart ranking) is displayed along with the TRL and overview (Figure 13).

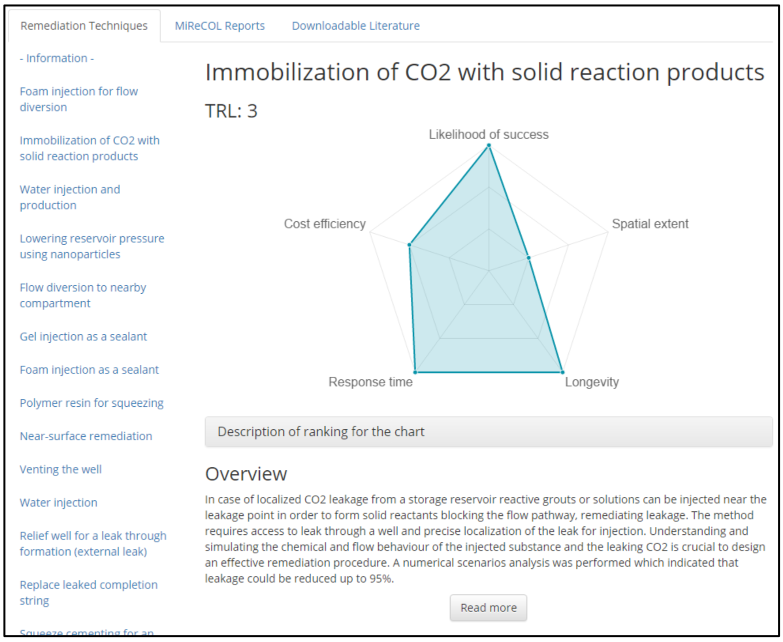

Figure 13. The remediation techniques tab in the online handbook, showing the TRL, a radar chart, and an overview of the selected technique.

You can click on the “Read more” button to view more about the technique, including the methodology of either the remediation technique or the modelling of the technique, the materials related to implementing the technique, associated risks and impacts, application areas, case studies of this technique, the MiReCOL reports that deal with the technique, and finally references to information about the technique.

2.2.2 MiReCOL reports

Clicking on the second tab takes you to the “MiReCOL reports” section of the handbook. In the column on the left, you see the list of remediation categories, which split up the remediation techniques into groups. By clicking on one of these, you will see a list of MiReCOL reports at the top of the main content area. Then, you select one of those deliverables, which will then display the abstract of the report, as well as a link to download the deliverable.

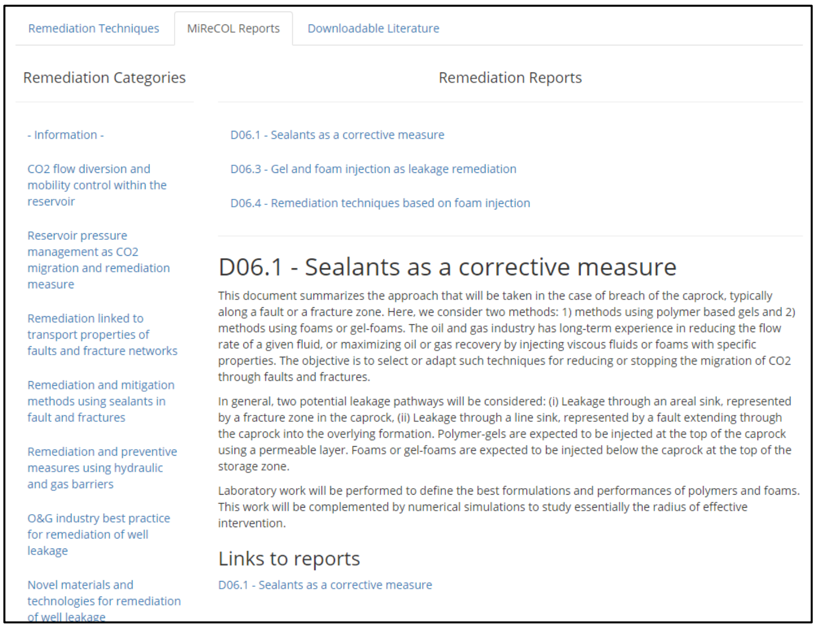

Figure 14. Screenshot of the MiReCOL Reports section of the online handbook. Remediation categories are listed on the left, and once a category is chosen, the remediation reports are shown in the middle, followed by the abstract and link to the selected report.

2.2.3 Downloadable literature

The final tab of the online handbook is a large listing of the different literature that has come out of the MiReCOL project. This information is grouped into three categories: scientific publications, conference presentations, and MiReCOL deliverables. The scientific publications are articles written during the project, while conference presentations are the slides from MiReCOL presentations. You can select each listed item to download the piece of literature.

3 TOOL DEVELOPMENT

The web tool has been developed in the latter half of the MiReCOL project. The appearance of the tool has not been changed drastically, but the inner workings of the tool has been. The website is written in JavaScript, with the front-end framework being developed using React Bootstrap and the back-end using Node.js and Express. The site uses a MySQL database to store some information displayed on the website. The three main interactive functionalities of the web tool are the technique analysis (Section 2.1.1.1), the site analysis (Section 2.1.1.2), and the well remediation (Section 2.1.2). While the technique analysis and the well remediation information is rather static (developed primarily from MiReCOL deliverables), the site analysis information is sourced from many scientists within the project. Thus, this section will focus on the development of the site analysis feature.

What the tool is founded on are the simulated results from the remediation techniques within the project. The difficult task was to translate those results into this tool, so that intensive calculations would not have to be performed within the web tool. The idea that was developed was to use a lookup of the scientists' simulations to provide the user with similar sites to his own.

3.1 Final version

The final version of the tool relies on a lookup table to present information to the web tool user. The scientists in the project were asked to make a list of the important input parameters into their simulations of their remediation technique. What was determined important were input parameters that changed the outputs when they ran simulations of their remediation technique. These are similar to the input questions in the aforementioned iteration, such as permeability or amount of CO_2 stored. The scientists themselves then selected a range of scenarios to run, by varying the different input parameters. For each of the simulations, they were asked to provide output values for the five output criteria: 1) likelihood of success, 2) spatial extent of remediation, 3) cost of remediation, 4) response time of the remediation, and 5) the longevity of the remediation. Along with these output criteria, the scientist was asked for a list of the materials required (to primarily show to the user to aid with the estimation of cost), as well as any extra comments they wanted to note about the technique.

Having this as the base of the information, the tool was then developed to read in user input about his site and compare that input to the scientists' scenarios. By comparing all the scenarios from each technique to the user's input parameters, then the closest scientist scenario for each technique could be displayed to the user to help him evaluate his own site. The manner in which the tool selects the closest scenario is via Gower's similarity coefficient (Gower, 1971), further detailed in the calculations in Section 3.2. The selected scenario for each remediation technique is then displayed on the output page after the user submits his site details.

These output criteria were then incorporated into the radar chart displayed on the output page. Each criterion is normalized on a 10-point scale so as to be able to compare the different techniques. After having these scenarios to display, an overall score and the TRL for each technique was thought to be useful. The overall score is the summation of the five output criteria normalized on a 10-point scale. Note that since low cost and fast response time are desired, these values were appropriately valued so that higher values of these would result in a lower overall score than lower values. The TRL values were estimated by scientists in the project, so that the web tool user could determine how developed the techniques are.

To touch on the remaining two aspects of the tool, the technique analysis and the well remediation are based on more static data relating to the remediation technique in general, as opposed to the scenario-based methodology of the site analysis. The technique analysis was developed having the MiReCOL deliverable dealing with the classification and ranking of the various remediation methods (Korre, 2017, link). This data could easily be displayed in graphical form, along with criteria that specify the user's preferences. The well remediation part of the web tool is based on the material from assessing the best practices from the oil and gas industry (Abdollahi et al., 2017, link). These resulted in several barriers that could fail, along with their typical remediation. The three aspects of the tool try to interactively engage the user to best describe the various techniques of remediating a CO_2 storage site.

3.2 Calculations within the tool

Despite the tool mostly displaying static information, the scenario aspect of the site analysis provides opportunity for calculations in the background of the tool. The main one is encountered after the user inputs the parameters to his site in the site analysis tool. What the tool then does is searches the scenarios simulated by the scientists to find the most similar scenario to that of the user. The tool then uses Gower's similarity coefficient to come up with a single value related to how similar the user's input is to each scientist scenario.

The way this method works is that there are two sets of data (in our case, the user's input and one scientist scenario). Then, this algorithm goes through each data entry, comparing that of the two sets of data. The way that it compares the data depends on the type of data it is. If the data point is categorical, then the algorithm compares whether the text is the same or not. If the data point is binary, then the algorithm compares whether they agree positively or not. Finally, if the data point is numerical, then the algorithm finds the relative proximity of the data points (relative to the range of the numerical data). These each generate a "score" that can then be multiplied by a weight, and summed to form the numerator of the similarity equation. The denominator is made up of the applicability of comparing the data point from the two data sets multiplied by the weight, and summing that value. The numerator is divided by the denominator to result in the overall similarity coefficient between the two data sets.

To further explain, this is the equation used to calculate Gower's similarity coefficient:

$$S_{ij} = \frac{\sum_{k=1}^{v} s_{ijk} w_k}{\sum_{k=1}^{v} \delta_{ijk} w_k} \quad [1]$$

Where S_{ij} is the total similarity between data sets *i* and *j*; *v* is the total number of data points in data sets *i* and *j*; *k* is the single data point; s_{ijk} is the "score" of data sets *i* and *j* with regard to data point *k*; w_k is the weight of data point *k*; and δ_{ijk} represents the ability to compare data point *k* between data sets *i* and *j* (this value is a 0 if they cannot be compared, and a 1 if they can be compared).

The "scores" depend on the type of data. For categorical data, the score is either a 1 if the two entries match, or a 0 if the two entries mismatch. For binary data, the "score" and the applicability are determined by the following Table 1 from Gower (1971).

Table 1. Table from Gower (1971) showing scores and applicability value used for binary data.

	Values of character *k*			
Individual *i*	+	+	-	-
j	+	-	+	-
s_{ijk}	1	0	0	0
δ_{ijk}	1	1	1	0

Lastly, for numerical data, the score is calculated using the equation

$$s_{ijk} = 1 - \frac{|x_i - x_j|}{R_k} \quad [2]$$

Where x_i and x_j are the numerical data points of data sets *i* and *j*, and R_k is the total range of the data point *k*. Thus, s_{ijk} can range between 0 and 1 for numerical data.

In this way are all the similarity values for each scenario and the user's input generated. Once that is calculated, then the scenario with the highest similarity coefficient within each remediation technique is selected to display to the user.

The next calculation are the normalized data to show on the radar chart on the output page. For each of the remediation techniques, there is one set of normalized data for each of the 5 output criteria, given by each scientist for each scenario. These normalized values are calculated by using the minimum output criteria and the range of each output criteria across all the remediation techniques. For each output criteria for each technique, a value from 0 to 1 is generated by using the following equation, and then multiplied to create a normalized value from 0 to 10.

$$x_{ij} = \frac{c_{ij} - m_i}{r_i} \quad [3]$$

Where x_{ij} is the normalized value of output criteria i for remediation technique j; c_{ij} is the value for output criteria i for remediation technique j; m_i is the minimum value for output criteria i, across all remediation techniques; and r_i is the range of output criteria i, across all remediation techniques.

The final calculation is the overall score, also shown on the output page. This score is based on the five normalized values previously calculated. These five values are summed, and then normalized to a 10-point scale (similar to the normalized calculation in equation [3]).

4 SOURCE OF INFORMATION IN THE WEB APP

The information found in the online web app is based on the MiReCOL deliverables, as well as from the scientists who participated in this project. When material outside of the deliverables was required, the scientists or experts were asked to provide additional knowledge, simulations, or text for the web app.

4.1 Tool

4.1.1 Site Remediation

4.1.1.1 Technique analysis

The data behind this section of the tool come from results from Deliverable 11.2, Report on the individual remediation techniques scoring method and classification/ranking results, as well as values from scientists within the project (Korre, 2017, link). The values for the bar graph are a result of D11.2, which was sourced from deliverables in the MiReCOL project, while the overview paragraph and TRL value estimations come from the scientists within the project, based on the EU Horizon 2020 definition of TRL (TRLs, 2014). The probability of success was found by plotting every scenario run for each remediation technique on a cumulative probability vs. percent remediation graph. Then, the probability of success displayed in the bar graph is when the percent remediation reaches a value of 20%. To provide an example, Figure 15 shows the data points from the scenarios of the brine/water injection remediation technique (Drysdale et al., 2017, link), the line where the percent remediation is at 20%, and an orthogonal line pointing at 65% cumulative remediation. The value of 35% (calculated from 100% - 65%) is then the displayed probability of success in the bar charts on the “Technique analysis” page.

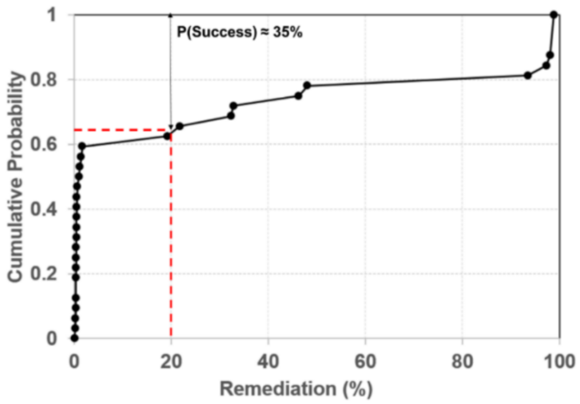

Figure 15. Example plot of cumulative probability vs. percent remediation for the remediation technique of brine/water injection, taken from MiReCOL Deliverable 11.2.

4.1.1.2 Site analysis

The site analysis is based on material requested specifically from the scientists within the MiReCOL project. The development of this aspect of the web tool was influenced by the type of scientific simulations performed for each of the techniques. The use of some of these are explained in Section 3.2, which details the calculations behind the tool.

Input variables: Initially, a list of the input variables used in the simulations was requested from each remediation technique scientist. This was not intended to include all input variables which influence the simulations, but rather the most important variables which affect the results of the simulations.

Weight of input variables: For each input variable, their estimated weight of influence was asked of the scientists, summing up to a value of 100. Thus, if an input variable #1 had little influence on the output simulations and input variable #2 had a high influence, then input variable #1 would have a low weight, while input variable #2 would have a large weight.

Range of input variables: Then, the range of these input variables used in their scientific simulations was requested, as well as logical sub-ranges which divided the ranges up into different groupings. To take the input variable of permeability as an example, the suggested range for all simulations was between 0 and 1000 mD, and the corresponding sub-ranges were 0-30 mD, 30-100 mD, 100-500 mD, and 500-1000 mD. These ranges are the selections shown on the “Site analysis” page of the web tool.

Scenarios (list of simulations run): The scientists listed the simulations they ran, which appeared as a list of the input variables they used accompanied by the values they used for each input variable. Each simulation they ran was considered a “scenario”. This resulted in a set of scenarios for each remediation technique.

Output criteria: After establishing the scenarios for each remediation technique, each scientist was asked to provide an estimation/calculation of the five output criteria used throughout this project: likelihood of success, spatial extent of remediation, cost of remediation, response time of the remediation, and the longevity of the remediation. This was asked for each scenario. Because cost heavily depends on site location and situation, they were placed in ranges, and the scientists provided a list of materials required to accompany this output criterion.

Overall score and TRL: The values for the overall score provided are calculated from the aforementioned output criteria and explained in Section 3.2. The TRLs were provided by project scientists involved in the remediation technique studies, based on the EU Horizon 2020 guidelines for TRLs (TRLs, 2014).

Other Notes and Associated Risks: These two parts were provided by the scientists performing the simulations to explain any additional meanings of the output criteria, as well as any risks that should be noted to better assess the remediation technique.

4.1.2 Well remediation

The information for the well remediation came from the deliverables in Work Package 8, O&G industry best practice for remediation of well leakage, and Work Package 9, Novel materials and technologies for remediation of well leakage. More specifically, the knowledge comes from Deliverable 8.3, Assessment of Oil & Gas Remediation Technologies for CO_2 Wells (Abdollahi et al., 2017, link), as well as analysis from the well experts involved in the project. The knowledge the experts shared was the risks associated with the remediation practices, as well as images of the various well remediation techniques.

4.2 Handbook

The first tab on the handbook page contains most of the remediation techniques covered in the MiReCOL project. The sections of text were written by the scientists in the project who performed the modelling of the techniques.

The second tab simply lists the work packages within the projects and the corresponding deliverables from each work package. The abstract shown comes from the associated deliverable.

The final tab, Downloadable Literature, comes from literature published or presented about studies in the MiReCOL project. The majority comes from the Greenhouse Gas Control Technologies, CO_2GeoNet, and the Trondheim CCS conferences.

The following two sections contain the reports and publications from the MiReCOL project that can also be found on the MiReCOL website.

4.2.1 Public reports from the MiReCOL project

- Current flow diversion techniques relevant to CO_2 leakage remediation (D3.1 – link)
- Adaption of injection strategy as flow diversion option (D3.2 – link)
- Gel and foam injection as flow diversion option in CO_2 storage (D3.3 – link)
- Brine-water injection as flow diversion option in CO_2 storage operations (D3.4 – link)
- Blocking of CO_2 movement by immobilization of CO_2 in solid reaction products (D3.5 – link)
- Reservoir pressure management (D4.1 – link)
- The impact of hysteresis effects as remediation measure (D4.2 – link)
- CO_2 back production at the Ketzin and K12-B sites (D4.3 – link)
- Brine/water withdrawal as pressure management and flow diversion option (D4.4 – link)
- Lowering reservoir pressure by accelerating convective mixing (D4.5 – link)
- Remediation linked to faults and fractures (D5.1 – link)
- The effects of stress on leakage through faults (D5.2 – link)
- Remediation of leakage by diversion to nearby compartment (D5.3 – link)
- Sealants as a corrective measure (D6.1 – link)
- Gel and foam injection as leakage remediation (D6.3 – link)
- Remediation techniques based on foam injection (D6.4 – link)
- Hydraulic and gas barriers as a corrective measure (D7.1 – link)

- Study of N_2 as a mean to improve CO_2 storage safety (D7.2 – link)
- Remediation and preventive measures using hydraulic barrier method (D7.3 – link)
- Description of leakage scenarios (D8.1 – link)
- Overview of available well leakage remediation technologies (D8.2 – link)
- Assessment of OG Remediation Technologies for CO_2 wells (D8.3 – link)
- CO_2 reactive suspensions (D9.1 – link)
- Polymer resin for squeezing (D9.5 – link)
- Novel materials and technologies for remediation of well leakage (D9.7 – link)
- Near-surface CO_2 leakage remediation methods (D10.1 – link)
- Report on individual remediation techniques (D11.2 – link)
- Methodology for the CO_2 storage remediation portfolio optimisation (D11.3 – link)
- Handbook of corrective measures (D13.1 – link)
- Web-based tool of corrective measures - summary report (D13.2, this report – link)

4.2.2 Publications from the MiReCOL Project

- Antropov, A. et al., 2017. Effect of in-situ stress alterations on flow through faults and fractures in the cap rock. *Energy Procedia, in press*.
- Batôt, G., Fleury, M. and Nabzar, L., 2016. Study of CO_2 foam performance in a CCS context. In *The 30th International Symposium of the Society of Core Analysts-Snowmass*. (link)
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- Fleury, M. et al., 2017. A silicate based process for plugging the near well bore formation. *Energy Procedia, in press*.
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5 CONCLUSION

The web app[5] is intended to cater to several stakeholders in the carbon storage field: storage operators, storage authorities and regulators, decision makers, and the public. The website is a platform to inform these stakeholders and make them aware of the practices performed and risks that are evaluated when dealing with such technologies.

The web tool portion of this website is an interactive manner in which users evaluate the different options and then make an informed decision as to what they should do in the case of unwanted CO_2 migration. This can either be performed based on a user's input site, or simply by viewing the general functionality of all the techniques. For storage operators, this is practical to know what remediation techniques are available and how far developed they are. This tool can also help operators create their contingency plan, something required before operating a CO_2 storage site, by having a single place to learn about and assess several different remediation techniques.

As for regulators, decision makers, and the public, the web tool can also aid them in knowing what actions are available to storage operators. It is possible that these stakeholders are not aware of the choices and trade-offs that an operator has to consider, so this tool also serves as a resource to inform them about various remediation techniques.

The handbook shares many of the same applications as the tool, but also offers the ability to view the journal articles, reports, and presentations conducted within the MiReCOL project. This can be useful for those who would like to go more in-depth into a remediation technique.

This web app is a contemporary way of presenting and summarizing information for a large carbon storage remediation project. This is an important step in disseminating information to stakeholders and interested parties.

[5] http://tool.mirecol-co2.eu

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