Geoscience for a sustainable Earth

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Microbiological CO_2 conversion to methane in sedimentary aquifers

Being able to promote and speed up the biological conversion of CO_2 to methane in geological formations via the stimulated activity of bacteria could constitute a very advantageous strategy. United States and Canada are conducting research projects where coal seams is the geological formation targeted to host this bio-conversion process. An efficient in situ bio-reactor must combine several characteristics: good hydrogen source, or high content of electron donor species, and good permeability of the host rock. Good permeability is essential to favor the growth and functioning of bacterial strains and recovery of methane. Biofilm development could be particularly favored in porous sandstone or limestone aquifers where very good permeability is frequently encountered. A preliminary description of this concept is presented in this paper.

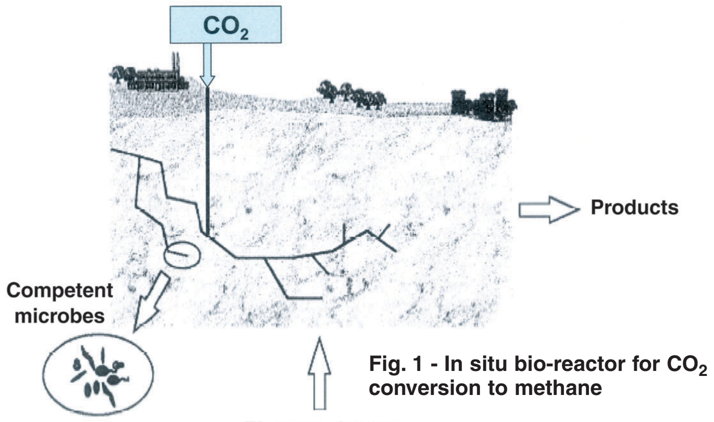

Fig. 1 - In situ bio-reactor for CO_2 conversion to methane

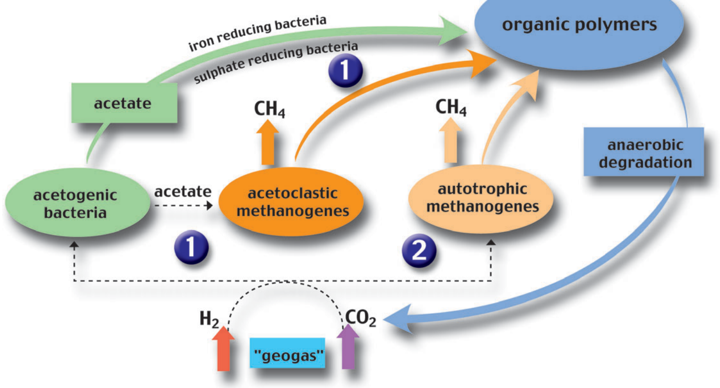

Fig. 2 - Two biogenic methane pathways

> The functioning of an "ideal" bio reaction in a porous or fractured aquifer requires that growth of one given bacterial strain be favored over that of many other different living organisms. It will also be essential to have ample feed stock (CO_2) and an electron donors available. Moreover, the drainage of the valuable product (CH_4) must be very efficient.

> Biogenic methane is the result of complex biochemical reactions by groups of bacteria during the decomposition of organic matter in anoxic environment (Pathway 1). In the context of CO_2 sequestration strategies, it seems more favorable to promote the functioning of autotrophic methanogenesis where CO_2 and H_2 are used by autotrophic strains to produce methane (Pathway 2).

Location, depth (m)	Microbial count, (cell ml^{-1})	Reference
Paris Basin Dogger limestone aquifer 1000 - 2000	$10^3 - 10^3$	(Daumas et al., 1986)
Montana Deep aquifer, 1200 - 1800	10^3	(Olson et al., 1981)
Columbia River Deep Basalt aquifers, 1200 (viable counts)	$10^3 - 10^4$	(Stevens and McKinley, 1995)
Aspö deep granitic groundwaters, 192 - 860	10^5	(Petersen and Ekendahl, 1992)

Table 1 - Total microbial counts in subsurface environments

> Table 1 gives some examples of microbial counts in subsurface environments. The study in the Paris Basin Dogger limestone aquifer has revealed the presence of sulfate reducing species and autotrophic methanogens. The fluid chemistry of the Dogger aquifer is in fact highly variable with respect to its sulfate and chloride content. Hence, the conditions for the development of the different strains may vary widely throughout the aquifer.

$$Fe^0 + 2\,CO_2 + 2H_2O \rightarrow Fe^{2+} + 2\,HCO_3^- + H_2 \uparrow$$

$$Fe^{2+} + 2\,HCO_3 \longrightarrow FeCO_{3(s)} \downarrow + CO_2 \uparrow + H_2O$$

$$Fe^0 + CO_2 + H_2O \longrightarrow FeCO_{3(s)} \downarrow + H2$$

Corrosion of iron metal in the presence of CO_2 and water

Environment	Hydrogen at 20 °C	Reference
Geothermal springs	46 – 48 mM	(Conrad et al., 1985)
Fennoscandian Shield	60 µM – 28 mM	(Sherwood Lollar et al., 1993a)
Canadian Shield	10 µM – 300 mM	(Devol et al., 1984)
Columbia Deep Basalt groundwaters	0.01 – 100 µM	(Stevens and McKinley, 1995)
Äspö granitic groundwaters	0.05 – 100 µM	(Kotelnikova, 1996, 1997)

Table 2 - Concentrations of hydrogen detected in different subsurface environments

> Although table 2 demonstrates that hydrogen concentration can reach quite appreciable amounts in a geothermal environment. Its in situ production in large quantities is probably the most difficult step for the functioning of the biochemical process. The very well known, and sometimes detrimental mechanism of iron reduction in the presence of CO_2 could provide some solution to this problem.

> The GESTCO project (fig 3), carried out in the European Commission 5th Framework Program, has shown that some important CO_2 point sources are located immediately above, or very near the Dogger limestone aquifers. In the near future, we propose to study the feasibility of the concept of CO_2 bio-reduction in the Dogger limestone aquifer.

Other possibilities could exist in the underlying Triassic sandstone aquifer, but today, very little is known about the bacteria living in this Triassic horizons. The general concept is summarized in fig 4 : CO_2 could be injected in a first injection well, a mixture of CO_2 and iron scrap in a second injection well, so that methane could then be produced in the upper part of the reservoir and recovered through a production well. At this very preliminary stage, numerous questions remain unsolved but we think that this novel concept deserves further research work.

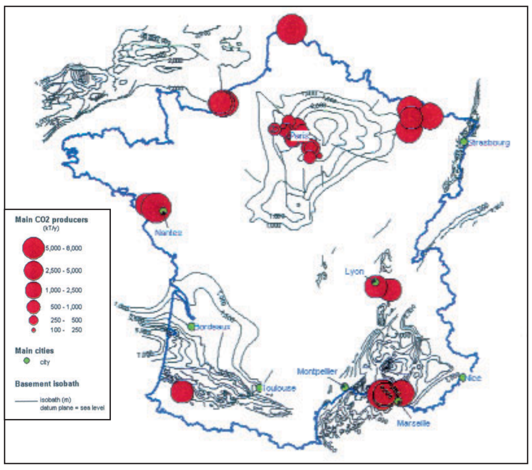

Fig.3 - Main CO_2 Sources and deep Aquifers

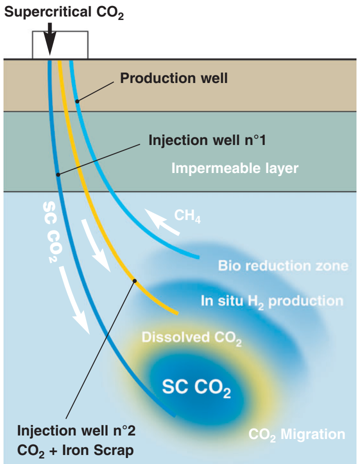

Fig.4 - General concept of microbiological CO_2 conversion to methane in a sedimentary aquifer

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