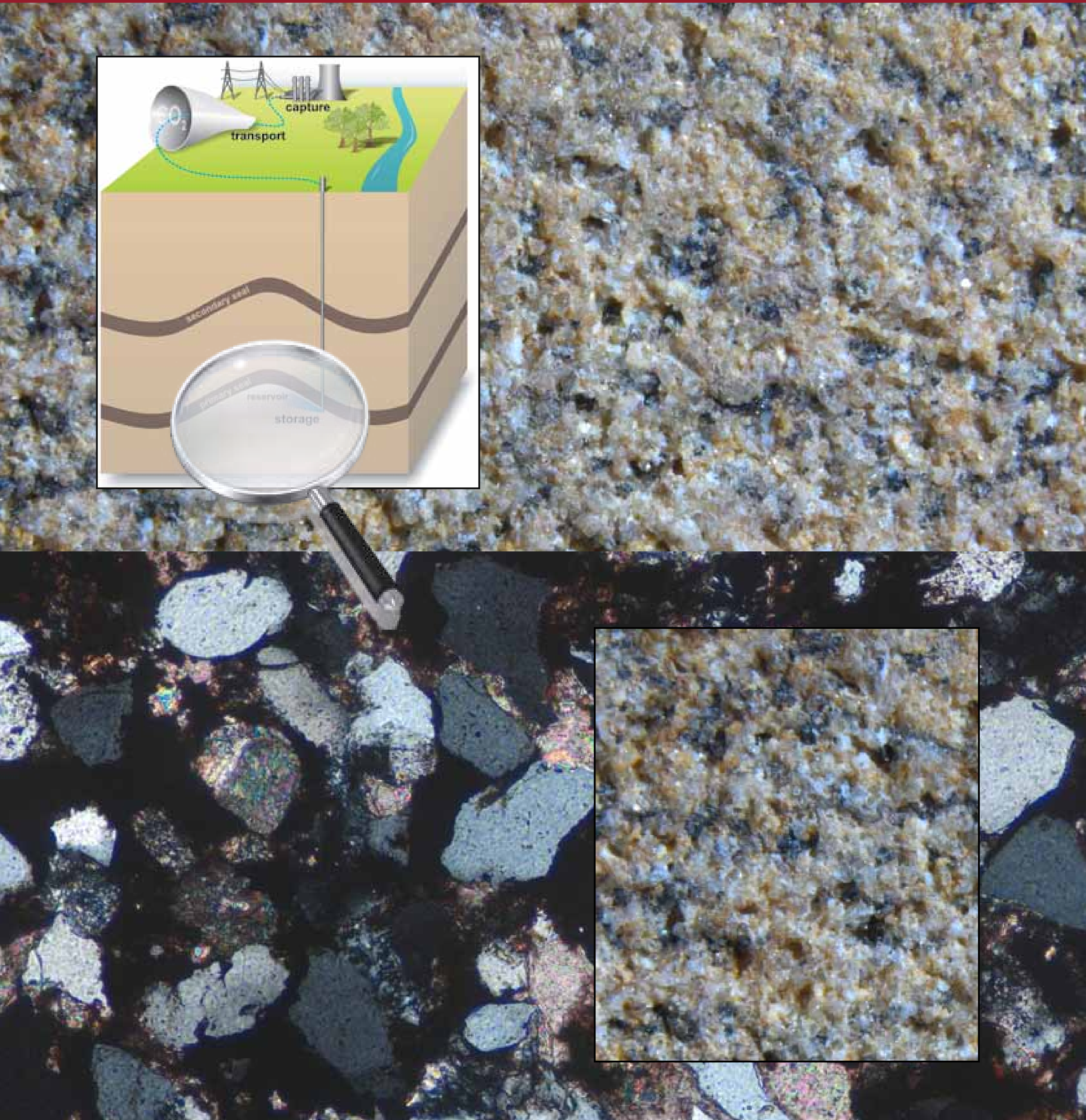
N° 33

May 2012

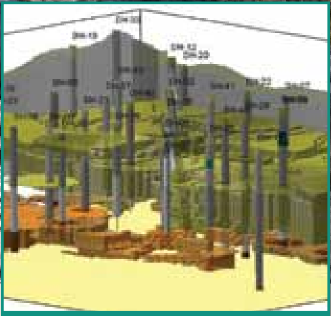
European Geologist

Journal of the European Federation of Geologists

Carbon, capture and storage - potential in Europe and barriers to take up



Not Just Software. . .RockWare.
For Over 29 Years.

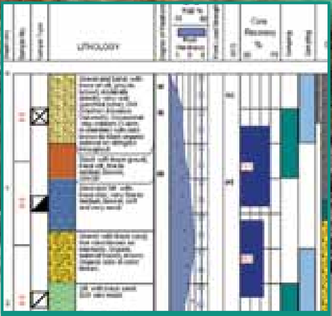


RockWorks®

3D Data Management, Analysis and Visualization

- Powerful measured-section/ borehole database for managing
  - Lithology
  - Stratigraphy
  - Hydrology
  - Hydrochemistry (e.g. Contaminants)
  - Geophysics
  - Fractures
  - and more
- Create striplogs, cross-sections, fence diagrams, and block models
- Contour data in 2D and 3D (isosurfaces)
- Extensive on-line help and sample data sets
- Includes RockWorks Utilities

$3,000

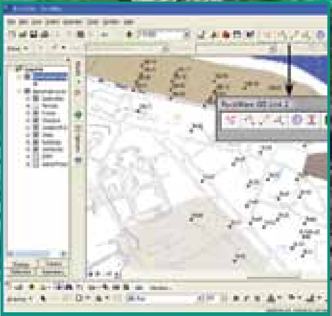


LogPlot®

Powerful, Flexible, Easy-to-Use Borehole and Well Log Software

- Dozens of templates available or design your own in the drawing-style log designer window
- Tabbed data sheets
- Import/Export data from LAS, Excel, RockWorks
- Paginated and continuous logs at any vertical scale
- Export to a variety of formats
- Free viewer can be distributed to clients

$699

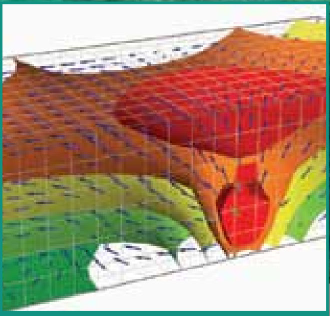


RockWare GIS Link 2™

Connecting RockWorks15 and ArcMap

- Load RockWorks well locations as an ArcMap layer
- Pick profile, section, and fence diagram locations in ArcMap, generate the diagrams automatically in RockWorks
- Create contour maps of formation tops and isopachs, surface elevation
- Generate strip logs

$349



PetraSim™

A Preprocessor and Postprocessor for TOUGH2, T2VOC, TMVOC, TOUGHREACT and TOUGH-FX/HYDRATE

- Model multi-component fluid flow, heat transfer and reactive transport processes
- Saturated and unsaturated conditions
- Fractured and porous media
- Mesh generation, parameter definition, and display of results
- Now supports TOUGH2-MP (parallel version of the TOUGH2 simulator)
- Applications include geothermal studies, carbon sequestration, contaminant transport modeling, vadose zone hydrology and more

Call for pricing

Free trials for most of our products available at www.rockware.com

Follow us on:

You Tube Blog

RockWare® Since 1983

European Sales
++41 91 967 52 53 • F: ++41 91 967 55 50
europe@rockware.com

US Sales
303.278.3534 • F: 303.278.4099
sales@rockware.com

Contents

Advertisers:
Rockware (pages 2 and 44); Golder Associates (page 8) ; Geobrugg (page 21); SLR (page 38).

Cover photo:
The schematic drawing represents the main steps of the CCS technology: capture of CO_2 from the flu gas, transport to the injection place, then injection and underground storage. In the background of the drawing, the storing sandstone reservoir rock is shown (grain size 0.5 - 1 mm). Below and behind it, the microscopic picture of the same rock can be seen. Photo by Ferenc Mádai and schematic drawing by Kris Welkenhuysen.

ISSN: 1028 - 267X

EUROPEAN GEOLOGIST

is published by the
European Federation of Geologists
C/O Service Geologique de Belgique
Rue Jenner 13
B-1000 Bruxelles, Belgium
Tel:+32 2 7887636
info.efg@eurogeologists.eu
www.eurogeologists.eu

Foreword

EurGeol. Ruth Allington, President

This issue of European Geologist includes a themed set of papers on geological aspects of carbon capture and storage. Kris Piessens, who is the co-ordinator of EFG's Panel of Experts on Geological Storage of CO_2, has provided an excellent introduction to the topic, which highlights the essential roles and responsibilities of geologists in developing and implementing this emerging technology. Kris's introduction highlights the need for deployment of a full range of professional skills in this field, including the importance of interdisciplinary collaboration and the imperative of speeding the passage of pure research into the applied arena. Achieving these things requires effective communication between specialists, between applied practitioners and researchers, and with non-specialists (particularly the public).

The professional practice requirements of CO_2 storage highlighted by Kris's introduction were all important themes highlighted and discussed in relation to a wide range of geoscientific discipline areas (minerals and mining, natural hazards, engineering, water, energy, etc.) at the 4th International Professional Geology Conference which was held in Vancouver, British Columbia in January this year: "Earth Science - Global Practice". EFG was a co-convener for 4IPGC (as well as the previous three in the series), working closely with the American Institute of Professional Geoscientists (AIPG) and the 4IPGC hosts, Geoscientists Canada (CCPG). The Australian Institute of Geology (AIG) joined the organizing group of IPGC for the first time.

EFG's next activity on the international stage will be as convener of a symposium at the 34th International Geological Congress in Brisbane, Australia in August this year: "Strengthening communication between fundamental and applied geosciences and between geoscientists and public" (Theme 36, Symposium 6). The symposium will discuss the benefits to be gained from a better understanding between geological communities. These include: incorporation of more relevant and informed education in applied geology and professional skills at university level; an improvement of industry competitiveness through more rapid conversion of research findings to applied technologies and methodologies; clear pathways and assessment criteria for geoscience graduates seeking to attain Professional Qualifications and their employers and mentors; and design of research projects and allocation of research funding based on a better appreciation of societal needs. We are again collaborating on this with CCPG, AIPG and AIG, and also the American Geological Institute (AGI) and the International Union of Geological Sciences (IUGS).

It is hoped that the establishment of an international Professional Affairs Task Group will be approved by IUGS before 34IGC, allowing for its official launch at the seminar.

Ruth E. Allington.

Introduction by the EFG Panel of Experts on the Geological Storage of CO_2:

Geologists at the centre of CCS research in Europe

Kris Piessens[*]

There are no doubt days when we feel inclined to spend a large amount of our professional time proving that geology and geologists are not just important, but actually crucial in our everyday life and economy. This is not always an easy task, and it is good to know that the European Federation of Geologists is out there backing us up. Emphasizing geology is not simply a matter of professional pride, but actually about correctly approaching subjects or projects and keeping focus on the essential aspects. CO_2 Capture and Storage (CCS) is one nice example where about two decades were needed to fully appreciate the importance of geology, and especially the impact of geological uncertainty.

The concept of CCS was first proposed in 1986 in Norway as a technological solution to reduce the emission of CO_2 from large point sources. The concept was easy: at a sufficiently large industrial source, preferably emitting in the range of millions of tonnes of CO_2 per year, CO_2 would be separated from the flue gas (or in later concepts also directly from the fuel), compressed, and then transported to a suitable location to be stored for 'eternity' in sufficiently deep and large geological reservoirs. As such, it would be possible to reduce the emission of greenhouse gases drastically, without the urge to hastily abandon the use of fossil fuels.

But as with any concept, a few blanks needed to be filled in. On the capture side, the efficiency of the capture process has been at the forefront from the beginning. This is the cost-determining part of the CCS chain, and any small improvement makes CCS more economic. It is therefore not surprising that the eyes of the industrial investors have kept turning in this direction.

Figure 1: At the Sleipner project, natural gas is produced which is too rich in CO_2 to be marketed. Therefore about 1Mt of CO_2 is removed annually. Instead of releasing this CO_2 into the atmosphere, which is the standard practice, it is injected into an aquifer above the natural gas field (Courtesy Statoil).

But they also understood that CCS was going to be a complex chain of technologies, and that any weak link could jeopardize an entire project. Rather quickly, therefore, European projects started to address a general concern: is the capacity of the geological reservoirs large enough for large-scale deployment of CCS, and are they located sufficiently close to industrialized regions? The outcome from these very first studies was very reassuring and was interpreted by the outsider as 'geological storage is not the issue'. After all, the living proof seemed to be out there, with the Sleipner project (***Fig. 1***) pumping a million tonnes of CO_2 into the subsurface each year, and glamorously passing each monitoring test. This high level of confidence reduced the attention to the geological aspects, and caused things to run less smoothly that they could have.

Looking back, there were issues that needed to be addressed urgently. One of them had to do with the nature of geological numbers, which has, in the mean time, been visualized in a comprehensible way by applying the resource pyramid to CO_2 geological storage (***Fig. 2***). This pyramid grasps a well-known geological truth: the longer you look at a resource (or reservoir), the smaller it gets. In other words, the first, often regional, estimates of potential storage capacities tend to be considerable overestimates compared to the actual capacity that can be developed in projects.

Following this logic, storage capacity numbers from initial studies were systematically revised downwards during follow-up projects. This must have surprised policy makers since 'more funding for less capacity' will not have been what they expected. Additionally, some NGOs used this trend of shrinking capacity to question the feasibility of CCS on a large scale.

Experiencing how the capacity numbers were received, or without context used to hastily draw conclusions, geologists across Europe have been emphasizing the need for a European storage atlas. In spite of numerous efforts, it has proven very difficult to put the mapping of geological reservoirs back on the European R&D agenda.

[*] Geological Survey of Belgium, Coordinator of the EFG Panel of Experts on CCS, kpiessens@naturalsciences.be

Therefore, in spite of the early start, Europe is now trailing Australia and the US who have published well-elaborated, continent-wide storage atlases.

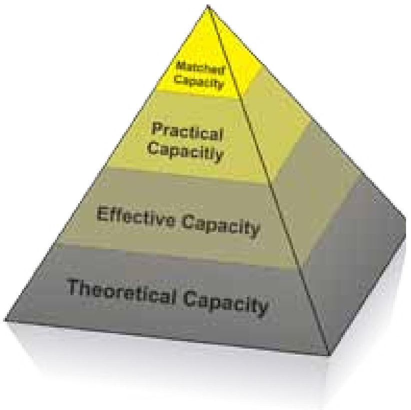


Figure 2: Initial estimates of reservoir capacities are by definition almost always over estimates. Theoretical capacities are regional estimates based on typical parameters of reservoirs rocks (permeability, thickness, etc.), while additional factors, which require more detailed knowledge, usually further restrict these initial numbers (e.g. structural traps, storage efficiency…) until at the level of practical capacity the true number is reached. Matched capacity further takes into account the transport and capture aspects (e.g. the proximity of sources) (After Bachu et al., 2007).

A second issue is that utility companies and industry are not used to dealing with geological uncertainty. It is indeed fundamental to see the difference with financial uncertainties, security of supply, performance issues, etc. All of these can usually be resolved by waiting, taking a strategic action, or investing in development. Geological uncertainty is different in two ways: it can only be resolved by exploration and it is site-specific (exploration elsewhere will not resolve your problem).

During the planning of a CCS project, from a geologist's point of view it is prudent to verify early on if the targeted geological reservoir is reliable and sufficiently large. However, from the perspective of the project planners it is sensible to first worry about the economics (costs) of a project, and then deal with the practical and planning issues, such as geology. Someone familiar with geological uncertainty knows that this is a huge risk, especially if you realize that the time line for geological exploration easily expands to more than five years before conclusive results can be presented, and should not overlap with the construction of a major coal-fired power plant which takes around seven years. Fortunately, this now seems to be better understood, and demonstration projects, which need to be realized in a limited timeframe rely on proven reservoirs that were for other reasons already well explored. However, when further developing CCS, the lack of regional or targeted exploration may become a crucial bottleneck.

A final issue is that of public perception of CCS. Right from the beginning it was realized that the concept and necessity of CCS would need to be explained to the wider public. Most CCS researchers expected that first of all the lack of sustainability would need to be justified, because CCS is a technology that can prolong the use of fossil fuels. Explaining that CCS is needed, in addition to the portfolio of renewable energy, energy efficiency and consumer behaviour, is indeed challenging and of relevance at the level of policy makers. The public however has proven to be much more sensitive to the 'fear of the unknown': geological storage.

As geologists it is important to continuously remind ourselves how abstract the deep subsurface is to almost everyone else. Personally, I always keep a core of reservoir and one of a cap rock (***Fig. 3***) at hand during interviews to throw a casual question like 'a reservoir, you do know what I'm talking about?' at the journalist. Time and time again you can watch his or her expression change from a self-confident 'I've done my bit of background reading', to a highly confused 'and the CO_2 goes where?' when being confronted with a slab of Bunter sandstone.Taking into account that a science journalist is usually well informed, it will come as no surprise that the average man in the street has no clue as to what underground storage of CO_2 encompasses. He will therefore be easily scared by vague or incorrect facts. This unfortunately seems to be well understood by the opponents of CCS, because most public campaigns against CCS are based on raising fear of the unknown.

In summary, CCS is certainly a topic with many different aspects. As geologists, we should trust the engineers with optimizing the capture side to shrink the costly head of CCS. Danger however lies in the uncertain tail, and the geological uncertainties should be properly addressed in CCS projects. On a national or basin scale it is important to address the potential overestimation of the storage capacity, and ensure that for each project exploration is quickly initiated since the go/no-go decision will depend on the availability of storage. Equally challenging is to weigh up the communication strategy which, especially for onshore storage, will inevitably need to deal with the 'dangers' of geological storage.

But the bottom line is that geology has proven to be of crucial importance for CCS, and that is a source of joy for our professional hearts.

Figure 3: The result of a small test with water as an analogue to the behaviour of CO_2 at large depths. Water infiltrates rapidly into the porous sandstone (reservoir) on the left, but not into the impermeable siltstone on the right (reservoir seal).

The European Federation of Geologists, engaged with the responsible use of natural resources, as well as environmental protection and sustainability, aims to promote geological activity in this area.

Reference

Bachu, S., Bonijoly, D., Bradshaw, J., Burruss, R., Holloway, S., Christensen, N.P., Maathiassen, O.M. 2007. CO_2 storage capacity estimation: methodology and gaps. Int. J. *Greenhouse Gas Control 1 (4)*, 430–443.

The cost of CO_2 geological storage is more than a number

Kris Welkenhuysen[*]

CO_2 geological storage is the last stage in the CO_2 capture and storage process which aims to reduce CO_2 emissions into the atmosphere. The cost of storage has frequently been regarded as minor compared to the cost of the whole CCS process. There is, however, a multitude of cost parameters that will form a unique combination for each storage project, with costs projected from one to several tens of Euros per tonne of CO_2 stored. Several research efforts have recently been trying to identify the main cost drivers and relatively wide cost ranges. Reservoir type and location, geological uncertainty, injectivity and capacity are recognized as the main sources of cost variation between potential storage projects.

Le stockage géologique du CO_2 représente la dernière étape du processus de capture et d'emmagasinage du CO_2 dont le but est la réduction des émissions de CO_2 dans l'atmosphère. Le coût de stockage a souvent été considéré comme mineur en comparaison de celui de l'ensemble des opérations de capture et de stockage. Cependant, le coût global dépend d'une quantité de paramètres qui constituent une palette unique pour chaque projet de stockage, le prix pouvant varier entre un et dix euros par tonne de CO_2 emmagasiné. Plusieurs essais de recherche ont récemment essayé d'identifier les vecteurs principaux conditionnant le coût et cela dans un domaine de prix relativement étendu. Le type de réservoir et sa situation, l'alea concernant le contexte géologique, les conditions d'injection et les possibilités de stockage sont reconnus comme les causes principales de variation des prix entre différents projets d'emmagasinage potentiel.

El almacenamiento geológico de CO_2 es la última etapa del proceso de captura y almacenamiento de CO_2, cuyo objetivo es reducir las emisiones de CO_2 a la atmósfera. El coste del almacenamiento se ha considerado frecuentemente como un coste menor en comparación con el coste total del proceso. Sin embargo hay multitud de parámetros del coste que constituyen una combinación única para cada proyecto de almacenamiento, con costes estimados que varían entre uno y carios cientos de euros por tonelada de CO_2 almacenada. Recientemente se han realizadodiversas investigaciones para intentar identificar los principales responsables dedichos costes y sus relativamente ampliosrangos de variación. El tipo de almacén y su ubicación, la incertidumbre geológica, las condiciones de inyecicón y su capacidad se consideran las principales razones de las variaciones del coste entre diferentes proyectos de almacenamiento.

Storage costs in the CO_2 capture and storage chain.

Global climate is influenced by the anthropogenic emission of large quantities of greenhouse gasses, including carbon dioxide (CO_2), into the atmosphere. CO_2 capture and geological storage (CCS) is, amongst others, a possible option to achieve deep emission reductions and can be applied to large industrial CO_2 sources. It is a succession of processes in which CO_2 is captured, purified if necessary, compressed and transported to a suitable injection location where it is stored safely and permanently in a geological reservoir (IPCC, 2005; ***Fig. 1***). Possible reservoirs include depleted oil and gas fields, deep saline aquifers and coal sequences (Holloway, 2005). CCS is currently in a transition between pilot and demonstration phase, with a commercial deployment projected around 2020.

In the CCS chain, capture is generally regarded as the most expensive part, while transport and storage are relatively cheaper. Storage costs include exploration, monitoring, well drilling and several other parameters that will be highlighted later. The European Technology Platform for Zero Emission Fossil Fuel Power Plants has recently published a series of reports on the costs of CCS (ZEP, 2011). Herein, average storage costs are estimated to be 2 to 15% of the total cost of electricity production (LCOE, levelized cost of electricity), depending on the production technology. The average storage cost is indeed expected to be only a minor part of the total cost of CCS. It forms, however, an important part because it includes a large up-front investment, from the planning phase on. The cost of the storage part is generally expressed in euro per tonne of CO_2 captured and stored. ZEP (2011) gives a range of 1 to 20 €/t CO_2 for storage; the earlier assessment by McKinsey (2008) provides a range of 4 to 12 €/t CO_2. Geo-techno-economic simulations for Belgium have provided a range of 2 to 18€/t CO_2 (Welkenhuysen *et al.*, *in prep.*). These cost ranges give a first indication of the case-specific costs and uncertainty ranges of CO_2 storage. For specific cases, costs can be even higher than the upper values stated here. Vidas *et al.* (2009) calculated storage costs of up to 80 \$/t CO_2 for saline aquifers. Although a cost reduction of the entire CCS process is needed and expected, no significant reduction is expected for the storage part, mainly because of the experience from the oil and gas industry.

When making cost calculations for CCS, an average cost figure for storage is often used. However, the cost ranges from the reports cited above, already indicate that each potential reservoir is unique and storage costs depend heavily on the geological environment. An overview is given hereafter of the relevant cost factors. Those introducing the largest variations in cost are discussed in more detail. The uniqueness of each storage possibility provides a distinctive cost pattern for each project. This paper is a summary of the most important cost drivers, since it is impossible here to cover all of the factors.

---

[*] Geological Survey of Belgium,
Jennerstraat 13, 1000 Brussels, Belgium,
kris.welkenhuysen@naturalsciences.be

Analysis of the cost factors

The geological storage of CO_2 can be subdivided into three phases: pre-injection, injection and post-closure. In the pre-injection phase a potential reservoir must first be identified and characterized through geological exploration. After identification, an in-depth exploration and monitoring plan is conducted. This exploration typically consists of several exploration wells and a 3D seismic survey. Data is gathered to ensure reservoir quality and containment, and to create a pre-injection reference state, so as to be able to track the injected CO_2 over time with subsequent monitoring. The exploration wells can be reused as monitoring wells if the situation permits.

For the operational phase, one or more injection wells are drilled and equipped for injection of CO_2. The storage operation itself consists of compression and pumping and in some cases heating of the CO_2 to bring the CO_2 to reservoir conditions. During injection, several monitoring techniques have to be used to keep track of the injected CO_2 plume and make it possible to remediate the CO_2 in case any leakage from the reservoir occurs. The chosen set of monitoring techniques is site-specific and is partially imposed by law (EC, 2011). The most common techniques are pressure, temperature and CO_2 monitoring in the injection wells, aquifer monitoring in the monitoring wells, 3D seismic studies at certain time intervals and surface CO_2 detection using a number of techniques. Other possible monitoring techniques include well logging, 2D seismics, CO_2 flux measurements, surface deformation, micro-seismicity and surface water monitoring.

When injection is finished, the injection wells are plugged, and monitoring is continued. The guidance documents to the EU CCS directive (Directive, 2009/31/EC) demand at least 20 years of monitoring before liability of the storage site is transferred to the authorities. McKinsey (2008) suggests a post-closure period of 50 years before liability transfer. Before starting injection operations, sufficient financial provisions are required by the EU Directive to account for leakage risks. In the post-closure phase, before the liability transfer, the EU directive also demands a financial contribution to continue 30 years of monitoring to ensure permanent and safe storage. The total of these liability funds will be a function of the amount of CO_2 stored.

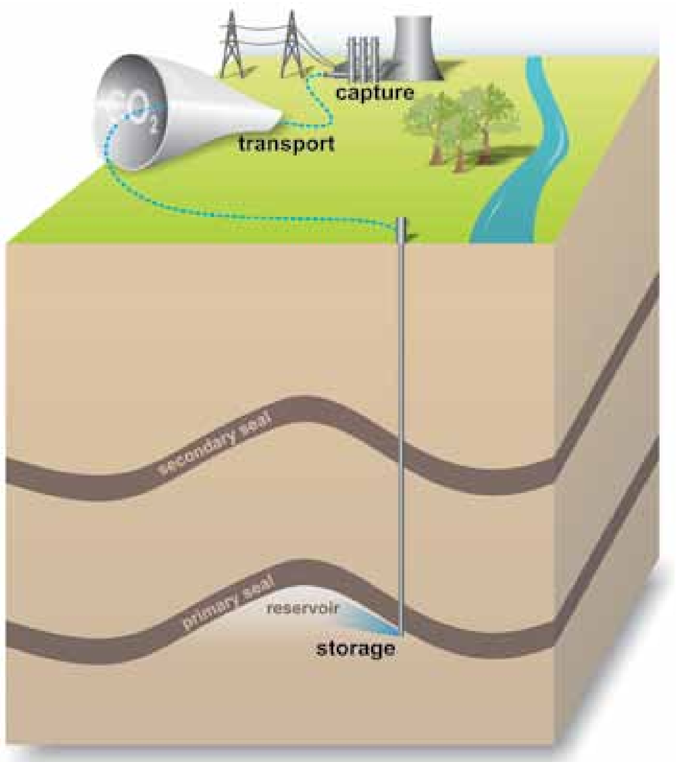


Figure 1: Simplified illustration of a CCS project. CO_2 is captured at an industrial installation, transported via ship or pipeline, and injected into suitable reservoir rock. Multiple sealing formations help to prevent CO_2 from migrating out of the reservoir.

The most expensive individual cost factors in the storage operation are the 3D seismic monitoring, at around 25,000 €/km², injection and monitoring well drilling and completions at several millions of Euros per well (depending on depth, lithology and location), and post-closure well plugging at about 15% of the well construction costs (ZEP, 2011).

Reservoir type driving storage costs

The reservoir type and location introduce a very large cost variation. Geology is unique to each location, and each storage project will need a customized solution. An initial distinction of reservoirs can be made between storage onshore or offshore. Most offshore operations, such as injection, drilling and monitoring, are more expensive, due to the demanding environment. This results in a cost range difference of about a factor of 2 between on- and offshore (***Fig. 2***).

Major cost differences also occur between depleted hydrocarbon fields and saline aquifers. Deep saline aquifers contain salty water that is of no commercial interest. These potential reservoirs are therefore less explored. Depleted hydrocarbon fields are generally well explored, and have a proven capacity and containment. This greatly reduces exploration and monitoring costs. Furthermore, these reservoirs might have reusable infrastructure, wells or platforms. On the other hand, saline aquifers generally have a larger capacity which reduces costs by the effect of scale, while depleted hydrocarbon fields generally have a limited capacity. The cost of storage in coal is highly variable due to the very site-specific requirements for ensuring sufficient injectivity, and potential methane production through ECBM operations. Coal layer thickness, permeability, sequence build-up and fracturing are just some of the factors influencing storage operations. Vidas *et al.* (2009) estimate coal storage costs to be at the higher end (about 7 \$/t CO_2 for the United States), though revenues from methane production can keep costs low. There is, however, an important difference in permeability between the average American and European coal: injectivity in European coal is expected to be much lower, which will increase costs per tonne of CO_2.

The volume affected by the injection of CO_2, the storage complex, is in most cases far greater than the volume where CO_2 is

Figure 2: Storage cost ranges for different reservoir types. Offshore storage is up to twice as expensive compared to onshore. The use of existing wells and equipment (legacy wells) for depleted hydrocarbon fields can reduce costs by a few € per tonne. Storage in aquifers on the other hand is more costly because less is known about these reservoirs. This is most apparent for offshore storage (ZEP, 2011).

actually stored. Added pressure, for example from CO_2 injection, will propagate through the storage complex farther than the CO_2 itself. The EU Directive therefore demands not only characterization and monitoring of the storage site, but of the whole storage complex. This difference between injected volume of CO_2 and the area of the storage complex is unique to each reservoir and can be very large. Large aquifers and the pressure increase therein can extend for hundreds of km, while storage in a closed sandstone body will hardly influence the surrounding formations.

The role of geological uncertainty

Uncertainties are inherently connected to geology, simply because it is practically impossible to characterize the whole subsurface. Exploration can greatly reduce this uncertainty, but it will always exist. This uncertainty will also result in the fact that not all reservoirs on which exploration has started will be fit for storage. Even for projects where injection has started there might at some stage in their lifetime appear an unforeseen reduction in injectivity. This will increase the investment risk and the cost per tonne of CO_2 that is eventually stored in other reservoirs. In poorly explored areas, geological uncertainties are large. As mentioned before, this causes an important difference in storage cost between depleted hydrocarbon fields and the less known aquifers (***Fig. 2***). Generally, the characterization of large unknown structures will pose a higher cost than better-known, local storage options, because of the need for more exploration.

The storage cost calculations by ZEP (2011) result in a cost range of up to a factor of 10 per reservoir type, originating mainly from geological uncertainty (***Fig. 2***). Decreasing this uncertainty is essential to increase the rate of exploration success and reduce costs. Keating *et al.* (2011) found that geological uncertainty significantly influences CCS infrastructure in general. Results for Belgium also indicate that geological uncertainty has a significant impact on storage costs, reservoir choice and the overall economic deployment of CCS (Piessens *et al.*, in press; Welkenhuysen, *in prep.*).

Injectivity and pressure management

It is important for a CCS project to have a match between the CO_2 production and the injection rate, or injectivity, into the subsurface. This injectivity has a substantial influence on the total storage cost and specific cost per tonne of CO_2 stored. Closely related to the injection rate is pressure management, which is essential when injecting CO_2 into an underground reservoir. If the reservoir pressure exceeds the host rock's strength, the reservoir and possibly its sealing cap rock will fracture and CO_2 might leak out of the reservoir. Moreover, pressure is not equally divided throughout the reservoir during injection. As with hydrocarbon or water production wells, a pressure cone is created when injecting CO_2 into a reservoir, and pressure decreases with increasing distance from the injection well.

The first and most evident factor influencing injectivity and pressure is reservoir rock permeability. A highly permeable reservoir rock will in general provide high injectivity and a fast pressure propagation throughout the storage complex. The boundary conditions of the reservoir also influence the pressure build-up of injection. A closed structure will, for example, have a lower injectivity than a comparable open reservoir where pressure can disperse through a large storage complex.

There are a number of possible techniques to manage injectivity and pressure build-up in the reservoir. An obvious method is using multiple injection wells. Pressure increase is spread more evenly and injectivity can be multiplied by the number of wells. Formation water production from the reservoir is an option to lower reservoir pressure and allow a greater injec-

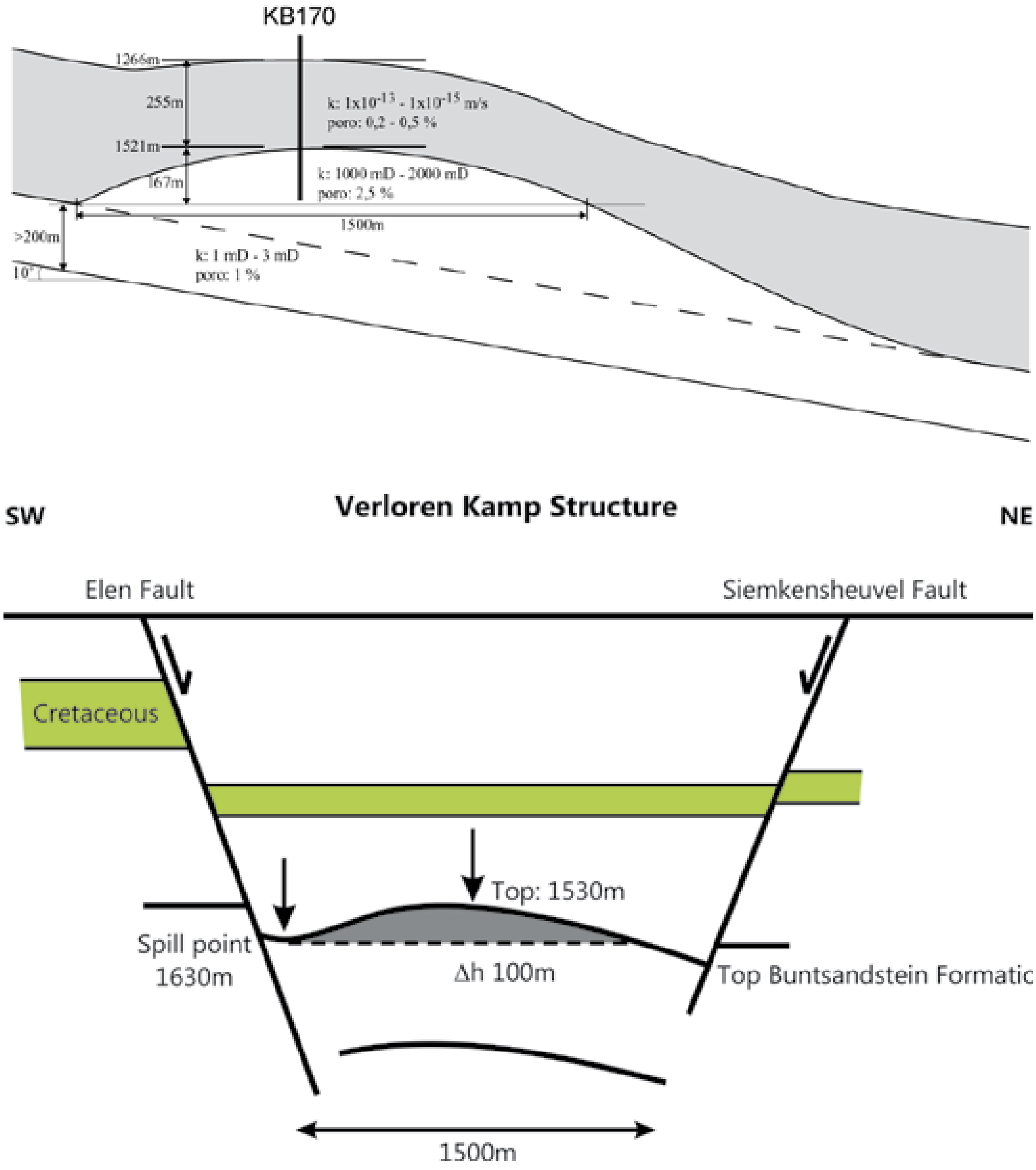


Figure 3: The effect of scale on monitoring costs, illustrated by two potential Belgian reservoirs, the 3 Mt Poederlee dome structure (a) and the 20 Mt Verloren Kamp structure (b) (figures are not to scale). Monitoring costs are projected to be 13 M€ and 25 M€ respectively, or 4.3 €/t CO_2 and 1.25 €/t CO_2 (Piessens et al.*, in press; Van Tongeren, 2004).*

tivity using a push-pull configuration. It is also possible to fracture part if the reservoir hydraulically, increasing permeability. This technique should however be used with caution as there is a risk of fracturing the reservoir seal as well. All techniques pose significant extra costs and it is therefore essential to perform a detailed reservoir characterization to select the most suitable reservoir and avoid unpleasant surprises during injection.

Monitoring cost and the effect of scale

Monitoring is mostly regarded as a marginal cost factor compared to the cost of the whole CCS sequence, often well below 1 €/t CO_2 (e.g. Benson *et al.*, 2005).For large projects injecting millions of tonnes per year over several tens of years, this is likely to be true. It is however very scale dependent, since monitoring costs do not increase linearly with injected amounts of CO_2.

A calculated example of two potential Belgian storage structures, the Carboniferous Poederlee dome structure and the Verloren Kamp structure in the Triassic Buntsandstein Formation, provides insight (Piessens *et al.*, in press; ***Fig. 3***). Both structures are comparable in surface area. Their different geological configuration causes the Verloren Kamp structure to be able to store about 20 Mt, while only 3 Mt of storage capacity is expected to be available in the Poederlee structure. Monitoring operations for a storage project in the Poederlee dome would amount to almost 13 M€ in total, or 4.3€/t CO_2. A comparable storage project in the larger Verloren Kamp structure would provide a monitoring cost of 25 M€, or only 1.25 €/t CO_2. This effect becomes even larger when working with very low injectivities, e.g. for coal CO_2 storage, which results in monitoring costs of up to several tens of € per tonne of CO_2 stored. This also illustrates the need for proper geological exploration and modelling to ensure sufficient injectivity over the whole injection phase.

Conclusions

When analysing the cost factors it becomes clear that the cost of storage cannot be summarized in one number. Overall storage costs can range from 1 to several tens of euros per tonne of CO_2 captured and stored. The reservoir type, geological uncertainty, injectivity and capacity are the main cost drivers for storage. The most important cost factors are injection and monitoring well construction and 3D seismic monitoring. The effect of scale and the extent of the storage complex are important with regard to monitoring costs; for small projects monitoring might become a main expense, while a large storage complex will pose higher costs than a small storage project.

Each storage project will have a unique combination of cost factors and will need an individual geo-economic analysis to accurately assess total storage costs.

References

Benson, S.M., Hoversten, M., Gasperikova, E., Haines, M. 2005. Monitoring protocols and life-cycle costs for geological storage of carbon dioxide. In: Rubin, E.S., Keith, D.W., Gilboy, C.F. (Eds.), Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies (GHGT-7), Vancouver, Canada, 2, 1259-1265.

EC. 2011. Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide. Guidance Document 2: Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures. ISBN-13 978-92-79-19834-2. http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/docs/gd2_en.pdf

Directive.2009/31/EC. On the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF

Holloway, S. 2005. Underground sequestration of carbon dioxide: a viable greenhouse gas mitigation option. *Energy*, 30, 2318-2333.

IPCC. 2005. IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change (Metz, B., Davidson, O., de Coninck, H.C., Loos, M. & Meyer, L.A. (Eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442pp.

Keating, G.N., Middleton, R.S., Viswanathan, H.S., Stauffer, P.H.,Pawar, R.J. 2011.How Storage Uncertainty Will Drive CCS Infrastructure. Energy Procedia, 4, 2393-2400.

McKinsey & Company. 2008. Carbon Capture & Storage: Assessing the Economics. 49pp.

Piessens, K., Welkenhuysen, K., Laenen, B., Ferket, H., Nijs, W., Duerinck, J., Cochez, E., Mathieu, Ph., Valentiny, D., Baele, J.-M., Dupont, N., Hendriks, Ch. In press. Policy Support System for Carbon Capture and Storage (phase 2) and collaboration between Belgium-The Netherlands (PSS-CCS II &BeNe), Final Report. Research Programme Science for a Sustainable Development, Belgian Science Policy Office, Brussels.

Van Tongeren, P., Laenen, B., Weyten, H. 2004. Geotechnische en financiële aspecten van ondergrondse CO_2-opslag in Vlaanderen. VITO Rapport 2004/MAT/R/036, Limited distribution.

Vidas, H., Hugman, R., Clapp, C. 2009. Analysis of geologic sequestration costs for the United States and implications for climate change mitigation. *Energy Procedia*, 1, 4281-4288.

Welkenhuysen *et al.* In prep. Strategy for ranking potential CO_2 storage reservoirs: a case study for Belgium.

ZEP. 2011. The Cost of CO_2 Capture, Transport and Storage. European Technology Platform for Zero Emission Fossil Fuel Power Plants, 51pp. http://www.zeroemissionsplatform.eu/downloads/811.html

Public perceptions of Carbon Capture & Storage

Nick Riley[*]

"At the start of the 21st century, humankind finds itself on a non-sustainable course that, unless changed, will lead to catastrophes of awesome consequences. At the same time we are unlocking formidable new capabilities that could lead to much more exciting lives and glorious civilisations."
James Martin

It's around midnight. I have just gone to bed when I am rudely awakened by my mobile phone. My press officer is on the line, her anxiety tangible as she speaks; "Nick, take a look at this press website. It is going to really damage Carbon Capture & Storage!". I log on, bleary-eyed, to see the headline in bold "Lethal gas may have to be stored under English villages says government advisor". My brain wakes up and my heart sinks. My trust in a journalist and his newspaper had been betrayed. The day before, I had been a panel member at a press seminar in London attended by journalists from around the world. It was the UK's turn to host an intergovernmental initiative on Carbon Capture & Storage (CCS). My role on the panel was to answer technical questions from the world press about underground CO_2 storage. I had emphasized in my short presentation, as well as in response to questions from that particular journalist, that the UK had very limited onshore CO_2 storage opportunities geologically. I also emphasized that UK policy is for its CCS demonstration projects to store CO_2 offshore, deep beneath the sea bed, within the geology associated with the UK's oil and gas fields. Clearly this journalist had an agenda, which had little to do with reporting a truthful account and accurately informing his readership. Was he just against CCS, or fossil fuels generally? Or was he a climate change "sceptic"? Perhaps he was just trying to get his traditional readers' attention by sensationalizing and playing on their fears and anxieties (an Englishman's home, especially a leafy, rural one under perceived threat, is his castle!)? Whatever his motive, as Sir Winston Churchill once said "a lie gets half way around the world before the truth has a chance to get its pants on". That is "terabytes" more true in the internet age.

The psychologist Daniel Arily in his book "Predictably Irrational" points out that our attitudes to new concepts, ideas and information are conditioned by our previous experiences, values and memories. Campaigners, advertisers and propagandists are very clever at feeding and manipulating our conditioning, so that we are more likely to make the choice they wish us to make. This technique has been deployed to great effect by the climate change sceptic lobby (for an excellent analysis see Nerlich, 2010). As you read my article, your views on it will be, to some extent, pre-conditioned by your life experiences and how you perceive the world. The public perception of CSS is particularly vulnerable here. After you read the following words; "black, green, sunshine, dirty, waves, clean, wind, air, smoke, sticky, lungs, free, renew, finite, war, smell, trust, disaster, natural" which of those words stand out to you when I introduce the terms "fossil" and then "renewable"? Fossil fuels have a very long history, stretching back hundreds of years from the start of the industrial revolution and hence have lots of negative "baggage". Renewable technologies at industrial scale have had less time than fossil fuels to demonstrate that they too can have major negative impacts. Those who wish to lobby against new fossil fuel technologies, such as CCS, can easily harness and reinforce the negative by deploying words like "toxic" and "lethal", and present the public, press and policymakers with images of bombs, gas masks and skulls. That really is "visceral" communication! The choice to some appears clear: "fossil is bad, dirty, running out, obsolete; renewable is clean, good, everlasting and the future". If only it were

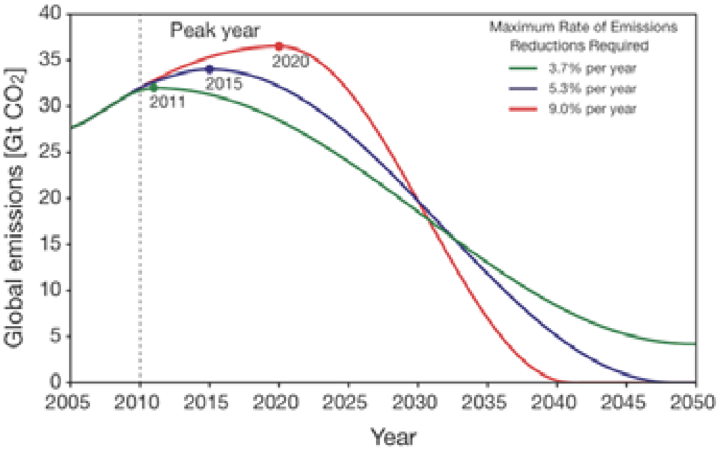


Figure 1: Emission pathways to give a 75% chance of stabilizing average global temperature no more than 2°C above pre-industrial level. Three scenarios are given: achieving peak emissions by 2011 requires a global emission reduction of 3.7% per annum, whereas if global emissions peak at 2015, or 2020, emissions need to reduce by 5.3% and 9% respectively. The later the peak the steeper the annual emission reduction required! The more restrictive the deployment of low carbon technologies is the more difficult it will be to reduce emissions. Unfortunately (as of 2011) global emissions are still rising at an accelerating rate (5% per annum). (Source - Copenhagen Diagnosis 2009 www.copenhagendiagnosis.com)

[*] British Geological Survey, Keyworth,
Nottingham NG12 5AH, UK,
njr@bgs.ac.uk

true in the year 2050 time-frame within which we have to reduce CO_2 emissions!

This polarity of views and values is destructive. Renewable and clean fossil energy technologies need each other. They are inseparable if we are to deal with reducing greenhouse gas emissions at the rate and scale required. It is not a case of "either/or". Much of the renewable energy infrastructure that we need to build on a vast scale requires, cement, concrete, steel, other metals and materials. All this infrastructure requires fossil-based energy to construct, repair and maintain it. Steel and cement production also has an added CO_2 emission factor derived from the limestone used and burnt. Renewable generated electricity, because of its intermittency and seasonality also requires back-up from fossil fuels. It is going to take a long time to get through the transition beyond fossil! We don't have that time if CO_2 emission reduction is the primary goal. Fossil fuels are also fundamental in fertilizer manufacture. So even if we could eliminate fossil from our energy and construction sectors, with a world population already locked in to reach over 9bn by mid-century, fossil CO_2 emissions associated with food production are here to stay beyond 2050. We need to deploy CCS as soon as possible. Reducing CO_2 emissions is the priority, fossil fuels are the problem and the world is failing to curb emissions (***Fig. 1***).

Fossil fuels are not running out, but time is. Carbon capture & storage is the only direct way to significantly decarbonize fossil fuels. Coupled with renewables, e.g. biomass co-firing, CCS can even result in negative emissions. Together, CCS and renewables are a "least regret" strategy. Whilst fossil fuels are available, deciding that renewable energy generation is the only low carbon trajectory will not guarantee that the fossil fuels are displaced. York (2012) in his analysis of the deployment of renewable energy over the last 50 years in relation to displacing fossil fuels, noted that it is a common public and policy view that 1 unit of fossil energy is replaced by 1 unit of renewable energy. However, he found "that the average pattern across most nations of the world over the past fifty years is one where each unit of total national energy use from non-fossil-fuel sources displaced less than one quarter of a unit of fossil-fuel energy use and, focusing specifically on electricity, each unit of electricity generated by non-fossil-fuel sources displaced less than one-tenth of a unit of fossil-fuel-generated electricity".

So what about the terms "toxic", "lethal" and images of skulls used by some anti CCS lobbyists to oppose underground storage of CO_2? Well, if CO_2 was toxic you would never have a fizzy drink? If there was no CO_2 in the atmosphere, your body would not be able to regulate your breathing. Nor would plants thrive. Is CO_2 lethal? Well, yes, it can be, but so can water. So the term "lethal" has to be placed in context. Indeed, regarding safety legislation for transporting CO_2, it is classed as a "hazardous gas".

I am often asked "is it safe to store CO_2 underground?". Compared to how we already use the subsurface for natural gas storage and distribution, it is safe. Many of us pipe methane (natural gas) into our homes through underground pipes. Europe is criss-crossed by an underground grid of natural gas pipes at high pressure, many converging on cities. Huge volumes of natural gas, under pressure, are stored in geological structures across Europe, some near to and under large conurbations like Berlin and Paris. Arguably, underground natural gas storage poses more risks than storing CO_2. For instance natural gas can burn, or explode (whereas CO_2 is used to fight fire). Underground natural gas storage has been managed exceptionally well in Europe for decades (which is why you may not be aware of it). So in the big picture it is fair to say that underground CO_2 storage is at least as safe as underground natural gas storage, which we already accept (and take for granted) in our daily lives. Any way, if you want to begin to learn more about underground CO_2 storage, a good start is CO2GeoNet's publication "What does CO_2 Geological storage really mean" (published in over 23 languages).

Because we are all predictably irrational (yes, even geologists!), an important factor in minimizing our human weakness here is to work from the evidence base. To get to the evidence base we need to ask the right questions. This is at the heart of scientific endeavour, discovery and communication. Indeed, an evidence-based approach is essential if society is to recognize and follow the path that could lead to much more "exciting lives and glorious civilizations".

References

Arily D. 2008. Predictably Irrational: The Hidden Forces That Shape Our Decisions. Harper Colins, ISBN9780061353239.

CO2GeoNet. What does CO2 geological storage really mean? http://www.co2geonet.com/ a mirror site is also available at http://www.cgseurope.net/

Nerlich, B. 2010 "Climategate": Paradoxical Metaphors and Political Paralysis. Environmental Values, 19 (2010), 419-442.

York, R. 2012. Do alternative energy sources displace fossil fuels? Nature Climate Change, 1451.

IT issues of CO_2 gas storage monitoring systems

Károly Jónap and József Subert[*]

Keywords: CO_2 monitoring, field communication, wellsite instrumentation

Introduction

In 1998, the newly implemented carbon dioxide (CO_2) Enhanced Oil Recovery (EOR) process and the associated gas flaring raised serious concern in the surrounding population about oil and gas technologies at Nagylengyel in the Transdanubian region of Hungary. For this reason engineers decided to develop safety monitoring systems for CO_2 storage at the same time as the first Carbon Capture and Storage (CCS) technology planning. Because of the bad experience, the public are fearful of the increasing number of carbon dioxide production processes and development of domestic CO_2 storage in Hungary.

An adequate monitoring system designed for CO_2 storage should cover several related fields and many measurement tasks from underground water monitoring to seismic indication and visualization.

Staff at the University of Miskolc Research Institute of Applied Earth Sciences (UM RIAES), Department of Instrument Development and Information Technology have many decades of experience in oil and gas instrumentation systems and related IT equipment operation, so we would like to be involved more and more in the tasks of developing CO_2 storage and monitoring systems in the future.

In this article we present the basics of gas storage instrumentation and monitoring, based onconventional wellsite instrumentation, and display options of data transmission, data storage and visualization andwe present our proposals for solutions to problems in these fields.

Reasons for monitoring

Oil and gas technologies (including mining, processing and distribution) should meet three very important requirements: protect the public, protect the environment, ensure protection of expensive technology and equipment, as well as error-free operation. Modern process control systems can provide these services, but given the fact that gas production is usually on a very large scale, safe operation requires task-specific instrumentation. This is particularly true in the case of CO_2 storage.

The fundamental purpose of geological storage of CO_2-monitoring is to isolate stored CO_2 from the atmosphere, freshwaters, groundwaters and the environment as much as possible.

Due to the monitoring, i.e., making continuous measurements of parameters, the measured data storage, the long-term data archiving and related analyzes, the supervisory staff can take their measurements for CO_2 storage based on objective data.

Among the reasons for monitoring the operation, security and financial conditions are the most important, and these include the following tasks:

- Monitoring of the injection process and control of safety conditions, and related effective documentation. This requires monitoring the conditions of the well borehole, the measurement of injection rates, wellhead and formation pressure monitoring. Experience shows that the cause of material leakage in the wells is directly related to the poorly developed mantle and packer or the problems with the cement.
- Control of the amount of injected gas. (This process can generate further controlling tasks).
- Optimizing the efficiency of storage, including storage size, the injection pressure and decision-making mechanism of new drillings for injection wells.
- Ensuring that the CO_2 remains within the configurations used by appropriate technologies. At present, predictions for the performance of the technology seem to be verified.
- Implentation of the required mitigation measures as soon as possible upon detection of leakage or puncture.
- In addition to the essential monitoring strategy, other parameters must be considered in the optimization of storage projects. These may be leakage, regulatory, legal and other social issues.

There are other important monitoring aims. These include assessment of the integrity of the producing and abandoned wells, calibration and confirmation of benchmarking models (including historical data comparisons), assessing the site defaults and the CO_2-induced changes in mapping of the storage, exploring microseismic events, CO_2 leakage detection on the surface, planning and control of the remediation.

The storage of CO_2 involves very extensive monitoring systems, so the Schlumberger defined parameters, such as groundwater monitoring, well head monitoring, high resolution time-lapse seismic imaging and data acquisition management, well

---

[*] József Subert, University of Miskolc, Research Institute of Applied Earth Sciences, jonap@afki.hu

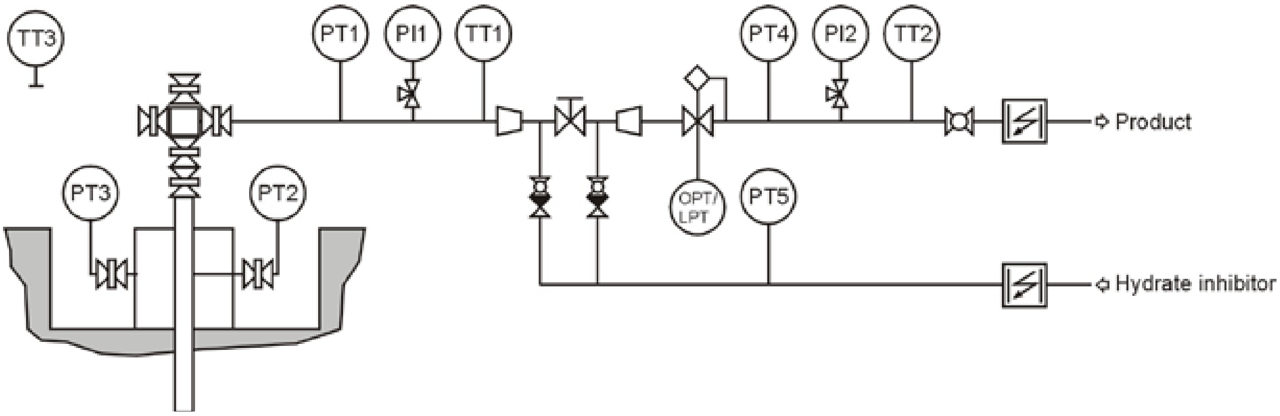


Figure 1: Primer instrumentation of the gas wellhead.

integrity monitoring, leakage detection by Eddy Correlation tower on the surface, accumulation chambers, measurement of microstrip electromagnetic well, seismic monitoring of the downhole, advanced services, hole logging and passive seismic monitoring will, together, build up the required monitoring system.

Before we start to plan the monitoring system, it is useful to review the injection technology because this will basically determine the instrumentation and communication tasks.

The injection technology

The first step, and the most dominant task, in the process of storing CO_2 is high pressure injection. There are a number of known and proven technologies for the underground storage of large amounts of CO_2. Closure of the injection wells and drilling technology have reached high quality technical standards in the oil and gas industry. This means that we are capable of drilling vertical and horizontal wells in addition to opening up deeper layers. The current state of technology in the transport of corrosive materials does not constitute a barrier. Injection techniques are acceptable from the oil and gas industry for the current CO_2 storage projects, with small changes in the technology.

The structure of CO_2 injection wells is very similar to wells in oil fields and gas storage projects. There are two differences between them: most of the drill hole mount must be scaled to higher pressure values and the materials used must have a higher corrosion resistance. CO_2 management processes have already been developed by methods for EOR and for acid gas disposal projects. One useful option for increasing the capacity of a simple CO_2 well is to transform the well into horizontal or extended access. The Weyburn field in Canada is a good example to review this action because the horizontal transformation increased the oil yield and CO_2 storage capacity. The horizontal injection technology will reduce capital costs by reducing the number of wells required. Another advantage of using this horizontal injection structure is that we can create several different injection profiles that will reduce the primary negative flow effects of the injected gas in the permeability zones.

An injection well design and installation of the wellhead and instrumentation is shown in ***Fig 1***. Injection wells are generally controlled by two valves, a general purpose valve and another reserved for security purposes. A safety valve is placed into the acidic gases injection wells borehole, which will automatically close and prevent back flow when a valve fails on the surface. Jarrell, in his publication in 2002, suggests that an automatic shut-off valve should be installed into all CO_2 wells, in order to prevent unintentional back flow of the CO_2 injection system and accidental leakage. A typical drill hole configuration contains a packer, one on-off valve and the shut-off for all events.

The annular pressure monitoring arrangement will help to detect leakage of the packer and tubing connections, which is important for the rapid implementation of security measures. In case of leakage, the injection should be stopped to prevent the release of CO_2 into the atmosphere and dangerously rising high pressure in the formation of surface pipe systems. Applying breaking safety valves and other breaking components can prevent the pressure increasing to dangerous levels. Proper planning is required for treatment of excess CO_2, in case of a failure in the injection process. Options include a one-function safety injection well design or the release of CO_2 into the atmosphere.

To prevent CO_2 leakage and well failures, proper maintenance is required for injection wells. A number of practical procedures are used to reduce the possibilities of CO_2 eruption (uncontrolled flow), possible crises, and to counteract negative effects of accidents. These include regular surveys of the integrity of injection well boreholes, increased outbreak prevention maintenance (BOP), additional BOP for the suspect wells, supplying staff with regular information, emergency planning and emergency response training.

Wellsite test instrumentation

The optimized primer instrumentation and the communication station operate in the well site and transmit all needed values of the measured process variables to the process control system at the upper control level in the control hierarchy. These are e.g., injected CO_2 consistency, process pressure, temperature, injected volume. The operating characteristics of a CO_2 injection project require the drilling of observer wells, which are responsible for monitoring only.

This is particularly common in Hungary.

Surveying the cementation and the condition of the borehole liner can be supported by permanently installed probes which monitor the well-spring quality. The well depth conditions - pressure, temperature - can be monitored by the primary measuring assembly, which can be completed by installation of additional instrumentation (temperature and pressure transmitters).

The small, mobile monitoring unit developed by staff at UM RIAES is easy to carry to the given wellsite or region and easy to install, complying with the measurement requirements.

With this system we can measure the process parameters directly on the wellhead assembly of the gas well, the casing and ventilation pipe pressure of the borehole. Furthermore, we measure the temperature of the pipeline and wellhead, pipeline and wellsite.

The well capacity, which is one of the most important features of the wells, can be inferred continuously by current values of measured process variables. A classic wellsite instrumentation is shown in ***Fig 1***.

Measured current values of process variables (PV.CV):

- Analog input parameters

1. Wellhead pressure (PI1, PT1)
2. Wellhead temperature (TT1)
3. Liner pressure (PT2)
4. Ventilation pipe pressure (PT3)
5. Pipeline pressure (PI2, PT4)
6. Pipeline temperature (TT2)
7. Wellsite temperature (TT3)
8. Inhibitor pressure (PT5)

- Discrete input parameters

1. Shut-off valve open
2. Shut-off valve closed

- Discrete output parameters

1. Close the shut-off valve

Communication

We recommend a Programmable Logic Controller (PLC) with some analog and discrete I/O ports, high quality GSM/GPRS modem and low power consumption for the data acquisition and transmission unit of the wellsite instrumentation. The scale of measurement does not require more. The operation temperature range of the PLC is particularly important but the other features, e.g., I/O channel number, communication interface, programming, etc. are not so critical. An optimal solution for these applications isequipment with a small number of composite (4 or 8 AI, 2 or 4 DI) channels and modular I/O interface structure used to carry out related functions.

We can formulate the most important key parameters of the monitoring system as follows:

- The unit has a sufficient number of AI and DI channels
- Event-driven mode of operation
- GSM / GPRS data traffic by high quality modem unit
- The device is able to operate in sleep mode with reduced power consumption in order to save power
- The instrument has a battery powered supply
- The device can operate error-free in the normal ambient temperature range
- The manufacturer of the programmable device is suitable for effective software support
- The device must have the appropriate application reference.

Wireless communication

The industrial monitoring systems with wireless communication operate with sta-

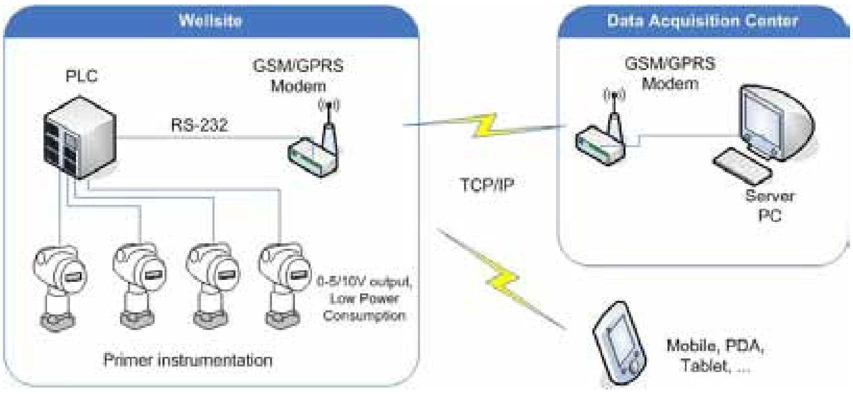


Figure 2: Wellsite surveillance system – test version.

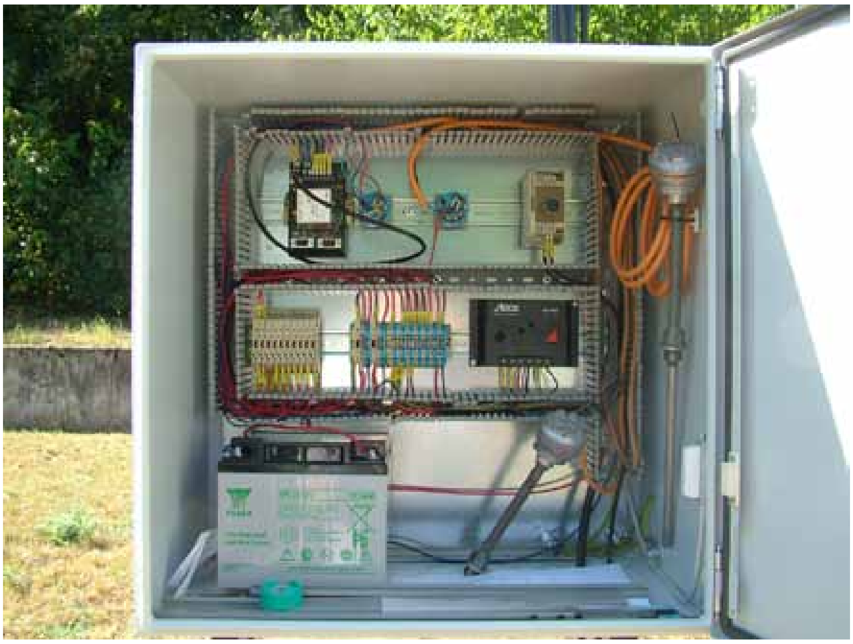


Figure 3: Mobile GSM/GPRS communication tester equipment.

Figure 4: Solar battery-powered mobile communication unit on the wellsite.

tionary objects with no electric power, so several solar cells were used in this project as a power supply for the well-site surveillance equipment, placed sensors, data acquisition and control systems.

During the first tests the PLC was mounted in an explosion-proof box (Ex d). The analog input terminal of the PLC has two temperature transmitters which connect to the PT100 temperature sensor, a few simulation devices simulating the pressure signals, and an intrusion detection tool. The terrain modelling system is shown in ***Fig 2 and 3***.

Field testing of communication

During the field test mode the PLC unit was mounted in an industrial metal cabinet in the area selected by MOL Plc. as shown in ***Fig 4***. Field strength values of the three domestic telecommunication suppliers (Vodafone, T-Mobile, Telenor) were determined in order to choose the strongest signal provider for the given industrial area. The unit is battery powered, backed up with two solar cells. The original proposed solution was modelled.

In addition, the wellsite process parameters (pressure, temperature), the field strength and the conditions of the communication link are tested and measured and the collected data is transmitted into the communication database and stored on the data acquisition server station. This application has two basic software components, one operating on the PLC as a remote field application and the other as the server application. The field strength and temperature data from the field measuring units are transmitted via GPRS line into the phpMyAdmin database and are accessible via the private web interface application. The field strength values are between 0 and 30, the latter indicating the best signal strength.

Actual data is stored with device (location) ID and corresponding time stamp supplied by the field signal strength meter units, as shown in ***Fig 5***.

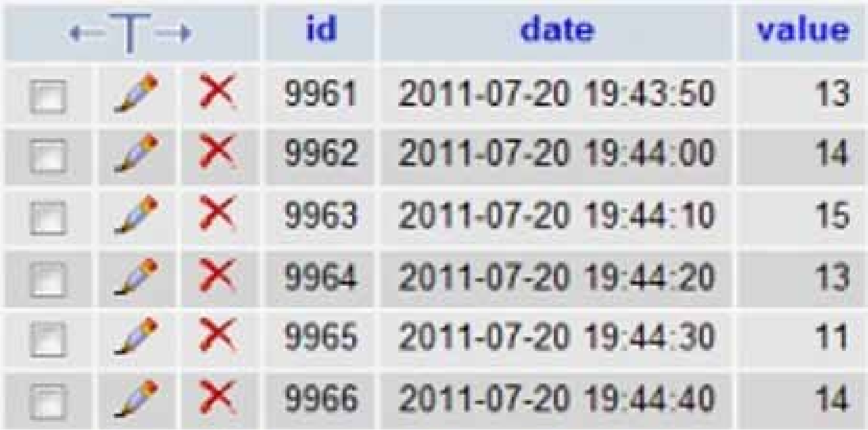
In this project, a non public application and visualization was built to provide all related information about the given wellsites for any location by internet connection or GPRS communication. The tables and charts have restricted access. Since this is an R & D project, only pre-defined users can access the site, registration from outside is not enabled.

Summary

During the project significant experience has been accumulated in safe and secure GPRS communication. Field tests provide valuable results in both fields of industrial communication and island-mode operating surveillance systems.

Acknowledgement

The described work was carried out as part of the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, co-financed by the European Social Fund.



←T→			id	date	value
☐	✎	✕	9961	2011-07-20 19:43:50	13
☐	✎	✕	9962	2011-07-20 19:44:00	14
☐	✎	✕	9963	2011-07-20 19:44:10	15
☐	✎	✕	9964	2011-07-20 19:44:20	13
☐	✎	✕	9965	2011-07-20 19:44:30	11
☐	✎	✕	9966	2011-07-20 19:44:40	14

Figure 5: Results of the wellsite communication and field strength test.

References

Lafortune, S., Pokryszka, Z., Bentivegna, G., Chaduteau, C., Agrinier, P. 2011. First steps in coupling continuous carbon isotopic measurements with already proven subsurface gas monitoring methods above underground carbon dioxide storage sites. *Energy Procedia 4*, , 3526–3533, Elsevier Ltd.

De Donato, P., Pironon, J., Sterpenich, J., Laurent, A., Piedevache, M., Pokryszka, Z., Quisel, N., Barrés, O., Thomas, S., Rampnoux, N. 2011. CO_2 Flow baseline: key factors of the geochemical monitoring program of future CO_2 storage at Claye-Souilly (Paris basin). *Energy Procedia 4*, , 5438–5446. Elsevier Ltd.

Vandeweijer, V., van der Meer, B., Hofstee, C., Mulders, F., D'Hoore, D., Graven, H. 2011. Monitoring the CO_2 injection site: K12-B. *Energy Procedia 4*, , 5471–5478 Elsevier Ltd.

Jones, D. G., Barlow, T., Beaubien, S. E., Ciotoli G., Lister, T. R., Lombardi, S., May, F., Möller, I., Pearce, J. M., Shaw, R. A. 2009. New and established techniques for surface gas monitoring at onshore CO_2 storage sites. *Energy Procedia 1*, 2127–2134 Elsevier Ltd.

Lafortune, S., Moreira, M., Agrinier, P., Bonneville, A., Schneider, H., Catalette, H. 2009. Noble gases as tools for subsurface monitoring of CO_2 leakage. *Energy Procedia 1*, 2185–2192 Elsevier Ltd.

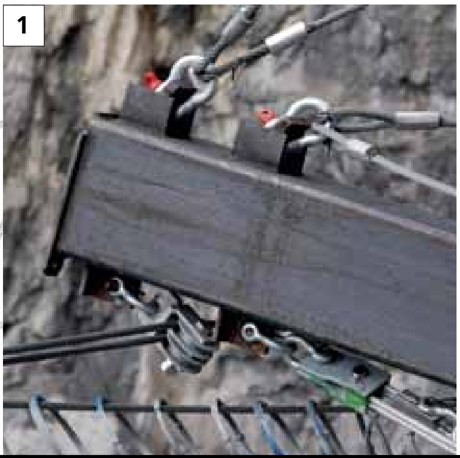
Picard, G., Bérard, T., Chabora, E., Marsteller, S., Greenberg, S., Finleyc, R.J., Rinck, U., Greenaway, R., Champagnon, C., Davard, J. 2011. Real-time monitoring of CO_2 storage sites: application to Illinois Basin–Decatur Project. *Energy Procedia 4*, 5594–5598 Elsevier Ltd.

Lescanne, M., Hy-Billiot, J., Aimarda, N., Prinet, C. 2011. The site monitoring of the Lacq industrial CCS reference project. *Energy Procedia 4*,3518–3525 Elsevier Ltd.

Fabriol, H., Becquey, M., Huguet, F., Lescanne, M., Pironon J. Pokryzska, Z., Vu-Hoang, D. 2009. Results of investigations to design a monitoring program for a CO_2 storage project in the Paris Basin (France). *Energy Procedia 1*, 2285-2291 Elsevier Ltd.

1. Support and transmission ropes are running virtually friction-free on running wheels
2. 20 metric tons impact into the barrier
3. Impact with 8,000 kJ successfully stopped

1



2

World record: 20 metric tons 103 km/h impact stopped!

3

The new GBE-8000A rockfall barrier set this world record at the Walenstadt vertical test facility 10.10.2011. Test results according to the ETAG 027 guidelines:

- 8,000 kJ impact energy
- 8.5 meter barrier deflection
- 85% residual barrier height

The GBE-8000A protects from large blocks producing high kinetic energies, where retention dams are not possible and exceeds the absorption capacity of most concrete galleries.

Scan or watch our movie on
www.geobrugg.com/GBE-8000A

GEOBRUGG®
BRUGG

Geobrugg AG
Geohazard Solutions
CH-8590 Romanshorn • Switzerland
Phone +41 71 466 81 55
Fax +41 71 466 81 50
www.geobrugg.com
info@geobrugg.com

The CO_2 natural analogues and the storage potential in Greece

*N. Koukouzas**, *V. Gemeni and A. Aggelopoulos*

A preliminary assessment regarding the potential of long-term storage of carbon dioxide (CO_2) in Greece showed that there are suitable Tertiary sedimentary basins in northern, western and eastern Greece. Those include the Prinos oil field and saline aquifer, the Mesohellenic Trough as well as the saline aquifers in the Thessaloniki basin. The potential storage sites need to be properly characterized. The natural CO_2 field in Florina could help towards a better understanding of the fate of the stored CO_2. Studies are in progress to evaluate the behaviour of the gas.

Une évaluation préliminaire en ce qui concerne le potentiel de stockage à long terme des émissions de CO_2 en Grèce a montré qu'il y a des bassins sédimentaires tertiaires appropriés dans le Nord, l'Ouest et l'Est de la Grèce. Ceux-ci incluent le champ pétrolifère de Prinos et l'aquifère salin, la Fosse mesohellénique ainsi que les aquifères salins du bassin de Thessalonique. Les sites de stockage potentiels doivent être correctement caractérisés. Afin de mieux comprendre le sort des émissions de CO_2 stockées, le domaine naturel du CO_2 à Florina aiderait dans cette direction. Des études sont en cours pour évaluer le comportement du gaz.

Una evaluación preliminar sobre el potencial de almacenamiento a largo plazo de las emisiones de CO_2 en Grecia ha demostrado que existen cuencas sedimentarias de Terciario en el norte, oeste y este de Grecia. Entre ellos se incluyen el campo de petróleo y el acuífero salino en Prinos, la depresión de Mesohellenic así como los acuíferos salinos en la cuenca de Salónica. Los lugares de almacenamiento potenciales necesitan ser adecuadamente caracterizado. Para entender mejor el destino de todo el CO_2 almacenado, el campo natural de CO_2 en Florina ayudaría en esa dirección. Se están realizando estudios para evaluar el comportamiento del gas.

The development of CO_2 capture and storage (CCS) technologies is considered to be a potential option in the portfolio of required measures to stabilize atmospheric greenhouse gas concentrations. Other options include energy efficiency improvements, the switch to less carbon-intensive fuels, renewable energy sources, enhancement of biological sinks, and reduction of non-CO_2 greenhouse gas emissions (IPCC, 2005).

Significant mitigation of climate change effects caused by greenhouse gas emissions is possible by geological storage of CO_2 captured at large stationary point sources (primarily coal and hydrocarbon power plants). The reliability of storage capacity estimates depends on the level of research undertaken.

In recent years, there has been gradually increasing interest in research focusing on CO_2 sequestration as part of climate mitigation approaches. Research has shown that it has potential to be a safe and effective way to rapidly decrease short-term anthropogenic CO_2 emissions. In parallel, the natural analogues studies have also received a growing interest as they can provide useful information that should be kept in mind when performing CO_2 sequestration.

Greece is committed under the European Community Burden-Sharing agreement, to limit its greenhouse gas emissions (GHG) (Hellenic Ministry for the Environment, Physical Planning and Public Works, 2004). Taking into account the expected increase in electricity demand and the continued high fossil fuel dependency of the Greek power sector (increased power generation capacity of some 9.6 GW in the period 1995–2020 will be mainly in new natural gas combined cycle power plants), the potential for CCS opportunities within Greece should be investigated as a way of mitigating the greenhouse gases, in line with other options.

Identifying the CO_2 storage potential in Greece

Carbon dioxide capture and geological storage has the potential to make a large reduction in the CO_2 emissions from power plants in Greece. The strong seismicity and the associated high heat flow anomalies in the tectonic framework of Greece indicate the need for detailed site characterization of any prospective CO_2 storage site (Kaldi and Gibson-Poole, 2008).

The aquifer potential of the Prinos and Thessaloniki Basins, falling into the theoretical category of the Techno-Economic Resource-Reserve Pyramid for CO_2 Storage Capacity (Bachu *et al.*, 2007; CSLF Task Force, 2007), produces a figure of 1990 Mt total CO_2 storage capacity based on structural traps with well-defined spill points (GESTCO, 2004). It is important to note that the CO_2 storage capacity of saline water-bearing reservoir rocks (saline aquifers) in Greece is overestimated because in reality CO_2 density will be much lower than 750 kg/m^3, as assumed in the GESTCO (2004) Project. It is believed to be around the 400–500 kg/m^3 range, due to high geothermal gradient and temperature values at storage depths of the specific basins (Bachu, 2003). Thus, a more realistic preliminary estimate would be of the order of 1100–1300 Mt.

Based on currently available information, the following outcome can be derived from the above Basin-Scale Assessment (Bachu *et al.*, 2007; CSLF Task Force, 2007) of prospective sedimentary successions in Greece (***Fig. 1***):

- The tectonically stable offshore Prinos Basin has favourable characteristics for CO_2 geological storage as well as sufficient storage potential to take in the total amount of CO_2 produced by

* Nikolaos Koukouzas, Director of Research
Centre for Research and Technology Hellas, Greece, koukouzas@certh.gr

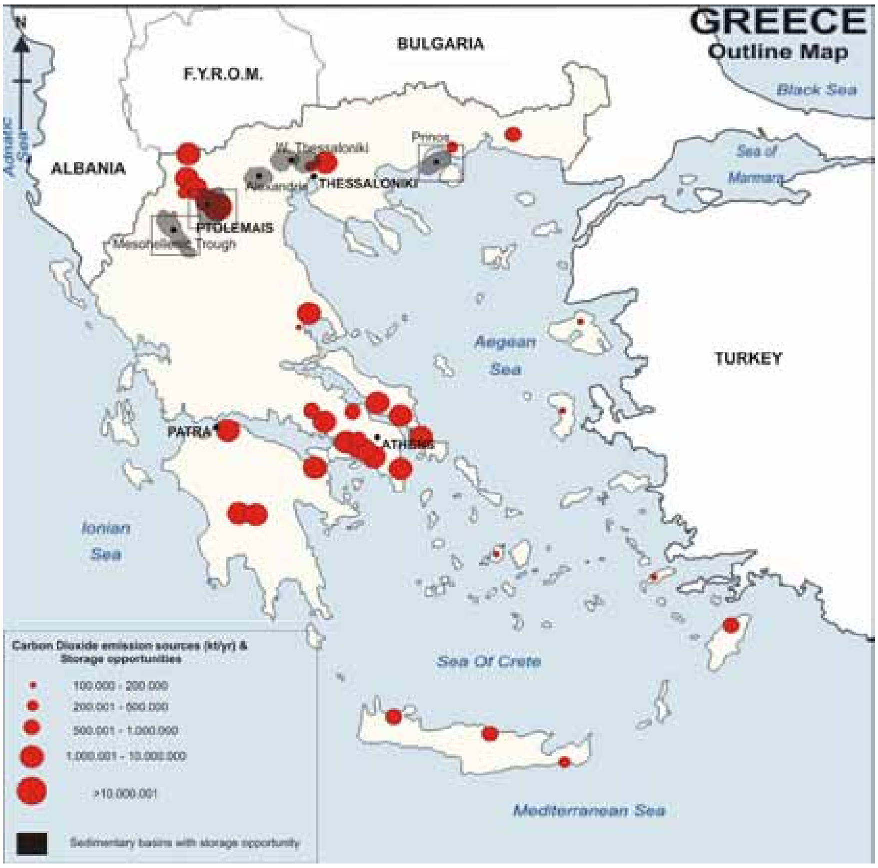


Figure 1: Stationary CO_2 emissions in relation to potential storage basins in Greece (Koukouzas et al.*, 2009).*

the nearby Komotini gas-fired power station (0.7 Mt/year CO_2) for several decades. In addition, the offshore location of the potential reservoir and seal units increases the transportation costs but it is countered by the well-established infrastructure framework within 30–40 km of the coast (pipelines, wells and platforms).

- The onshore Thessaloniki Basin appears to have very good technological and economic potential for CO_2 storage. Favourable factors include limited faulting, optimal depth range for CO_2 storage capacity, and relatively low drilling costs within the closures identified. It appears to have the capability to store all the regional stationary CO_2 emissions (one cement plant and one refinery with its 400 MW Combined Cycle Gas Turbine Unit emitting in total around 1.9 Mt CO_2/year) or the total lifetime output of a lignite-fired power plant located in the region of Western Macedonia (around 100 km distance).
- The aquifer properties and structure of the carbonate reservoir beneath the Ptolemais Basin requires further detailed site exploration to assess the basin's suitability due to the significant point sources of CO_2 in the region. In addition, a new coal-fired power plant is planned to be commissioned in the area in the next two years, providing a further opportunity for developing a large-scale CO_2 storage project.
- The CO_2 storage potential of the Mesohellenic Trough is unclear due to sparse drilling across the basin, although suitable reservoir and seal units appear to be present at appropriate depths. The extensive faulting, however, should be considered as a potential risk.

Additionally, there is another option that is currently being investigated. It concerns the Underground Coal Gasification with subsequent CO_2 storage. An ongoing European project, called UCG & CO_2 Storage (http://re.ucg-co2.eu/), studies the potential of implementing the technology in a Bulgarian coal basin. The feasibility of implementing that technology in a Greek coal basin is also under investigation in that project through geomechanical modelling and environmental study of the coal basins in Florina and Kozani.

A natural CO_2 field in Greece

Natural geological accumulations of CO_2 occur widely throughout Europe. At Mesokampos, in the Florina basin in northern Greece, a unique opportunity is offered for detailed studies of the long-term interaction between CO_2-rich waters and the reservoir rocks. It can also help improve the understanding of the possible environmental impacts of geological storage of CO_2.

The Florina basin is a tectonic graben in the NW of Greece aligned NNW-SSE. Its total length is about 150 km and, geotectonically, it belongs to the Pelagonian zone. In general, the basin can be considered as a northerly continuation of the Ptolemais – Amynteongraben. It has been a productive field for more than 10 years with an annual production of around 30,000 tons of CO_2. The produced CO_2 is sold to domestic markets.

Research has shown that the CO_2 accumulation occurs very close to the surface, at low pressure, with CO_2 dissolved in the groundwater. That can be proven by the carbonate-rich springs and CO_2-rich gas vents, which occur throughout the Florina basin (***Fig. 2***), resulting from a slow upwelling of CO_2 along rock discontinuities. The existence of the gas does not seem to be connected with the Tertiary or Quaternary formations or even with the presence of lignite (of xylitic type) that can be found inside the sediments. D'Alessandro et al. (2008) have identified, through isotopic analysis, that the CO_2 is of deep magmatic/hydrothermal origin.

The natural CO_2 field in Florina (***Fig. 3***) has been a subject of research for the last decade mainly via European projects such as the NASCENT project (Natural Analogues for the Geological Storage of CO_2), that ended in 2005 and the ongoing RISCS project (Research into Impacts and Safety in CO_2 Storage). NASCENT was developed in order to study the natural analogues in Europe and it has enabled an understanding of the long-term processes involved with the underground storage of CO_2, while RISCS is a project designed to study a wide range of potential impacts, thus providing tools for developing appropriate legislation and helping to ensure the safe management of CO_2 storage sites.

In the NASCENT project (2005), a detailed hydrogeochemical survey of the groundwater was performed across the whole basin in order to determine if there are any changes in the chemistry of the water in the areas where the high concentrations of CO_2 were observed. The waters close to the CO_2 field have increased concentrations of Ca, Mg and CO_3, as well as elevated total hardness. Waters from non-CO_2 impacted areas are of good quality with only some increased content of certainelements. The enrichment of the groundwater in those elements is a result of the mineral dissolution of the rocks that come in contact with the CO_2–impacted water.

Within the RISCS project, a detailed survey is being conducted not only regarding the potential impact of CO_2 on the groundwater but also on the reservoir rock, matrix, soil and the terrestrial ecosystem (microbiology and plants).

Conclusions

To conclude, the geological settings of the Tertiary and Neogene-Quaternary sedimentary basins presented in this paper appear to provide a promising option for CCS implementation. The identified potential reservoirs occur in proximity to the significant stationary CO_2 emissions in NW Greece, which is favourable in terms of infrastructure costs. However, a detailed investigation in order to define their practical and matched storage capacity as well as a proper characterization and site screening particularly in regard to containment and risk of leakage is essential prior to making any definite decisions.

Taking into consideration the research done for the storage of CO_2 in the above-mentioned aquifers, it can be summarized that the storage capacity is about 2.2Gt for about 13 years. For the oil field of Prinos, the storage capacity is 17*106 t CO_2 and it is calculated that it can remain stored for 0.3 years with annual CO_2 point source emissions of about 43*106 t CO_2.

On the other hand, the leaking natural analogue site at Florina, and other similar sites, can provide insight into both macro- and micro-scale gas migration mechanisms, as well as spatial and temporal variations in gas behaviour. At Messokampos, at the northern part of the basin, high levels of dissolved CO_2 in groundwater occur close to the surface (below 300 m) in Tertiary sands alternating with silt and clay layers.

The presence of dissolved CO_2 in the groundwater causes dissolution of minerals (e.g. siderite) and enrichment of the water in the relevant elements with subsequent precipitation of iron oxides and gibbsite, triggered by the dissolution of feldspars. The impact of these reactions is minor and does not seem to influence the porosity of the sediment. Although the system has been in place for a long time, thermodynamic equilibrium conditions seem not to be established.

Figure 2: CO_2 leaking site in Florina, Northern Greece. The difference between the CO_2-impacted and the non-impacted ground is clearly visible.

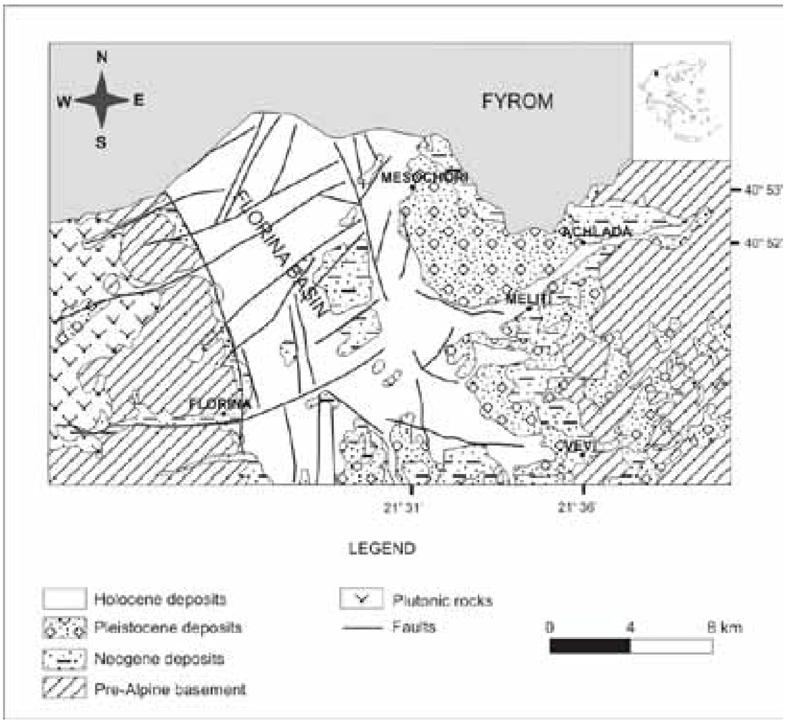


Figure 3: Geological map of Florina basin showing bedrock geology and tectonic features (modified after D'Alessandro et al.*, 2008).*

References

Bachu, S. 2003. Screening and ranking of sedimentary basins for sequestration of CO_2 in geological media in response to climate change. *Environ. Geol. 44*, 277–289.

Bachu, S., Bonijoly, D., Bradshaw, J., Burruss, R., Holloway, S., Christensen, N.P., Maathiassen, O.M. 2007. CO_2 storage capacity estimation: methodology and gaps. *Int. J. Greenhouse Gas Control 1 (4)*, 430–443.

CSLF Task Force, 2007. Carbon sequestration leadership forum: Phase II final report from the task force for review and identification of standards for CO_2 storage capacity estimation.

D'Alessandro, W., Brusca, L., Kyriakopoulos, K., Karakatsanis, S. 2008. Groundwater quality issues in the Florina area (N. Greece). Society of Environmental Geochemistry and Health, 26th European Conference - SEGH 2008: "Health implications of environmental contamination", Athens, Hellas, 31st March - 2nd April.

GESTCO Project: Geological Storage of CO2from Combustion of Fossil Fuel. 2004. European Union Fifth Framework Programme for Research & Development, second ed. Project No. ENK–CT-1999-00010. Summary Report.

Hellenic Ministry for the Environment, Physical Planning and Public Works. 2004. National Allocation Plan for the Period 2005–2007.

IPCC-Intergovernmental Panel on Climate Change. 2005. In: Metz, B., Davidson, O., Coninck, H.C., Loos, M., Meyer, L.A. (Eds.), Special Report on Carbon Dioxide Capture and Storage. Cambridge University Press, Cambridge, UK/New York, NY, USA.

Kaldi, J.G., Gibson-Poole, C.M. 2008. Storage Capacity Estimation, Site Selection and Characterisation for CO_2 Storage Projects. Cooperative Research Centre for Greenhouse Gas Technologies, Canberra, CO_2 CRC Report No. RPT08-1001.

Koukouzas, N., Ziogou, F., Gemeni, V. 2009. Preliminary assessment of CO_2 geological storage opportunities in Greece. *Int. J. of Greenhouse Gas Control* 2009; 3(4): 502-513.

NASCENT. 2005. Natural analogues for the geological storage of CO_2. NASCENT Final Report 2005/6 March.

The potential options of storing CO_2 in saline reservoirs in Hungary

Ágnes Szamosfalvi, György Falus and Györgyi Juhász*

Hungary has more than 40 years of industrial experience in subsurface injection of large volumes of carbon dioxide (CO_2), related to enhanced oil recovery (EOR) activities. Furthermore, the results of the preliminary-stage assessment of storage capacities in Hungarian saline reservoirs show significant storage volumes that could be used for the sequestration of industrial CO_2. Our paper gives a summary of CO_2 injection activities and provides an overview of the most favourable saline formation, its geological characteristics and estimated storage capacity.

La Hongrie bénéficie d'une expérience industrielle de plus de 40 ans dans le domaine de l'injection, à faible profondeur, d'importants volumes de CO_2, liée aux opérations de récupération accrue des hydrocarbures (Enhanced Oil Recovery). De plus, les résultats de l'étape initiale d'évaluation des capacités de stockage au sein de réservoirs salins hongrois montrent l'existence de volumes de stockage significatifs qui peuvent être utilisés pour le confinement du CO_2 industriel. Cet article résume les opérations d'injection de CO_2 et fournit une vue d'ensemble des structures salines les plus favorables, leurs caractéristiques géologiques et une estimation de leurs capacités de stockage.

Hungría tiene más de 40 años de experiencia en la inyección profunda de grandes volúmenes de CO_2 relacionado con las actividades de mejora de la recuperación de petróleo (EOR en sus siglas en inglés). Además los resultados preliminares de la evaluación de la capacidad de almacenaje de los almacenes salinos húngaros, muestran unos volúmenes de almacenamiento significativos que se podrían utilizarse para el almacenamiento de CO_2. Nuestro artículo aporta un resumen de las actividades de inyección de CO_2 y de las formaciones salinas más favorables, sus características geológicas y su capacidad de almacenaje estimado.

The most widespread potential carbon dioxide (CO_2) storage objects worldwide are "saline" reservoirs, which can be defined as porous and permeable reservoir rocks that contain salty water in their pore volume. These rocks are located much deeper than the normal potable water reservoirs and because of their high salinity and depth they are economically non-exploitable. For long-term, safe storage of CO_2, the following conditions must be met by the potential reservoirs (after Chadwick *et al.*, 2006):

- adequate reservoir depth (900 - 3000 m)
- the integrity and low permeability of overlying cap rock, or closure
- large enough volume for economic CO_2 storage
- appropriate reservoir geological parameters
- sufficient separation from potable and thermal water systems.

If the studied reservoir conditions fulfill these requirements, as many of the saline aquifers do, worldwide, it is theoretically suitable for CO_2 storage. However, further aspects, such as the conflict of use, should be considered. Decades-long experience in subsurface injection of large volumes of CO_2 for EOR purposes is one important advantage that Hungarian geoscience possesses.

In the following paper we give a brief overview of the most promising aquifer storage formation and summarize over 40 years of experience of CO_2 injection-related EOR activity, which provides a solid basis for the large-scale industrial application of carbon capture and storage (CCS) technology in Hungary.

Summary of earlier EOR activities in Hungary

Hydrocarbon exploitation by CO_2 flooding has been tested in some of the major oil fields in Hungary. *Budafa* and *Lovászi*, the two oldest oil (and gas) fields in the SW part of Hungary, discovered in 1937 and 1940, respectively, are sandstone reservoirs. Hydrocarbon production was started in both fields using natural reservoir energies. Already in 1939 and 1944, re-injection of hydrocarbon gas was used as a secondary recovery method. Later, edge and subsequent areal water flooding was used as additional recovery. Natural CO_2 from a nearby source was injected into the depleted reservoir to increase oil recovery. The aim of flooding was to increase the pressure in the depleted reservoir to its initial value. The process was immiscible. The additional recovery factor of oil in the reservoir was around 10%.

The bulk of the oil in the *Nagylengyel* oil field (SW Hungary), discovered in 1951, is accumulated in karstic Cretaceous rudistic limestone and Triassic dolomite. During the primary recovery, unlimited water inflow was the dominant driving mechanism. Water encroachment became more and more intensive by the end of the 1970s. CO_2 was injected to establish an artificial gas cap in the karstic reservoir. During the blow down of the gas cap, the oil moved upward and was recovered by water drive. The process was immiscible and the additional recovery factor was again around 10%.

The *Szank*-field reservoir is a special massive type reservoir. The exploitation started, using natural energies in 1969. The predominant displacement mechanism has been the water inflow from the edge. By 1990, production wells located at the edge of the reservoir watered out and the production rate decreased dramatically. The injected 95-98 mole % CO_2 comes from the enrichment of the gas in

[*] Ágnes Szamosfalvi, Eötvös Loránd Geophysical Institute, Budapest, Hungary, szagi@elgi.huszagi@elgi.hu

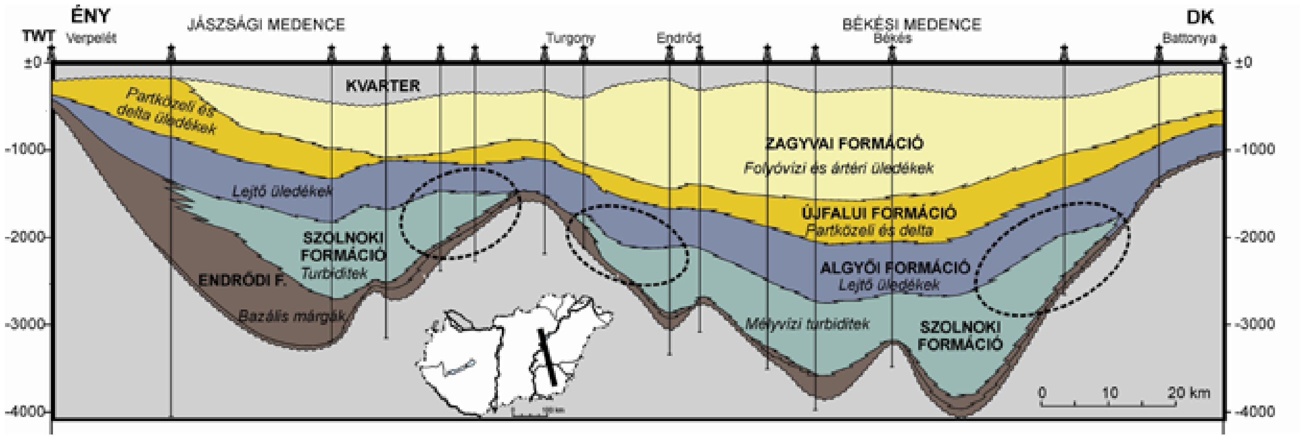


Figure 1: NW - SE lithostratigraphic and sedimentological cross section in the Pannonian s.l. sequence. From Verpelét through the Jászság Basin, the Middle Hungarian basement high and the Békés Basin to Battonya (Juhász, 1992). The approximate location of the cross-section is shown on the inset map.

fields near the studied metamorphic reservoir.

CO_2-related EOR activities were motivated by the possibility of practical use of the substantial reserves of natural CO_2 in Hungary. The conditions of field-scale applications have varied over a wide range, from immiscible displacement in sandstone and karstic reservoirs to miscible displacement in metamorphic and mixed rock type reservoirs. Results show that CO_2 gas injection can be used successfully in various lithology types. The additional oil recovery varies from 5 to 14% depending on the type of reservoir and the technology applied.

Extensive EOR activity in recent decades has led to valuable expertise that can be used to exploit saline aquifers for CO_2 storage.

Characterization and areal distribution of Pannonian (Upper Miocene) sediments potential for saline reservoir storage

Following a basic selection procedure with the criteriashown above,suitable saline storage reservoirs can be considered mainlyin Upper Miocene (Pannonian) sediments. Among these basin filling facies units, the Lower Pannonian Szolnok Formation and the Upper Pannonian Újfalu Formations have the required thickness to potentially store the CO_2.

These formations not only fulfill the volumetric minimum requirements, but they also satisfy other necessary conditions. Both formations are covered by thick, low-permeability formations (Zagyva Formation for Újfaluand the Algyő Formation for Szolnok - ***Fig. 1***). Taking into account other considerations, such as conflict of use, the Szolnok and Algyő Formations are suggested to be the most prospectivestorage and sealing formations, respectively. The actual storage is considered to take place in the vicinity of basement highs where onlapping and pinching out of sandstone layers and the formation of pseudo-anticlines occur.

The areal distribution of turbidites is shown in ***Figure 2***. The highlighted area covers the region where the thickness of the Szolnok Formation exceeds 200 m and the top of the formation is deeper than 900 m. The thickness of the formations can reach 900 min some of the deep basins.

The Szolnok Formation is limited to the zones of deep basin areas. The top of the formation follows the basement morphology. In the western and northern part of the Great Hungarian Plain, the surface of the formation rises to approximately 1000-1500 m, whereas the deepest zones are below 3500 m.

The turbiditic sandstone sequences of the Szolnok Formation may be easily followed on seismic sections. The lithology of the potential storage formation is fine-grained sandstone, and clayey marl layers alternating with siltstone. Even the thicker sandstone layers are built up by smaller lamellae. The turbidite sandstone layers have heterogeneous geometry and spatial distribution. (Juhász, 1998).

A large variety of trap structures occurs in the Szolnok Formation. The most frequently developing trap type is the structural trap that is related to compaction (pseudo-) anticlines. However, stratigraphic traps, as well as lithological traps, are also very common. Tectonic traps

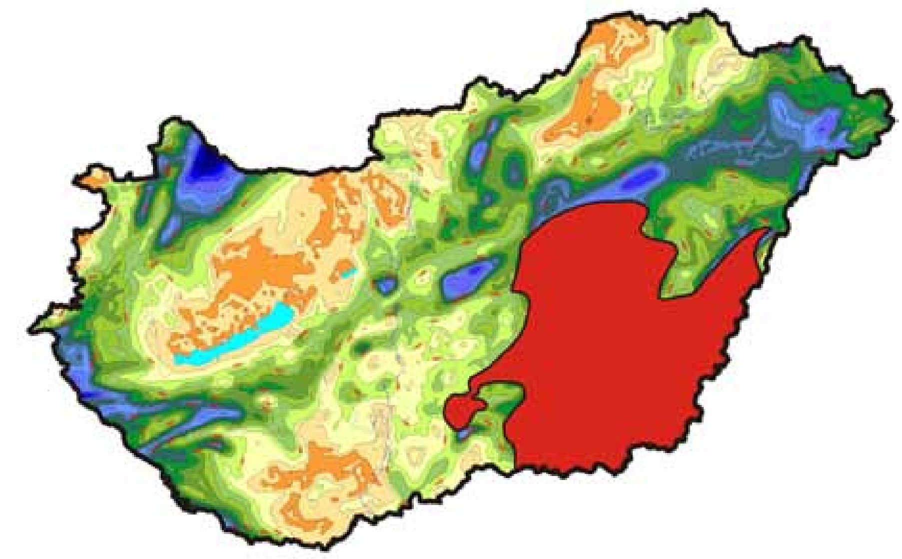


Figure 2: Areal distribution of the Szolnok Formation (turbiditic sandstone – in red) on the Great Hungarian Plain plotted on the pre-Tertiary basement depth map from Kummer (2003).

develop near troughs and tectonic zones that crosscut or occur within the formation. Tectonic traps are formed near to the protrusions in tectonically disturbed areas.

Estimation of storage capacity in the designated area

Before carrying out the storage volume calculations, the selected areas were filtered according to their minimum thickness. Hence, volume estimations were limited to those areas where formation thickness reached 200 m. We have used a conservative approach for the volume estimation coming from the decades-long experience of natural gas storage in Hungary, applying the following formula:

The storage capacity in the selected area was found to be between 1.5 and $2.0*10^8$ t on the northern and between 5.0 and $5.5*10^8$ t in the southern part of the Great Hungarian Plain. The total potential geological CO_2 storage volume of the Szolnok Formation is about 650 - 750 million tons in the Great Hungarian Plain. The estimated CO_2 storage volume for the Szolnok Formation in Hungary is estimated to be around 1000 million t.

It is important to note that the values shown above represent the quantity of CO_2 that could be stored in a given area in the formation, assuming that the whole volume behaves as a single hydraulic unit.

$\Delta V = \Phi \times c \times V \times \Delta p$	*ΔV – regional aquifer or trap storage capacity (m^3)*
	Φ - average reservoir porosity of regional aquifer or trap structure (-)
	c - eff. compressibility (1/bar), 1/bar) value ~$5*10^{-5}$ for rock and pores
	Δp - built-up pressures; value: Δp~0.2x hydrostatic pressure at given depth (bar)
	V - volume of regional or trap aquifer (m^3)
$M = \Delta V \times \rho CO2/1000$	*$\rho CO2$ - density of CO_2 at reservoir pressure and temperature*
	M - Theoretical mass of maximum storable CO_2 in regional aquifer [t]

Summary and future work

The results of our calculations show that the CO_2 storage potential of the Szolnok Formation in the study area is about 650-750 million tons. However, we have only considered the storage capacity without calculating mineral reactions and dissolution processes. The actual storage volume is strongly influenced by the size and geometry of closed structures and the volume of hydraulically interconnected water bodies, as well as other crucial parameters, such as, injectivity, pressure build-up, reservoir heterogeneity, etc. Such information is not yet available.

Therefore, the next step to facilitate storage in the"saline" storage reservoirs should be the detailed mapping of closed structures within the formation and allocation of the hydrodynamic units.

Acknowledgements

We are indebted to MOL Plc and MBFH for making the necessary data available. The research was supported by (OTKA (T-060861)).

References

Chadwick, R. A., Arts, R., Bernstone, C., May, F., Thibeau, S., Zweigel, P. 2008. Best practice for the storage of CO_2 in saline aquifers. *British Geological Survey Occasional Publication No. 14*. Keyworth, Nottingham.

Juhász,Gy. 1992. Pannonian s.l. lithostratigraphic units in the Hungarian Plain: distribution, facies and sedimentary environments. *Földtani Közlöny 122/2-4*, 133-165, Budapest.

Juhász, Gy. 1998. A magyarországi neogén mélymedencék pannóniai képződményeinek litosztratigráfiája. In: Bérczi I., Jámbor Á. (szerk.) *Magyarország geológiai képződményeinek rétegtana*. Magyar Olajipari Részvénytársaság és a Magyar Állami Földtani Intézet kiadása, Budapest, 469-484.

Kummer, I. 2003. Magyarország földtani térmodellje. ELGI Z árójelentés - Magyar Állami Földtani, Geofizikai és Bányászati Adattár.

Span, R., Wagner,W. 1996. A New Equation of State for Carbon Dioxide Covering the Fluid Region from the Triple-Point to 1100 K at Pressures up to 800 MPa. *J Phys Chem Ref Data 1996*; 25, 1509–96.

CCS research in Hungary - A student perspective

*György Lévai, Csilla Király and Márton Berta**

The concentration of CO_2 in the atmosphere has increased significantly since the industrial revolution causing severe damage to the environment, such as climate change and ocean acidification. To reduce the anthropogenic CO_2 emissions, technological improvements have been achieved towards a sustainable energy industry. However, the transition to renewable energy sources is not happening as fast as it should do. That is why the emissions from existing power plants using fossil fuels must also be reduced. This can be achieved by carbon capture and sequestration (e.g. Oelkers and Cole, 2008).

We first encountered this topic under the supervision of Csaba SZABÓ, PhD in the Lithosphere Fluid Research Laboratory, where we were working on different topics in geochemistry. Our main motivation from the beginning was this question: what is actually happening with the CO_2, the water and the rock in the reservoir during and after injection?

To answer this, geochemical experiments have been carried out in a joint research project between Eötvös Loránd University, Budapest University of Technology and Economics (Dr. Edit Székely) and Eötvös Loránd Geophysical Institute (Dr. György Falus).

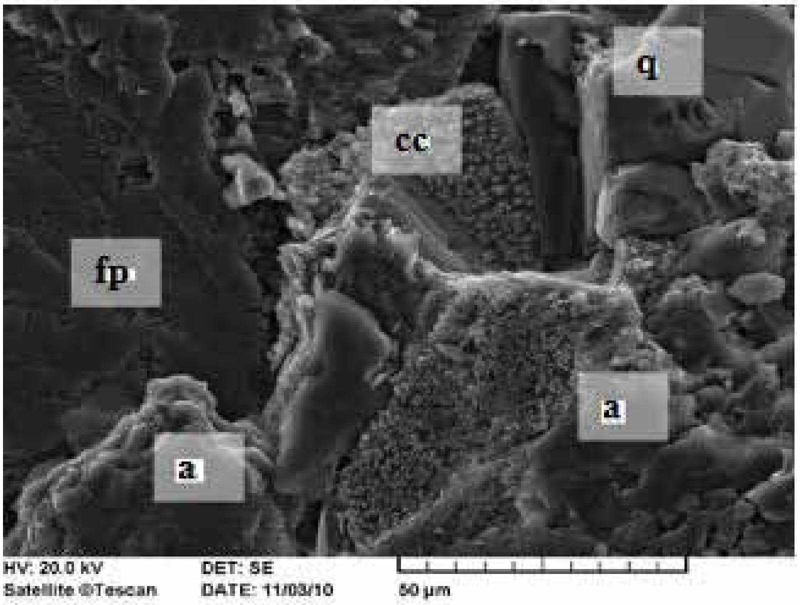


Figure 1: Signs of solution by supercritical CO_2 + brine on the treated calcite (cc) and feldspar (fp) grains of an immature sandstone. Note that quartz (q) and clay minerals (a) remained intact.

In our work we applied high pressure and high temperature reactors to treat rock samples representing potential Hungarian CO_2 storage reservoirs to model the conditions in a future CO_2 sequestration system (the Jászság Basin). To track the changes (e. g. solution, crystallization), a wide range of analytical techniques were used; for instance, scanning electron microscopy on the solid materials and inductively coupled plasma mass spectrometry on the liquid phases (e.g. Berta *et al.*, 2011).

Parallel to this experimental work, we have started to study a natural CO_2 site, an analogue area for the storage of industrial CO_2. This is the Répcelak-Mihályi Field, where CO_2 has been exploited for decades for industrial purposes. Our work here was to collect all the available data from literature, previous geophysical and geochemical research, and hydrocarbon exploration to set up a descriptive model from the selected area (e.g. Király *et al.*, 2012).

* György Lévai, Budapest University of Technology and Economics.
Csilla Király and Márton Berta, Eötvös Loránd University, Faculty of Science, Hungary, szagi@elgi.hu

References

Oelkers, E.H., Cole, D.R. 2008. Carbon Dioxide Sequestration: A Solution to a Global Problem. *Elements 4*, 305-310.

Berta, M., Király, Cs., Falus, Gy., Juhász, Gy., Szabó, Cs. 2011. Preliminary physical and geochemical study on a sedimentary rock series of the Pannonian Basin for CCS (Hungary). *Energy Procedia*, 4, 4719-4723.

Király, Cs., Berta, M., Szamosfalvi, Á., Falus, Gy., Szabó, Cs. 2012. An „inverse CCS site" in NW Hungary – Geology and modeling. Poster on the Third EAGE CO_2 Geological Storage Workshop, 26-27 March 2012, Edinburgh.

XXXIV GEOLOGORUM CONVENTUS
BRISBANE
2012
AUSTRALIA
MENTE ET MALLEO

International Union of Geological Sciences
IUGS
50 years
Earth Science For The Global Community

34th International Geological Congress (IGC)

Unearthing Our Past And Future – Resourcing Tomorrow

Brisbane Convention and Exhibition Centre
Queensland, Australia
5 - 10 August, 2012

www.34igc.org

AGC

The 34th IGC is supported by the member societies of the Australian Geoscience Council

AusIMM THE MINERALS INSTITUTE
IAH AUSTRALIA

Courtesy of Brisbane Marketing

MAJOR SPONSORS AND CONTRIBUTORS

VALE
AGC
Australian Government
Geoscience Australia
Events Queensland
Queensland Government
MOULTRIE GROUP
bhpbilliton
resourcing the future
The University Of Queensland
AUSTRALIA
Rowland.
RioTinto

QUT
Queensland University of Technology
Brisbane Australia

UNESCO
United Nations
Educational, Scientific and
Cultural Organization
Under the patronage of
UNESCO

34th International
Geological Congress
AUSTRALIA 2012

www.34igc.org

Congress Secretariat
Carillon Conference Management Pty Limited
PO Box 177 RED HILL
QLD 4059 AUSTRALIA

Office 14, 152 Musgrave Road,
RED HILL QLD 4059 - AUSTRALIA

T: 61 7 3368 2644
F: 61 7 3369 3731

34th International Geological Congress
Brisbane - Australia
5-10 August 2012

http://www.34igc.org/

EFG will participate in the 34th IGC with a symposium on

Strengthening communication between fundamental and applied geosciences and between geoscientists and public (Symposium 36.6)

The symposium will discuss the benefits to be gained from a better understanding between geological communities. These include: incorporation of more relevant and informed education in applied geology and professional skills at university level; an improvement of industry competitiveness through more rapid conversion of research findings to applied technologies and methodologies; clear pathways and assessment criteria for geoscience graduates seeking to attain Professional Qualifications and their employers and mentors; and design of research projects and allocation of research funding based on a better appreciation of societal needs.

Co-conveners organizations:
American Geological Institute, AGI
American Institute of Professional Geologists, AIPG
Australian Institute of Geoscientists, AIG
European Federation of Geologists, EFG
Geoscientists Canada, CCPG
International Union of Geological Sciences, IUGS

Women in leading positions in geology

Isabel Fernández Fuentes, Eva Hartai and Anita Stein*

This article opens a series of contributions on the topic of professional profiles that will give a voice to professional geologists and allow them to express themselves on different topics within the European Geologist magazine.

The choice of this first topic on women in leading positions in geology is due to different coincidences as in the last couple of years the presence of women executing important posts has considerably increased in the traditionally masculine dominated world of geology and the issue of gender balance has recently been valorized at European level through a publication and a consultation assessing the impact of possible EU measures issued by DG Justice.

Cet article ouvre une série de contributions traitant d'expériences professionnelles, donnant ainsi la parole aux géologues professionnels et leur permettant de s'exprimer sur des sujets divers, dans les pages du magazine European Geologist.

Le choix du premier sujet concernant les femmes aux postes de Direction en géologie est motivé par diverses coïncidences : actuellement, quatre des cinq membres du Bureau de la FEG sont des femmes et, de plus, le problème d'une représentation équilibrée homme/femme a été récemment mis à l'honneur au niveau européen par l'intermédiaire d'une publication et d'une consultation évaluant l'impact de mesures potentielles européennes émises par la DG Justice.

Este artículo abre una nueva serie de contribuciones en nuestra revista: Prófiles profesionales. Este nuevo espacio pretende dar voz a experiencias profesionales y permite expresarse sobre diferentes temas en la revista European Geologists.

El primer tema elegido, mujeres en posiciones de liderazgo en geología, se debe a diferentes coincidencias. En el mundo de la geología, tradicionalmente dominado por hombres, en los últimos años la presencia de mujeres ocupando puestos de decisión ha aumentado considerablemente. Por otro lado, una reciente publicación sobre mujeres en la toma de decisiones en la UE, y a la consulta europea que se está efectuando en estos momentos para evaluar el impacto de las posibles medidas de la UE emitidas por la Dirección General de Justicia, hace que el tema elegido para este artículo sea de gran actualidad.

The Europe 2020 Strategy, the European Union's growth strategy, relies on knowledge, competences and innovation. Human capital is crucial for addressing the demographic challenges of falling birth rates and an ageing society. Therefore, according to the recently released progress report "Women in economic decision-making in the EU", one of the approaches to improve Europe's competitiveness can be to aim at a more balanced representation of women and men in economic decision-making positions. It can be taken for granted that gender balance in companies can contribute to a more productive and innovative working environment and an overall improved company performance.That is why gender imbalance on corporate boards remains an important challenge for all EU Member States. As evidenced by the discrepancy between the high number of female graduates and their under-representation in top-level positions, there currently exists an unexploited potential of skilled human resources. As a matter of fact, the key indicators of gender representation on corporate boards in the EU shows that the proportion of women involved in top-level business decision-making remains very low, although there are small signs of progress. In January 2012, women occupied on average just 13,7 % of board seats of the largest publicly listed companies in EU Member States.

Apart from this unprecedented evolution in the EFG Board, it can be observed that in the last couple of years the presence of women executing important posts has considerably increased in the traditionally masculine dominated world of geology. This evolution can be observed in several professional geologists' associations where women have recently acceded to key positions. (Suzette M Kimball, USGS (United States Geological Survey) Deputy Director; Deborah McCombe, CRISCO Chairperson (Committee for Mineral Reserves International Reporting Standards); Jo Venus, YES (Young Earth Scientists Network); Barbara Murphy, AIPG President; Ruth Allington, EFG President; Ulrike Mattig, BDG President; Isabelle Cojan, SFG President).

This article does not pretend to do an exhaustive analysis of the situation but intends to contribute to the objectives of women in leading positions by discovering more about the experiences of some of these women. Therefore, the article will be based on interviews conducted with three women working today in key positions in international geological associations, in order to find out more about their professional experiences: Ruth Allington (EFG), Ulrike Mattig (BDG) and Barbara Murphy (AIPG).

Figure 1: Women in leading positions in geology at the 4th International Professional Geological Congress, 4IPGC, Vancouver, 2012.

* Isabel Fernández Fuentes,
EFG Office Director,
isabel.fernandez@eurogeologists.eu

Ruth Allington

President of the European Federation of Geologists (EFG), UK

1. How and when did you take the decision to become a geologist?

When I was 17, I was studying mathematics, physics and geography at A Level. My favourite subject was physical geography and one of my teachers was a keen amateur geologist who offered a small group of us the chance to study geology at an introductory level alongside our A Level studies. This opened my eyes to geology as a subject and I was also inspired by a visit to the Engineering Geology department of Portsmouth Polytechnic (now University of Portsmouth) – this made me think about the possibility of a career as an engineering geologist. When I applied to universities I was looking for courses that would combine physical geography and geology and I was accepted at King's College London for a joint honours degree in geography and geology. In the summer vacation of my first year I worked as a technical assistant in the engineering geology section of the Institute of Geological Sciences in London (now British Geological Survey). In my second year, I had the opportunity to work with a consulting firm in Oxfordshire, England on an undergraduate research project which combined aspects of geology and geomorphology and gave me a further taste of the application of engineering geology in practice – this time in mining and quarrying. I received fantastic support and encouragement from the proprietor and his colleagues and was lucky enough to be offered a job with this firm following completion of an MSc in engineering geology at the University of Durham (1981). I am now one of the joint senior partners with this firm – GWP Consultants LLP.

2. Please describe your experiences as a woman during your studies in geology.

As a joint honours student, I spent time in two departments. Women were not in a minority in geography although we were a minority in the geology department. There were two women and 7 or 8 men on my MSc course.

I don't recall feeling that my gender was an issue at any time during my studies - certainly not a disadvantage. I recall being judged on my own merits and getting on well with staff and fellow students.

> ***« I do feel it's important for senior women to be role models and mentors for women in early career and still at university and I try to contribute in this way where I can. »***

3. What were your experiences as a female geologist during your first years of professional life?

I have been lucky to have worked in a small organization throughout my professional career and to have been encouraged early in my career to interact directly with clients and contractors, whilst being supported with on the job training and mentoring. This gave me confidence and belief in my abilities which helped me to grow and develop as a professional.

I was never in competition with others at the same level and generally found that, whilst clients and others may have found it initially unusual to find a young woman in the mining and quarrying industry, the normal attitude was "if she's got to the position she's in, she must know what she's doing".

4. What where the most important obstacles you met with during your professional life as a female geologist?

I don't think there have been any obstacles that I have had to overcome during my professional career that are directly associated with my gender.

5. What are in your opinion the advantages of starting a professional career as a woman?

In the majority of circumstances, I have found being a female geologist neither an advantage nor a disadvantage and, in many, I find that it is an advantage - people remember me.

6. How do you feel about executing a key position in the field of geology from the point of view of a woman?

Proud - but not necessarily to be a woman in a key position but to be in a key position at all! I do feel it's important for senior women to be role models and mentors for women in early career and still at university and I try to contribute in this way where I can, both within my organization and for women I meet in the course of professional voluntary activities.

7. According to your experience, how are female geologists perceived in your organization/company?

Gender is irrelevant in our organization, save that I think we agree that a mixed gender group is generally more effective than a single sex group.

8. Have you noticed any changes in perception during the last few years?

Not particularly - capable, confident, well educated and well trained women will normally succeed and I believe that this has always been the case.

> ***« Somehow, we need to reach a point where gender is simply irrelevant. »***

9. To which point should our profession advance in order to make sure that the professional activity of female geologists will be perfectly accepted and integrated in the future?

Somehow, we need to reach a point where gender is simply irrelevant, except in a widespread acceptance that diversity (of all kinds) is desirable for better functioning organizations.

Ulrike Mattig

President of the Professional Association of German Geoscientists (BDG), Germany

1. How and when did you take the decision to be come a geologist?

I decided to become a geologist during my first year of studying geography. There I discovered my deep interest in sub-surface topics of geosciences and finally (after one year) switched to geology, but I always - already at school - had been very interested in "reading the book of nature" which was promoted by my grandfather and my parents.

2. Please describe your experiences as a woman during your studies in geology.

First of all, there were only a few of us (10 female versus 125 male students) during the study, which led to a kind of "exotic" position. There were no problems with our male colleagues – apart from some "jokes" from time to time – but our teachers and professors were not so familiar with the situation.

Once, I did not get permission to enter a tunnel under drilling, because the Austrian miners regarded women as "voodoos"; another problem was to get an interesting position for the necessary industrial practices, e.g. due to the fact of a missing ladies' lavatory. The head of mineralogy refused a gendered advertisement because "there are no women in mineralogy" (by the way, he had a female assistant!).

> ***« We need more positive examples of strong professional female geologists, especially in leading positions. »***

On the whole, I survived by simply neglecting some and overcoming most of these obstacles.

Especially encouraging for me had been a longer stay in Norway in connection with my Ph.D., where I met a lot of tough professional female geologists in leading positions and learned to know how different life can be in a society where equal rights for everybody play an essential role.

3. What were your experiences as a female geologist during your first years of professional life?

In fact, in the first three years they were not very encouraging: I entered the Geological Survey in one of the Federal States in Germany and became the first female Senior Geologist in the Mineral Raw Materials Section. Already during my presentation I was asked "if I would have problems with visiting the quarries and pits on my own, because it would not be possible to give me a male colleague as a bodyguard" …! It was, especially, the simple-minded point of view of some male colleagues concerning female geologists that turned out to be a problem in my daily work situation. So I decided after three years to leave the Survey and to enter the responsible controlling function in the ministry.

> ***« Female geologists are no longer 'exotic birds'. »***

4. What were the most important obstacles you met with during your professional life as a female geologist?

- In the first years: the lack of positive examples – there were simply no or only a few female geologists.
- The bad or missing working conditions (see above). Beside this there was and is still a lack of possibilities to combine professional work and private life.
- The obstacles created exclusively in male minds (e.g. is our female colleague able to meet the requirements of this profession or is it only her "hobby"?).
- The difficulties for some male colleagues to work under a female "boss".
- Other female colleagues, who were not self-confident enough and tried to meet only the role of an "exotic bird" – this was especially disappointing for me.

5. What are in your opinion the advantages of starting a professional career as a woman?

For me, it seemed logical to start a professional career after studies and training – and earn money! From my point of view, the advantages are:

- to be independent, first of all from an economic point of view.
- self-realization, based on a good professional education.
- meeting a lot of different challenges and coping with them.

6. How do you feel about executing a key position in the field of geology from the point of view of a woman?

It's great to have power – and to use it! Executing a key position is o.k. and it is quite normal (even if we are still a minority) – that's also what I try to live by. At the same time I'm very well aware of the problems that some male colleagues have with this situation as well as of meeting the expectations and fulfilling this example function as a female professional. Sometimes not easy!

7. According to your experience, how are female geologists perceived in your organization/company?

There is no difference between male and female geologists from a qualitative perspective, except from the fact, that women have improved the formerly masculine-dominated structures e.g. through better communication. Due to this, I would appreciate very much to have more female geologists in leading positions, e.g. as working group leaders.

8. Have you noticed any changes in perception during the last few years?

Fortunately: yes! Female geologists are no longer "exotic birds".

9. If the answer is yes, what were these changes due to in your opinion?

Beside the basic discussions and advances on equal rights of men and women in society during the last 25 years, the rising number of female geologists – especially in leading positions – supported the changes. This had been achieved by recruiting more women and developing them for and into leading functions.

10. To which point should our profession advance in order to make sure that the professional activity of female geologists

will be perfectly accepted and integrated in the future?

From my personal point of view, we need more positive examples of strong professional female geologists, especially in leading positions. Therefore BDG started a mentoring programme some years ago, which is open to men and women. Here, a lot of very useful information and skills – e.g. how to overcome obstacles as female geologists in professional life or how to arrange professional and private life – are explained in a face-to-face-cooperation. Another important point is to make female geologists personally visible.

Barbara Murphy

President of the American Institute of Professional Geologists (AIPG), USA

1. How and when did you take the decision to become a geologist?

My interest in the Earth Sciences started when I was quite young. I had a dinosaur set that I used to play with and I liked going to museums and reading books about dinosaurs. I spent a lot of time outside playing "explorer" in the countryside. I had an earth science class in the first year of high school and found it interesting to learn about the Earth. I also had other science courses such as biology, chemistry and physics but liked Earth Sciences the most. The other factor was that I also enjoyed doing things outside, such as hiking, camping, photography, canoeing, horseback riding and other out-of-door activities, so becoming a geologist was of interest to me when I applied to colleges. I took many geology courses in college, went to summer geology field camp, and completed some field research projects in the summer while in college. One summer field research project was in northern Labrador, Canada where I was thought to be the 4th person in modern times to be there, so this was part of my interest in "exploring". I was also fortunate that I had several great college professors who passed on their enthusiasm for studying geology. I think these various factors led me to earn a college degree in geology and become a professional geologist.

> ***« I was also fortunate that I had several great college professors who passed on their enthusiasm for studying geology. »***

2. Please describe your experiences as a woman during your studies in geology.

My academic background included a co-educational college preparatory high school that encouraged equality among gender and race so I grew up with a strong sense of equality and ability. I attended college in the early 1970s. The undergraduate college I attended was one of the top liberal arts colleges in the US; there were several top liberal arts colleges in the area so, as geology majors,we were also encouraged to take geology courses at neighbouring colleges to add to our academic background. I was fortunate in college to be well regarded and have thoughtful discussions with other students and faculty about geology and other topics. We were encouraged to undertake research projects with the faculty and submit abstracts/papers to professional journals for publication or for presentation at professional meetings.

3. What were your experiences as a female geologist during your first years of professional life?

During my professional life, my focus has been to be a good geologist. I wanted to be known for doing good work, learning new skills, completing my work on schedule, being enthusiastic about my work and for working well with my colleagues. I did not often think about being a "female geologist". One early event though, I had interviewed for a job with the federal government and was offered the job a few weeks later, and started workshortly thereafter. Between interviewing for the job and accepting the job, I got married. I still remember while I was completing the various employment forms, that the guy who had interviewed me and hired me, came into the office and said "you didn't tell me you were married". My response was factual, that I had married after the interview and I didn't remember him even asking the question..............I can't remember if that question was even allowed to be asked at the time. Employment laws have changed and I believe that question may not be asked now. I suspect this guy was looking for a date and not just a geologist to complete the work.Other than that one incident, I feel that most of the time, I was working as a geologist and not referred to as a "female" geologist nor treated differently when working on a variety of projects. From working at the federal government for a few months in a temporary job, to working in a large international engineering/environmental consulting firm for 22 years, and then with a smaller hydrogeology/environmental geology consulting firm for more than 12 years, I have been fortunate to work with many very professional people and conduct numerous interesting projects. I think my willingness to work hard and also from being a professional geologist, that I was assigned a wide variety of projects – some were very prominent projects – and it was a nice honour to be assigned these and to work with geologists, engineers, and other resource specialists.

My first professional job was doing research and field work on locating active and historic mining properties for a portion of the State of Arizona for the federal government. It was a good way to get to know the geology and mineral resources of a portion of the State, review old mine files, and to travel to these sites by truck or helicopter. It was also a way to get to know other geologists in the federal and state government. After working as a geologist for the federal government, I worked for a large international engineering/environmental consulting firm for 22 years and worked on coal resource evaluations; mine permitting and related environmental work; siting and design of highways, dams, bridges, transmission line, pipelines, landfills; flood control and water storage projects; Superfund remedial investigation/feasibility studies; military site use environmental evaluations; land exchange applications; and public meeting information, legal support and expert witness reporting for environmental sites. The types of projects were quite diverse and afforded an opportunity to evaluate and report some projects on a regional basis while others require evaluations in the parts per billion realm. In the 1970s and 1980s, most of the women in the company were administrative staff but that started changing in the 1990s.Over the years more women were hired as geologists and engineers and other professional staff so the make-up of the company began to change from very male dominated to more balanced.

Through much of my early career, I worked mostly with men and a few women but I wasn't that focused on that fact. It was fun when I was expecting my first baby in the 1980s, to have a surprise baby shower attended by all of the men in the office and one of the top principals in the firm. They had never been to a baby shower. Thank goodness there were no silly games – just beer, chips, and a cake – and some very nice gifts. The company I worked for at the time allowed me to switch to working part time for several years when my children were young. They were also flexible about my taking work home and completing work outside of the office. I was very appreciative of being able to continue to work but also to spend more time with my children and husband. This was before computers were readily available to work from home. Each year was a bit different as my daughters got older and were in school but I was glad to work out an arrangement to continue work on a part time basis for several years.

4. What where the most important obstacles you met with during your professional life as a female geologist?

I think the biggest challenges were trying to balance work and family. I think what I learned was to communicate with my boss and to think of solutions to continue to work part time in the office, at home, or whatever was necessary to try to keep a balance.

5. What are in your opinion the advantages of starting a professional career as a woman?

I am not quite sure how to respond to this question.People are so different and I enjoy working with most men and women.I don't know if there is an advantage professionally as a woman or if it's having a personality where taking the time to listen thoughtfully adds to a sense of trust and openness and working together.

6. How do you feel about executing a key position in the field of geology from the point of view of a woman?

I think in serving in a key position in the field of geology, that it's important to take the time to listen, be enthusiastic, and make problem solving a team effort so that all involved feel they have made a contribution. Maybe women are better listeners than men but that is certainly not always the case.

7. According to your experience, how are female geologists perceived in your organization/company?

From the standpoint of the American Institute of Professional Geologists (AIPG), I am not really aware of any separate perception about women/female geologists. The issues that AIPG addresses typically involve the profession and have not been male/female issues. I have served on the AIPG Executive Board and on various committees and in various roles at the national and section level for many years and have not felt there were male/female issues. We all seem to be working together for the good of the profession and the organization.

> *« I think the biggest challenge is to balance work and family. »*

8. Have you noticed any changes in perception during the last view years?

No.

9. To which point should our profession advance in order to make sure that the professional activity of female geologists will be perfectly accepted and integrated in the future?

It seems that we need to encourage all geologists to become active in professional organizations and to conduct their work to high professional standards. I am aware there are cultures that may not allow or encourage (or educate) women to be geologists or many other professions but that is a global challenge.

Conclusions

The responses from these three women to our questionnaire reveal a big diversity. On the one hand, this diversity is certainly linked to the different personal experiences of each of them, but on the other hand maybe also to different cultural contexts in their home countries.

In spite of the variety of the replies, some interesting points can be stressed throughout the three interviews:

- Need for positive role models: It is important to know female geologists in leading positions for women in early career phases in this profession to emphasize how different life can be in a society where equal rights for everybody play an essential role.
- Balancing work and family is a challenge.
- Gender is usually not an issue at personal level; however it is necessary to reach a point where gender will simply become irrelevant in the professional career.

Finally, we would like to draw your attention to the public consultation recently launched by the European Commission that intends to contribute to assessing the impact of possible EU measures, including legislative ones, to redress the situation in gender matters. Following this input, the Commission will take a decision on possible measures later this year.

Link to the consultation:

http://ec.europa.eu/justice/newsroom/gender-equality/opinion/120528_en.htm

Reference

European Commission, Directorate-General for Justice, 2012. Women in economic decision-making in the EU: Progress report, Luxembourg, Publications Office of the European Union, 5-9. http://ec.europa.eu/justice/newsroom/gender-equality/opinion/files/120528/women_on_board_progress_report_en.pdf

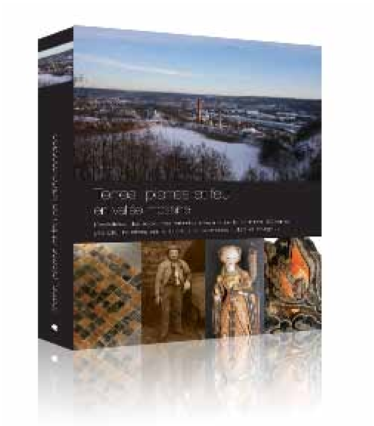
Book review:

Terres, pierres et feu en vallée mosane

*Michiel Dusar**

Terres, pierres et feu en vallée mosane. L'exploitation des ressources minérales de la commune d'Andenne: géologie, industries, cadre historique et patrimoines culturel et biologique
by Eric Goemaere (ed.)

Published by: Geological Survey of Belgium Collection GEOSCIENCES n°3
ISBN: 978-2-9600676-2-0,
Price: 28,00 €
Date: 2010
Format: hardcover A4, 544 pages.
More information and sale : http://www.naturalsciences.be/institute/structure/geology/gsb_website/products/geosciences/geo3



The antecedent Meuse valley south of Namur is a showcase for geotourism, a natural cross section through folded Devonian and Carboniferous strata and an area that has supplied many international stage names (Givetian, Frasnian, Famennian). The Meuse valley north of Namur, on its subsequent course to Liège and further on to Visé and Maastricht, remains entrenched in mainly Carboniferous limestones. From this region rich in coal, ores, raw materials and water, sprouted the industrial revolution on the continent. It is no longer considered attractive and worthy of attention. But then there is Andenne, a municipality - never a city - of ancient origin, which possessed superb examples of all these mineral resources within its territory and has thoroughly exploited them for many centuries. This legacy forms the subject of an impressive book compiled by Eric Goemaere and his 28 co-authors. They take the geoheritage perspective, describing the rocks of the Andenne, land use, architecture, collections, documents, active exploitation and man-made biodiversity resulting from mineral exploitation, prevailing today.

The book covers 440 million years of Earth history, naturally progressing through the history of human occupation and extraction activities from prehistoric to recent times. The Dinantian (Lower Carboniferous) limestones and dolomites still dominate the industrial landscape, home to world leading lime producing companies.

The Meuse valley between Namur and Andenne was equally the centre for building stone production supplying the downstream region with quality stones as far as the North Sea coast, from Roman times to the present. Hard sandstones of Lower Devonian, Famennian and Namurian age were quarried as aggregates and building stones, in particular providing a unique pink-coloured quartzitic sandstone, which became very popular among art nouveau architects. The massive sandstone deposits gave rise to the Andenne Formation of Middle to Upper Namurian age in Belgian stratigraphy. Basal Namurian 'Chokierian' shales were exploited as alum shale, upper Namurian and basal Westphalian coals were exploited from 12 rather small underground coal mines, in production till the 1960s but which have faded from the landscape today. Of greater importance are the iron, lead and zinc mines, exploiting both stratiform and vein deposits. A whole suite of minerals (66 named species) were discovered on the metallurgical waste dumps. Of special renown are the brilliant-coloured fluorites from Seilles, used in jewellery. Andenne houses a museum of ceramics dedicated to the refractory industry which manufactured the most intricate tiles, pipes, chimneys, earthenware and china, from white and variegated clays of Tertiary age, preserved in karstic depressions and quarried underground. Unique in the world is the Neandertal child unearthed in Scladina cave, delivering the oldest DNA and enabling identification of its exact age - 8 years and 17 days! The Scladina showcave serves as a research centre and a memorial to the natural and cultural heritage preserved in the earth.

The publication of this book would not have been realized without the enthusiastic support of the local authorities, ceramics museum, scientific showcave management, associations of archeologists, historians and amateur mineralogists. Therefore, it will greatly facilitate a better understanding of the remarkable link between mineral resources and prosperity during the last two thousand years (no longer sustained among the local communities) and embolden the conservationists. Although written in French, the book's logical structure, emphasis on documentation and lavish illustrations make it accessible for non-French readers who will not fail to appreciate the rich geo-industrial heritage of this historic site.

*Head of Department, Geological Survey of Belgium,
michiel.dusar@naturalsciences.be

EFG member news:

Société Géologique de France

*Antoine Bouvier**

The merging of Union Française des Géologues (UFG)*, Comité National Français de Géologie (CNFG)** and Société Géologique de France (SGF)*** into a new and larger SGF was made official through a State decree taken on November 21 2011.

This amalgamation of three different Associations in Geosciences follows the wishes of the French geological community with the following specific goals:

- to satisfy the national needs in terms of scientific and technical competence
- to meet the expectations of the public in terms of information and knowledge
- to be more representative of and heard by the industrial and academic employers
- to be active and efficient in training and employment domains (dealing specifically with young job seekers)
- to participate in the promotion of the Earth Sciences while enhancing and safeguarding professional representation at an international level.

SGF numbers now about 1700 geologists including all categories: professional, newly trained and amateur.

The new Administration Council of the SGF, established on March 13, includes 24 members while the Board (see below) is headed by Isabelle Cojan.

* UFG was founded in 1965 with the objectives of gathering together the geological practitioners, representing and defending the profession within the public sector while instigating, through a professional deontology, a best practice policy.

** CNFG was founded in 1967 by the Académie des Sciences and is the French organization in charge of any links between the IUGS, the International Geological Congress and French geologists. It proposes to the Académie des Sciences the constitution of official French delegations for attendance at the International Earth Sciences Congress.

*** SGF was founded in 1830 and aims to promote the progress of Earth and Planetary Sciences with development linked to Industry, Agriculture, Environment, Education and Civil Society.

SGF Board:

President	COJAN Isabelle
Vice-Presidents	
- in charge of the professional affair commission	JARRIGE Jean Jacques BARBEY Pierre
- in charge of the international affair commission	GAPAIS Denis
- in charge of the European relations	BOUVIER Antoine
Secretaries	GROSHENY Danièle TROUILLER Alain
Treasurer	AUGUSTE Patrick
Conservator	BUFFETAUT Eric
Publication adviser	LACOMBE Olivier

EFG news:

*Isabel Fernandez Fuentes and Anita Stein**

PERC

PERC
PAN-EUROPEAN RESERVES +
RESOURCES REPORTING
COMMITTEE

About PERC

The Pan-European Reserves & Resources Reporting Committee, PERC, is the European equivalent of the Australasian JORC, SAMREC in South Africa and similar reserves reporting standards bodies in the USA, Canada, and Chile, and with them is a constituent member of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO - www.crirsco.com). Representation on PERC covers major and minormining sectors, industrial minerals, aggregates, coal, the investment and financial community and the professional accreditation organizations, including the Institute of Materials, Minerals, and Mining (IOM3), the European Federation of Geologists, the Geological Society of London, and the Institute of Geologists of Ireland.

The PERC reporting standard is recognized by ESMA (the European Securities and Markets Authority), together with other CRIRSCO-aligned standards, for use in reporting mineral reserves, mineral resources, and exploration results on markets within the European Union, and is also accepted for reporting on stock exchanges in Canada. Because of the close similarity of all the CRIRSCO-aligned reporting standards, including the same classification system and the same set of standard definitions, it is also very simple to translate reports from one standard to another.

* EFG Office
info.efg@eurogeologists.eu

Relocation to Brussels and reconstitution

Since December 2011, a caretaker crew of PERC officials composed by Paul Gribble (acting secretary), Ruth Allington (acting treasurer) and Stephen Henley (acting chairman), and a few others have been preparing the reconstitution of PERC in a new formal structure and the relocation of the organization to Brussels.

A draft constitution for the new PERC has been prepared to replace the old 'terms of reference' and to provide a formal framework within which it will work in future, established as a not-for-profit non-governmental organization.

According to these draft statutes there will be a 'core' membership nominated by and representing the four parent organizations, with probably four members for each organization. These four parent organizations are the European Federation of Geologists (EFG), the Institute of Materials Minerals and Mining (IMMM), the Geological Society of London (GSL) and the Institute of Geologists of Ireland (IGI).

It further has been agreed that EFG shall provide an accommodation address and office facilities to PERC. EFG will furthermore provide to PERC secretarial and administrative services as may be requested and agreed, or as may be required by Belgian or other State authorities for the constitution of a not-for-profit association.

PERC update 2012 - consultation

There are a number of updates and modifications which have been included in a new draft version of the PERC Code (proposed to be renamed the PERC Reporting Standard). A consultation on these changes is now open, and comments and suggestions are invited. In particular, there are a number of questions on the principal changes which PERC would like to focus on. The new draft code and the consultation questions can be downloaded from http://www.perc.co/PERC2012draft.pdf and http://www.perc.co/PERC2012consultation.pdf.

The consultation will close at the end of June 2012, and all submissions should be sent by email in Microsoft Word .DOC or .DOCX, or PDF attachments by 17:00, British Summer Time, on **30 June 2012,** to consultation@perc.co.

For any enquiries about this consultation, or to let us know of any problems in sending your comments, you may email the above address, or alternatively perc@vmine.net.

4IPGC, 4th International Professional Geology Conference, Vancouver, Canada, 22-24 January 2012

About 4IPGC

Geoscientists Canada together with its co-conveners, the Australian Institute of Geoscientists, the European Federation of Geologists and the American Institute of Professional Geologists successfully hosted the 4th International Professional Geology Conference ("4IPGC"), in Vancouver, Canada, on January 22-24, 2012.

The IPGC conferences are unique events that take place every four years. They bring together both practising professional geoscientists and those involved in the operation of professional and regulatory bodies that govern the practice of geoscientists from across the world.

4IPGC continues the tradition of providing valuable coverage of topics related to professionalism and practice issues affecting Earth Scientists globally. Under the theme "Earth Science - Global Practice", the conference complemented the work of international professional geoscientists.

EFG participation

EFG worked in the Technical Program Committee, an international group with representatives from professional geoscience associations in Australia, Europe, the United States and Canada. The Technical Program Committee developed the two-day programme of oral presentations with seven quarter-day sessions each with a different theme.

- Securities Reporting – Global Perspective
- Geohazards – Keeping the Public Safe
- Geoscience Practice – Risk Management and Mitigation
- Practice Skills, Competencies and Capacity for Sustaining a Global Profession – Part I
- Practice Skills, Competencies and Capacity for Sustaining a Global Profession – Part II
- Geoscience in an Interdisciplinary World
- Serving Society – Effective Public Engagement

EFG chaired the sessions on Geoscience in an Interdisciplinary World and Serving Society - Effective Public Engagement. In addition, EFG members contributed to the Plenary Sessionled by EFG President, Ruth Allington, and by presentations in the different sections:

- Horses for Courses: CRIRSCO Template and UN Framework Classification Presentation: Horses for Courses, Ruth Allington, Stephen Henley.
- Terrain Motion measurements - Services to Society: Pangeo and Terrafirma projects Presentation: Terrain Motion Measurements-Services to Society, Isabel Fernandez Fuentes and David Norbury.
- Qualification framework for higher education in geology – the Euro-Ages project Presentation: Qualification framework for higher education in geology- the EuroAges project, Isabel Fernandez Fuentes and Eva Hartai.
- The Concept of sustainable development and the critical role of geoscientists in delivering it. Presentation: Geoscientists and sustainability, Ruth Allington.
- The Role of the Geological Surveys and Professional Bodies in Civil Protection Presentation: The Role of Geological Surveys and Professional Bodies in the Civil Protection, Nieves Sánchez.

All presentations made during the conference are now available in the Technical Program section of the 4IPGC website: Plenary Session, Keynote Address and Technical Sessions.

GEOTRAINET

About GEOTRAINET

The GEOTRAINET project, supported by the European Commission's IEE programme (Altener), aimed to develop a European-wide educational programme as an important step towards the certification of geothermal installations. The vision of the GEOTRAINET project was that the training and certification programmes will be recognized all over Europe and provide benchmark standards for consistent voluntary further education in the field of shallow geothermal in all participating countries.

The official activities of this project have come to an end, but the time is ripe to capitalize on the results of and knowledge harnessed by this project. To this end, EGEC and the EFG hosted a workshop on 14 October in Brussels, in order to bring together interested parties to discuss how to capitalize upon the efforts of the Geotrainet project in training drillers and designers of shallow geothermal systems. At the conclusion of this meeting it was decided to continue with this activity and a Geotrainet Kick-Off meeting was held on 15 February 2012.

Currently, working groups are reviewing the curricula of Geotrainet and preparing the statutes for the new phase. The European associations involved (EFG, EGEC, and a third partner yet to be confirmed) are working on the organizational infrastructure for the Geotrainet board.

GEOTRAINET+ meeting, Brussels, 14 October 2011.

Venue: EFG, C/O Geological Service of Belgium, Rue Jenner 13, B-1000 Brussels.

Representatives from 10 different countries gathered on 14 October 2011 in Brussels to discuss the future of the Geotrainet project that officially closed in February 2011 but is currently seeking a continuation, particularly with a view to supporting the implementation of the EC's Renewable Energy Directive. This directive requires Member States to ensure that certification and qualification schemes for equipment installers are available by the end of 2012 in the sectors of biomass, solar, shallow geothermal and heat pumps.

EGEC President Burkhard Sanner presented to the audience a proposal on the structure of a future *Geotrainet Education Committee and Training Board* that would be chaired by a *European Education Committee* (EEC) maintaining the quality standards of the training programme on an international level and managing all Geotrainet documents. The different *National Training Boards* (NTB) would be in charge of implementing the international quality standards at a national level with respect to specific national conditions. Finally, the *National Training Institutes* shall be responsible for putting the training schemes into practice. Financially, this education structure should mainly be maintained by course fees, but sponsorships as well as public funds could boulster the budget.

The participants of the Geotrainet+ meeting unanimously gave a very positive feedback on the ideas and inputs delivered and it was decided to organize a kick-off meeting in spring 2012 by which time the new bases, that is status and regulations of a new international non-profit association as well as a list of delegations per country, should be defined.

Geotrainet, Kick-Off meeting for the European Educational Board (EEB), Brussels, Belgium, 15 February 2012.

Venue: EGEC, Renewable Energy House – rue d'Arlon 63-67, B-1040 Brussels.

Fifteen delegates, representing a larger number of associations, and acting as National Coordinators met in Brussels to create the Geotrainet European Educational Board.

Delegates discussed the ambitious work programme and reviewed how to build upon the work undertaken during the Geotrainet Project.

Once the EEB was created, delegates discussed issues such as:

- GEOTRAINET curricula and learning outcome
- Training materials for future courses
- 2012 European training programme: Countries and Institutes
- GEOTRAINET training course: Application process.

The following countries are so far represented in the EEB: AT, BE, BG, DE, EE, ES, FR, HU, IE, IT, LT, PT, RO, SE and the UK. If your country is not listed, and if you are working in shallow geothermal energy (mainly ground source heat pumps), please contact your nationalgeothermal association, heat pump association, geological survey, etc. and interest them in the Geotrainet project!

Submission of articles to European Geologist magazine

The EFG calls for quality articles for future issues of European Geologist. Submissions should be in English, 1000 words for short articles and 3000 words for feature articles. An abstract of between 100 and 120 words should be included in English, French and Spanish.

Photographs or graphics are very welcome and should be sent seperately as tif or jpg files in CYMG colour.

Deadline for submission is 31 March and 30 September.

Notes for contributors

Articles for publication in the magazine should be submitted electronically to the EFG Office. These should be no longer than 3000 words including illustrations.

The article will then be sent for consideration to the Editorial Board and the text returned with recommended changes. Following discussion with the editor, the finalized article should be returned electronically with accompanying line-drawings, photographs and tables. Articles for peer review are also welcome.

Each article should be laid out in the following manner:

- Title followed by author name(s).
- A short abstract (not exceeding 120 words) in English, French and Spanish.
- Main text without illustrations (illustrations should be sent separately).
- Acknowledgements.
- References.

Where there is a REFERENCE list at the end of the article, entries must be laid out as follows: Journal articles: Author surname, initial(s). Date of publication. Title of article. Journal name, Volume number. First page - last page. Books: Author surname, initial(s). Date of publication. Title. Place of publication.

Correspondence

All correspondence regarding publication should be addressed to:

EFG Office, Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: info.efg@eurogeologists.eu

Note

All information contained in articles published in the magazine remains the responsibility of individual contributors. The Editorial Committee is not liable for any views or opinions expressed by these authors.

Further details may be found on the EFG website: www.eurogeologists.eu

Subscription

Subscription to the Magazine: 15 Euro per issue

Contact

EFG Office, Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: info.efg@eurogeologists.eu

Advertisements

EFG broadly disseminates geology-related information among geologists, geoscientific organizations and the private sector which is an important employer for our professional members, but also to the general public.

Our different communication tools are the:

- EFG website, www.eurogeologists.eu
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist Magazine, EFG's biannual magazine. Since 2010, the European Geologist Magazine is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

By means of these tools, EFG reaches approximately 50,000 European geologists as well as the international geology community.

With a view to improving the collaboration with companies, EFG proposes different advertisement options. For the individual prices of these different advertisement options please refer to the table.

Prices for advertisements

EGM	**One Insertion**	**Two Insertions**
Full page (colour)	820 Euro	1320 Euro
Half page (colour)	420 Euro	670 Euro
Quarter page (colour)	220 Euro	350 Euro
Full page (black and white)	420 Euro	670 Euro
Half page (black and white)	220 Euro	350 Euro
Quarter page (black and white)	120 Euro	200 Euro
Business card size	90 Euro	150 Euro
Preferential location	25% plus	
Price for special pages:		
Outside back cover (colour)	1200 Euro	1900 Euro
Second page (colour)	1000 Euro	1600 Euro
Second last page (colour)	1000 Euro	1600 Euro
Geonews	**Annual Price**	
Ad and regular newsfeed	1000 Euro	
EFG Homepage		
Ad and regular newsfeed	1000 Euro	
University ad		
Ad for training opportunities in the job area of the homepage	500 Euro	
Annual package		
Business card size ad in the EGM, GeoNews and homepage.	2000 Euro	

FÉDÉRATION EUROPÉENNE DES GÉOLOGUES
EUROPEAN FEDERATION OF GEOLOGISTS
FEDERACIÓN EUROPEA DE GEÓLOGOS

EFG - the voice of European Geologists

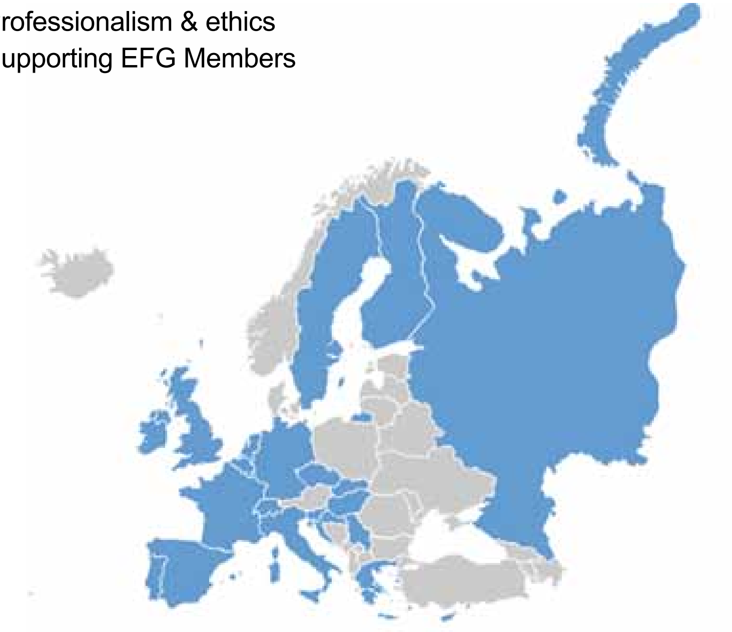
The EUROPEAN FEDERATION OF GEOLOGISTS, EFG, is a non-governmental organisation that was established in 1981 and today includes 21 national association members. It is the representative body for the geological profession in Europe.

EFG contributes to protection of the environment, public safety and responsible exploitation of natural resources by promoting excellence in the application of geoscience, by supporting research and teaching that underpins it, and also by creating public awareness of the importance of geoscience to society.

EFG encourages professional development by promoting training and Continuing Professional Development and offers validation (certification) through its internationally recognised title of European Geologist (EurGeol).

The EFG delivers its objectives through activity relating to:

- EU policies & environmental protection
- Education & outreach
- Free movement & professional titles
- Professionalism & ethics
- Supporting EFG Members



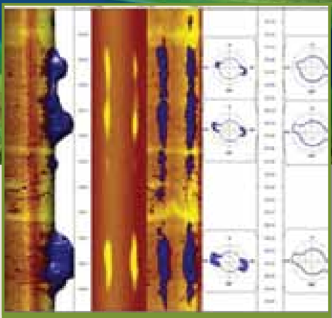
UBLG - Belgium-Lux'bourg
CGS - Croatia
CAGME - Cyprus
CAEG - Czech Republic
YKL - Finland
UFG - France
BDG - Germany

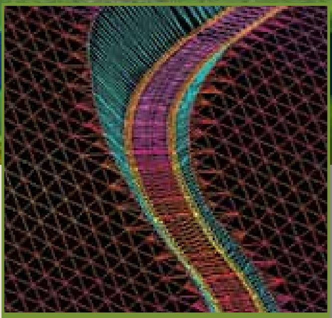
AGG - Greece
MFT - Hungary
IGI - Ireland
ANGI/CNG - Italy
KNGMG - Netherlands
APG - Portugal
NAEN - Russia

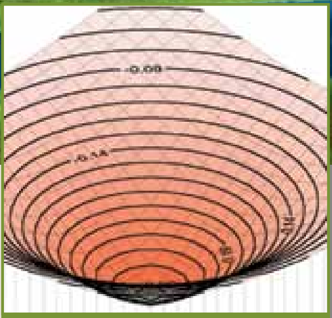
SGS - Serbia
UGAS - Slovakia
SGD - Slovenia
ICOG - Spain
SN - Sweden
CHGEOL - Switzerland
GSL - United Kingdom

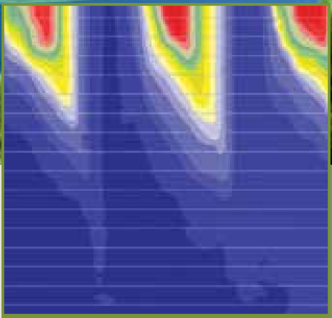
www.eurogeologists.eu

Not Just Software. . .RockWare.
For Over 29 Years.









WellCAD™

Well Log Data Management

- PC-based composite log package, combining comprehensive graphic editing and data processing tools
- Formula parser for log analysis
- Fracture and breakout analysis
- Optional modules for core logging, image analysis, LIS/DLIS import, sonic processing, deviation calculations, ODBC connectivity, automation and cross-section generation
- Integrates all data acquired in a well into a single document
- Combines excellent display, editing and analysis capabilities for well data

$3,120

QuickSurf™

Fast, Powerful Surface Modeling System for AutoCAD

- Runs inside of AutoCAD 2000-2012
- Converts surface mapping data such as point or break line data into contours, grids, triangulated irregular networks (TIN), and triangulated grids
- Dozens of imports and exports
- Topography, slope analysis, thickness maps, volumes, visibility analysis, road design
- Profiles and sections along polyline paths

$1,195

AQTESOLV™

Pumping Test, Slug Test and Single-Well Test Analysis

- All-in-one package for design and analysis of pump tests, step-drawdown tests, recovery tests, variable-rate tests, recovery tests, single-well tests and slug tests
- Active type curves and type curve families
- Visual and automatic curve matching
- Derivative matching and analysis
- Diagnostic tools for choosing solution methods

Starting at $500

Surface Water Manager™

Maintain data for Rivers, Lakes, Streams, Ponds, Oceans, or any Surface Water

- Monitor elevation, flow, ion, nutrient, pollutant, biological, zooplankton, and phytoplankton data or create new parameters
- Instantly plot a parameter over time using the new time series contour graph
- Easily create Google Earth™ maps
- 11 graph types, sample maps, statistics, and reporting tools
- Stratify lakes by thermal layer and trend data by layer
- Loading calculations, mass balance, and Trophic State Index analyses
- Easily Import data with 3 different methods – no database experience required

$999

Free trials for most of our products available at www.rockware.com

Follow us on:

RockWare®
Since 1983

European Sales
++41 91 967 52 53 • F: ++41 91 967 55 50
europe@rockware.com

US Sales
303.278.3534 • F: 303.278.4099
sales@rockware.com