GEO ENeRGY

Enhanced Oil Recovery and CO_2 Solutions

Demand for oil is expected to grow sharply in the near future. However, the world's oil reserves are diminishing and exploration for new discoveries are becoming increasingly more difficult and costly. Therefore, we will have to make better use of our current position and resources by increasing the recovery factor from the existing oilfields. The global energy dilemma is how to meet the world's increasing energy demand while, at the same time, reducing CO_2 emissions and maintaining economic growth.

During the past 40 years nearly 1 Gt of CO_2 has been injected into geological reservoirs as part of CO_2–EOR activities, mainly concentrated in USA with about 75% of the CO_2 derived from naturally occurring CO_2 sources. Captured (anthropogenic) CO_2 contributes the remaining 25% and has historically been derived mainly from gas processing and fertiliser plants. To achieve reductions in emissions to the atmosphere, CO_2–EOR operations must use anthropogenic CO_2. Virtually all sources of CO_2 for EOR projects outside the US are anthropogenic. During CO_2–EOR operations 30-40% of the CO_2 injected will not return to the surface because it gets trapped in pore channels or stuck on mineral surfaces. This 'loss' of CO_2 to the oil production cycle is actually a form of geologic storage, as the CO_2 will be contained indefinitely within the reservoir. Melzer (2012) indicates that essentially all purchased CO_2 for a CO_2–EOR project will be securely trapped in the subsurface, with any losses very minor and mainly related to surface activities (Fig. 1, Global CCS Institute, 2013).

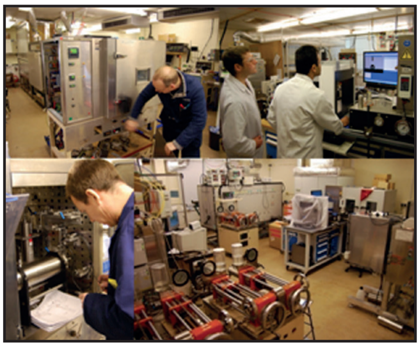

Fig.2 State of the art laboratories in the Centre for EOR and CO_2 solutions of Heriot-Watt University

At the Centre for Enhanced Oil Recovery and CO_2 Solutions of Heriot-Watt University (Fig. 2, http://www.pet.hw.ac.uk/research/hrm/team.cfm) we are using our state-of-the-art laboratories in collaboration with industry to investigate various enhanced oil recovery (EOR) techniques and also contribute expertise and techniques from subsurface oil and gas research to address a range of issues around CO_2 injection for maximising hydrocarbon recovery and geologic storage of CO_2.

A promising and cost-effective method for increasing oil recovery and storing CO_2 is carbonated (CO_2-enriched) water injection. In carbonated water injection (CWI), CO_2 is used efficiently and lower amounts of CO_2 are required compared to CO_2 flooding. Therefore, smaller sources of CO_2 that are usually available around oil and gas fields at relatively lower cost can be used for providing the required amount of CO_2. CWI also provides an opportunity for early implementation of CCS (carbon capture and storage) by addressing two most important barriers to CCS, i.e. cost of capture and safety of storage.

CO_2 foam injection is also being investigated in a joint industry project (JIP) as a method for enhancing recovery from heavy oil reservoirs while at the same time reducing carbon footprint by injecting produced CO_2 back in the reservoir. Our tests have shown that CO_2 foam injection can increase heavy oil recovery by more than double compared to conventional water injection.

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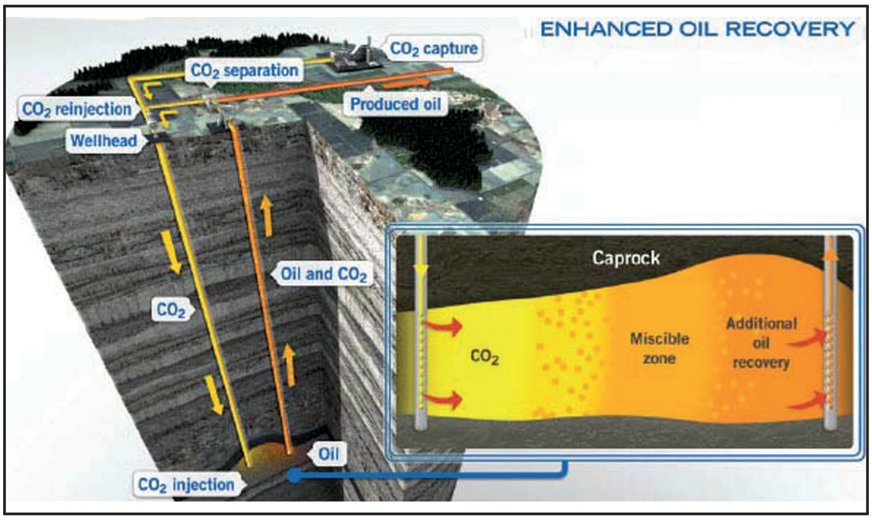

Fig.1 The CO_2 enhanced oil recovery process. Source: The Global Status of CCS: 2013. Global CCS Institute (http://www.globalccsinstitute.com/publications/global-status-ccs-2013)

CO_2-based geothermal heat mining for power production combined with CCS and EHR

Currently, one of the most technologically and economically feasible methods for large-scale reduction of anthropogenic carbon dioxide emissions involves injecting CO_2 underground into deep saline aquifers or depleted hydrocarbon fields. In the long term, the CO_2 injected during such carbon capture and storage (CCS) operations becomes sequestered through dissolution into native fluids and conversion to carbonate minerals, but it serves no purpose. In contrast, using CO_2 as an underground geothermal heat mining fluid converts this waste material and potential liability into a working fluid with which renewable electricity can be generated, simultaneously preserving water resources while still geologically sequestering 100% of the injected CO_2. This process results in a CO_2 sequestering geothermal power plant with a negative carbon footprint, a novel approach for carbon capture, utilization, and storage (CCUS) that is termed CO_2 plume geothermal (CPG) (Fig. 3).

As a consequence of the high mobility and expansivity of CO_2, compared to the water or brine used in conventional geothermal power plants, as well as the high efficiency of supercritical CO_2 power systems, CPG makes better use of geothermal resources than other technologies by a factor of two or three. Therefore, more regions worldwide could, for the first time, harness geothermal energy for electricity generation while simultaneously offsetting the high costs of CCS via renewable electricity sales. Through CO_2-based geothermal energy, carbon dioxide that is injected into the ground becomes a long-term resource for base-load and on-demand, clean power production.

However, CO_2-based geothermal systems can only operate if large amounts of CO_2 are injected into the subsurface. While a single CPG facility may require only the CO_2 produced by one year of operation of a conventional coal or natural gas power plant (i.e., one to six million tonnes of CO_2), few such CCS operations exist today. The vast majority of anthropogenic CO_2, as well as large amounts of naturally-occurring CO_2, that has been injected into permeable subsurface formations is located in hydrocarbon fields, having been injected to aid oil and gas production. CO_2 injected for enhanced oil (hydrocarbon) recovery (EOR or EHR) is continuously produced and recycled, presenting an opportunity for CPG system installation.

Heat Mining Company LLC based in Rapid City, South Dakota, USA has developed an enhanced CPG method (USA and international patents issued and pending) in order to efficiently capture the energy streams at EOR sites and convert them to electricity. EOR facilities are massive energy consumers, and for example in Texas, USA, consume more power than any other industry. Further, most of their power comes from hydrocarbon sources. Enhanced CPG is designed to harness geothermal energy, waste heat, process heat, and chemical energy that is otherwise un- or underused at EOR facilities and is estimated to produce electricity at \$0.03 to \$0.04 USA per kW-hour. Tens of thousands of megawatts of clean power could currently be installed in the US given the existing volume of CO_2 in EOR fields, and this volume is growing rapidly as additional CO_2 EOR facilities come online worldwide. As the hydrocarbon fields are depleted, the CO_2 left in the ground becomes a resource for geothermal heat extraction that will last well into the future.

CO_2-based geothermal technologies provide a method to expand the use of geothermal energy while helping reduce the cost of CCS. As such, CPG can help provide a bridge between a world with hydrocarbon-dominated electrical generation and one dominated by renewable power. At the same time, carbon dioxide-geothermal energy can help turn CO_2 from a liability into a valuable resource for our future.

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Carbon Dioxide Plume Geothermal - CPG™

University of Minnesota
Driven to Discover

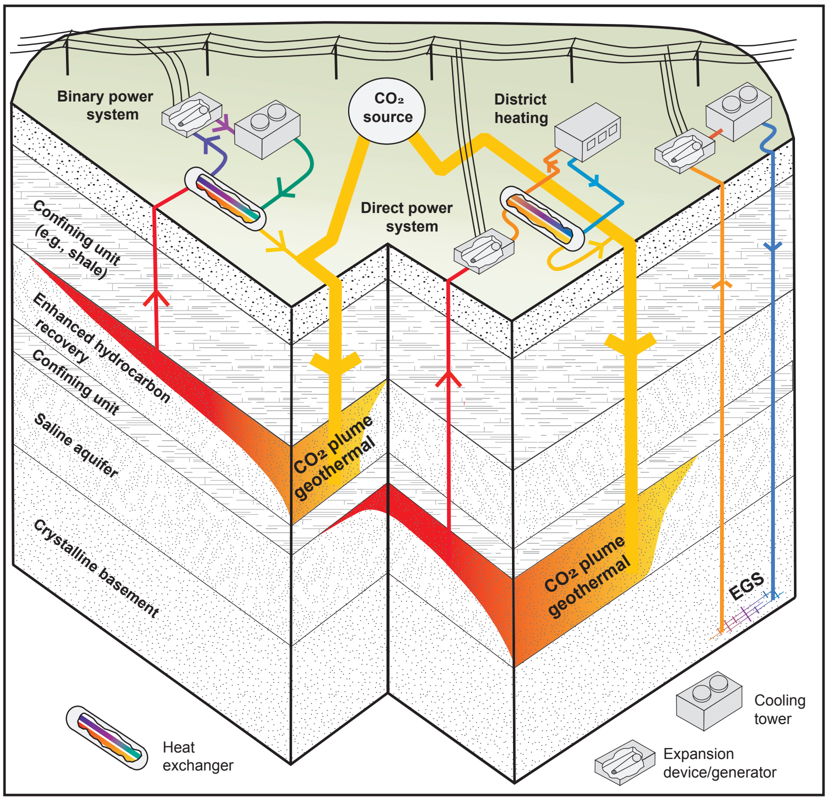

Fig.3 Potential implementations of CO_2-based geothermal systems. Pictured are simplified CO_2 plume geothermal (CPG) systems implemented in enhanced oil recovery (EOR) fields and in saline aquifers. Surface power systems include direct or binary cycles without or with waste/process heat and chemical energy capture. CO_2 sources include fossil fuel power plants and industrial facilities. Electricity generated by CPG systems could be provided to the grid as base-load or on demand power and/or used to power compressors during CO_2 sequestration or EOR, particularly in remote regions. EGS is Enhanced Geothermal System. The blue pathway is cold fluid (water or CO_2) injected into the subsurface, the orange pathway is hot fluid returned to the surface. In the binary power system, the green pathway shows cold secondary working fluid moving to the heat exchanger, where it is warmed. The deep blue pathway is hot secondary working fluid that is sent to the power conversion unit, where it is cooled to the purple pathway. The cool secondary working fluid is sent to the cooling tower, where it becomes cold. Then, the cycle repeats.

CO_2-DISSOLVED: storing industrial CO_2 emissions while producing geothermal energy for local use

The objective of the CO_2-DISSOLVED project is to assess the technical-economic feasibility of a novel CCS concept integrating geothermal energy recovery, aqueous dissolution of CO_2, and an innovative post-combustion CO_2 capture technology. The approach (Fig. 4) includes:

- CO_2 capture and separation in an innovative aqueous based technology
- Extraction of aquifer brine in a doublet designed for heat extraction via a surface heat exchanger system similar to that used in classical low energy geothermal facilities
- Re-injection of the cooled brine in the injection well of the doublet equipped with a patented novel CO_2 capture system designed to separate and dissolve the CO_2

Using dissolved CO_2 versus injection in a supercritical phase offers substantial benefits in terms of lower brine displacement risks, lower CO_2 escape risks, and the potential for more rapid mineralization. Finally, this project adds the potential for energy and/or revenue generation through geothermal heat recovery. This constitutes an interesting way of valorization of the injection operations, demonstrating that an actual synergy between CO_2 storage and geothermal activities may exist.

The major drawback of this approach lies in the quantity of CO_2 that can be injected, which is physically limited by the solubility of CO_2 in the brine. However, injection CO_2 rates of about 100 Kt/yr are a realistic target. Consequently, this project specifically targets low to medium range CO_2-emitters (ca. 10 - 100 Kt CO_2 per year), that could be compatible with a single doublet installation. Unlike the standard approach which focuses on very large regional emitters, the proposed CO_2-DISSOLVED concept opens new potential opportunities for local storage solutions dedicated to smaller emitters.

Even though the project mainly is a feasibility study using engineering methods, such as dimensioning calculations and numerical simulations, ambitious research work will be necessary as well:

- The methods for site monitoring and risk assessment must be reviewed in the light of new constraints inherent in this original approach. Innovating solutions for geochemical and geophysical monitoring will be evaluated and tested, both in the field and in the laboratory. A new methodology for risk analysis will be specifically designed and applied, in accordance with the modeled and observed properties of the system as a whole, i.e. capture, injection, CO_2 storage and heat recovery
- The brine acidified by dissolved CO_2 will be chemically reactive with the mineral phases of the aquifer as soon as it exits the injection well, contrary to the "classic" approach where the reactive acid front follows the extension of the supercritical CO_2 "bubble". Specific work will focus on the near-well area, based on new experimental and modeling approaches. An experimental laboratory installation will thus be specifically designed and used for this project
- The association of CCS with geothermal heat production, applied locally to small CO_2-emitters, makes obsolete previous conceptual economic models of CCS. New models will then have to be developed and validated. They will be fed by parameters arising from the results of the project and will be applied to two selected test-cases (one in France, one in Germany)

The expected results will permit to have at our disposal a complete portfolio of innovative technologies associated with adapted experimental, numerical, and theoretical tools, so that in case of positive conclusions on the feasibility of this concept, promising industrial pilot applications could be envisaged on the short term by the end of this 36-month project.

This project was launched in January 2013 as part of the SEED (Efficient and Decarbonized Energy Systems) program of the ANR (French National Research Agency). It is coordinated by BRGM (French Geological Survey) and the partnership is composed of four French and two foreign partners, which are respectively: CFG Services, GeoGreen, GeoRessources (Université de Lorraine), LEO (Université d'Orléans), Partnering in Innovation Inc. (USA), and BGR (German Geological Survey).

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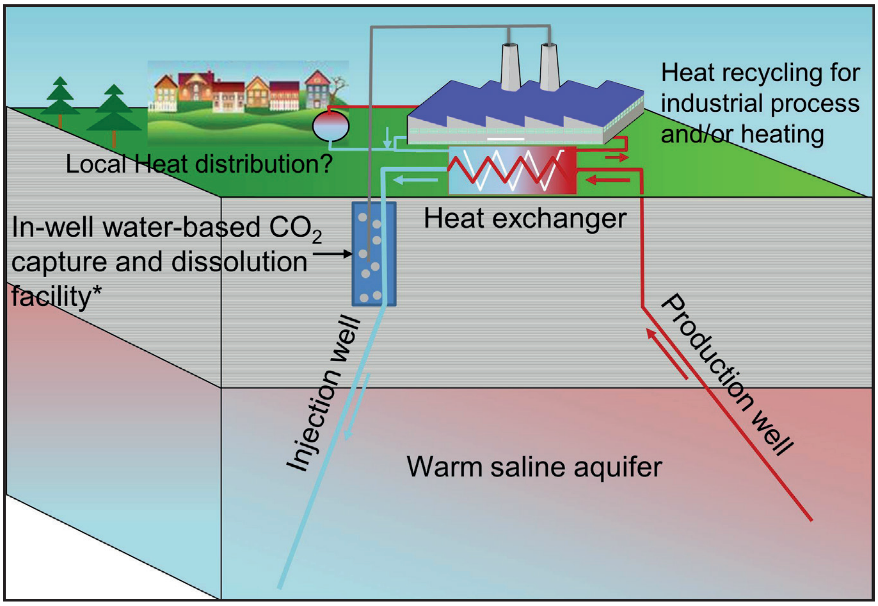

Fig.4 Principle of the coupled CO_2-storage and heat-recovery concept proposed in the CO_2-DISSOLVED Project

ENeRG – European Network for Research in Geo-Energy

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ENeRG Newsletter – GEO ENeRGY
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Utilization of slags for CO_2 mineral carbonation in Finland

Fixation of CO_2 to mineral matter offers an alternative for geological CO_2 storage. This topic has been studied in Finland for more than a decade on a laboratory scale and results have encouraged continuing development work towards piloting and demonstration. The Slag2PCC process route, developed in Finland, aims at converting calcium containing industrial by-products (with main focus on steel converter slag) into valuable precipitated calcium carbonate (PCC) product. In this method, an aqueous solution of ammonium salt is used to extract calcium from the by-product/waste material. After removal of the solid residue, CO_2 is bubbled through the solution producing stable calcium carbonate as an end product. Ammonium salt solution is recovered simultaneously and can thus be reused. In order to sequester 1 tonne (t) of CO_2 by using this concept, approximately 5 t of steel converter slag would be consumed, and 2.2 t $CaCO_3$ end product, as well as 3.8 t of residual slag, would be produced. If the produced $CaCO_3$ is used to replace conventionally manufactured PCC, then additional CO_2 emissions reductions are gained as the conventional PCC production method is very energy intensive.

The process benefits from the fact that it proceeds at room temperature and pressure, its end product is likely to have significant market value, and it does not consume significant amounts of chemicals. In addition, it uses raw material that is readily available, has a low price and requires some treatment and handling anyway. Furthermore, it is likely that flue gases could directly be used as a source of CO_2, a costly and problematic CO_2 separation step could be avoided.

The Slag2PCC concept was first developed during the Tekes (the Finnish Funding Agency for Technology and Innovation) funded project Slag2PCC_Plus (2007-2009), while current development work is mainly funded by CLEEN Oy's (Cluster for Energy and Environment) Carbon Capture and Storage (CCSP) research program (2011-2015). Since the start of the program, the concept has been taken from a two-stage batch process towards a continuously operating process that produces quite a good quality PCC and the design parameters for larger scale have been determined. A design for a pilot-scale test facility (three reactors, each of 0.25 m^3) has been completed and it is being built at Aalto University while a smaller lab-scale process unit at Åbo Akademi (reactor volumes ~25 litres) has been built for supporting the optimization work. The objective of the current development work is to move the concept further towards commercial application, aiming at processing 25 t/h (tonnes per hour) steel converter slag into 10 t/h PCC.

One of the main challenges of the concept is the quality of the end product PCC. While purity of the end product satisfies the criteria for industrial use PCC (≥ 97 % $CaCO_3$), particle sizes produced so far are too big (commercial size < 5 μm) and particle shape and crystal form are not yet fully controllable. The quality of the process residue (spent steel converter slag) is also problematic. It would be easier to find new utilization options for the spent slag, if leaching of the harmful elements could be reduced. Various process steps (such as solid/liquid separations) also present a challenge to concept development. Therefore, current research focuses on solving these issues.

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Fig.5 Photo of the pilot-scale test facility as its current state

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