

# MONITORING GEOLOGICAL STORAGE THE IN SALAH GAS CO<sub>2</sub> STORAGE PROJECT

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## ABSTRACT

In Salah Gas (ISG) is a Joint Venture (JV) Project between BP (33%), Sonatrach (35%) and Statoil (32%). The project comprises a phased development of eight gas fields located in the Ahnet-Timimoun Basin in the Algeria Central Sahara. The initial development focuses on the exploitation of the gas reserves within the 3 northern fields of Krechba, Teguentour and Reg to deliver the contracted sales gas stream of 9 bcm/yr. These gas fields contain CO<sub>2</sub> concentrations ranging between 1 to 9% which is above the export gas specification of 0.3% and therefore require CO<sub>2</sub> removal facilities. In addition to the CO<sub>2</sub> removal facilities, and instead of employing atmospheric disposal of the CO<sub>2</sub> ISG has made a further discretionary investment to enable compression and re-injection of the produced CO<sub>2</sub> stream (up to 70mmscf/d or 1.2 million tonnes per year) for geological storage. The CO<sub>2</sub> stream is re-injected back into the aquifer zone of one of the shallow gas producing reservoirs. This will be the world's first CO<sub>2</sub> storage operation in an actively produced gas reservoir. Production operations and CO<sub>2</sub> re-injection are planned to start during the middle of 2004.

Tools used in the design of the project have been presented at earlier conferences, including GHGT-6 in Kyoto. This paper provides an update on the In Salah Gas Project and the accompanying CO<sub>2</sub> Storage Assurance Project, which it is proposed will be managed under the umbrella of a Joint Industry Project. This CO<sub>2</sub> project differs significantly in geological character and storage process from the existing Sleipner and Weyburn monitoring projects and offers an ideal opportunity to gain important additional information on the permanence and safety of CO<sub>2</sub> geologic storage.

The ISG Project provides an important opportunity to study a gas field development project where geological storage at a field scale is employed to mitigate the environmental impact of the produced CO<sub>2</sub> stream, which represents ~60% of the projects emissions footprint.

## THE IN SALAH GAS CO<sub>2</sub> STORAGE PROJECT

The ISG project is a multi-field development comprising eight gas fields located in the Central Algerian Sahara. The initial development will exploit the gas reserves present in the three northern fields of Krechba, Teguentour and Reg. These fields will sustain production for up to 10 years after which development of the southern fields is required to sustain the plateau production rate of 9 bcm/yr. The production profile of the project is show Figure-1 where the gross gas production stream is plotted by field and the associated CO<sub>2</sub> stream shown separately. Although the gross gas production remains steady at 9bcm/yr the CO<sub>2</sub> stream increases over the first three years of production as the CO<sub>2</sub> rich Krechba Devonian reservoir is brought on stream.

A commitment by the shareholders to manage down the emissions footprint of the project and not to employ atmospheric venting of the CO<sub>2</sub> stream meant that an alternative solution needed to be identified by the project. Options for sequestration of the CO<sub>2</sub> production stream centred on the identification of robust sub-surface storage sites close to the planned In Salah Gas process facilities. These sites required the reservoir cap seal integrity be demonstrated, that sufficient storage capacity be available to meet the predicted CO<sub>2</sub> volumes estimated at ~12 bcm, that moderate to good reservoir properties be present and that the reservoir pressure be below 6000psi to negate the need to move into untested specialist compression equipment. Several opportunities for storage were evaluated during the design stage and ranged from distributed storage at each field location, to a single centralised facility and storage site. The high cost and increased system complexity associated with distributed storage, primarily around the need to employ multiple CO<sub>2</sub> stripping units, precluded this as an option and led to the identification of the shallow Krechba Carboniferous reservoir as the most suitable solution.

The storage scheme has the CO<sub>2</sub> re-injection directed into the aquifer region in the shallow Carboniferous reservoir, down-dip of the main hydrocarbon accumulation. To achieve a successful scheme a number of peripheral injection wells were required to mitigate potentially high injection pressures, access the peripheral reservoir volumes for sub-surface storage and manage the placement of the injected CO<sub>2</sub> stream. Effective placement of the CO<sub>2</sub> is important and requires that the injected gas which is driven by gravitational forces and the pressure sink associated with production, is retained within the aquifer zone and does not enter the main field area until after it has been depleted and abandoned, this projected to be after 25 to 30 years of production. The Carboniferous reservoir at Krechba offered the benefit of a high quality sub-surface data set, with good well coverage and associated log, core and test data, and importantly a high quality 3D seismic survey. These combined well and seismic datasets proved invaluable in assisting our understanding of the reservoir geology and for modelling field performance.

## KRECHBA FIELD GEOLOGY

The main gas bearing Carboniferous reservoir interval is prognosed from well and seismic data to comprise an incised valley feature deposit with the thickest and most extensive net reservoir development seen to lie along the axis of the valley, see Figure-2a. This section is the main gas bearing interval.

Reservoir areas outside the gas-water contact to the south and east are predicted from seismic and analogues to contain less well developed net sandstones, which is confirmed by the seismic net thickness interpretation and the development of a seismic coherency dataset shown in Figure-2b, which highlights reservoir architecture and sand body geometries within the carboniferous reservoir section. This work, calibrated to the existing Krechba well stock, shows excellent agreement along the axis of the valley system where all of the 9 existing wells and 4 new drill development wells are located. The sharp contrast seen in the reservoirs non-pay character in the seismic data was confirmed in 1998 by the drilling of the appraisal well Kb-10, which lies outside the valley-fill to the west and confirmed the validity of the seismically derived attributes. To the east there were no wells at the time of sanction, so the seismic response in this area was less well constrained and therefore carried greater uncertainty and risk. This has been addressed by the drilling of the first CO<sub>2</sub> injector Kb-501.

The relationship between seismic amplitude and reservoir presence in Krechba was established shortly after acquisition of the 3D dataset in 1997/8. Amplitude maps and their interpretation, aided by seismic modelling, suggested that the reservoir was not continuous across the whole field. This interpretation was successfully tested by two appraisal wells drilled in 1998. More recently, seismic techniques based on attribute interpretation, coherence analysis, spectral decomposition and Q-filter techniques have increased our understanding of this reservoir and have allowed a quantitative description to be built of the net-pay and reservoir sand body porosity. This heightened understanding of reservoir continuity, which clearly identifies a number of massive sinuous sand bodies within the axis of the system and a number of smaller feeder type features towards the edge of the valley-fill system has proved invaluable in the exercise of well targeting and the subsequent prediction of CO<sub>2</sub> migration and storage behaviour.

## **CURRENT PROJECT STATUS**

Recent development drilling activities in the Krechba field has seen the drilling of three horizontal production wells and two CO<sub>2</sub> injection wells into the Carboniferous reservoir. Real-time integration of porosity data from the bit with subsurface porosity models derived from 3D seismic data were used to steer the wells and optimize the reservoir quality penetrated. A third injection well Kb-502 will be finished 3Q04 to complete the injection well stock. These wells, located within the northern and eastern areas of the Carboniferous reservoir, see Figure-3, will be employed to store all of the produced gas CO<sub>2</sub> stream. The wells, each with horizontal sections in excess of 1000 metres, have been cleaned up and completed with ported liners in preparation for injection start-up. Water injection tests were performed to provide an estimate of their injectivity potential, but early injection data are required before a more comprehensive evaluation can be completed.

Reservoir simulation models for the field have been re-built to incorporate data obtained during drilling of the production and injection wells. These reservoir performance prediction models are designed to allow management of both hydrocarbon depletion and CO<sub>2</sub> storage processes, and will be further refined as early production and injection data become available.

A management strategy has been developed to provide context for operational decisions during the commissioning, start-up and operation of the storage scheme and focuses on proactive maintenance and performance monitoring of the plant and the field to maintain high operational efficiency for the CO<sub>2</sub> system. The activities of the ISG Project will be focused on delivering a cost effective strategy for the management of both the production and injection aspects of the project and will target key data elements to allow decision making in the short to medium term. Although the opportunity exists for acquiring a wealth of data on the CO<sub>2</sub> re-injection project, this is not viewed as a core activity in respect of delivering value for the project. The opportunity does, however exist for the project to be used for learning and to demonstrate technical innovation in a fully operational world scale geological storage scheme. It is proposed that such activities would be managed under the umbrella of a Joint Industrial Project.

## **THE IN SALAH GAS CO<sub>2</sub> STORAGE ASSURANCE JOINT INDUSTRY PROJECT**

Increased utilization of capture and storage of CO<sub>2</sub> across the world will require that a number of issues be addressed. The key technical issue to be addressed when evaluating capture and storage is the need to improve the understanding of long-term storage performance and in particular, the duration of storage. This then strongly influences the social acceptability of this technology and its eligibility within commercial mechanisms such as credit trading that could assist in managing down costs.

To improve the global understanding of the performance of CO<sub>2</sub> storage in geological systems and to validate and improve tools for the prediction of performance, a number of extensively monitored test sites will be required. There are more than forty small-scale storage projects currently injecting H<sub>2</sub>S/CO<sub>2</sub> mixtures into geologic formations in Canada and about seventy Enhanced Oil Recovery (EOR) projects operating world-wide. However, only two sites have the level of extensive monitoring required for understanding long-term CO<sub>2</sub> storage performance. These are the Sleipner field in the North Sea where CO<sub>2</sub> is injected into a saline aquifer and the Weyburn EOR flood in Saskatchewan, Canada. The significant differences that exist between geological reservoirs and the types of storage process that may be employed means that further monitored storage sites will be required to adequately validate our understanding of this process and the technology that can be used to monitor performance.

The largest hurdle facing CO<sub>2</sub> capture and geological storage as a GHG mitigation technique is acceptance that geological storage is secure. It

is proposed that the In Salah Gas CO<sub>2</sub> Storage Assurance Joint Industry Project will be a public demonstration of storage assurance. It is planned to cover a 5-6 year, \$30 million program focused on demonstrating best-practice application of CO<sub>2</sub> storage monitoring, integrity and verification technologies. This will be a Joint Industry Project (JIP) and participation will be invited from industry, academia, government and non-government organizations.

The project is expected to lead in setting precedents for monitoring, regulation and verification of geological CO<sub>2</sub> storage and establish CO<sub>2</sub> capture and storage (CCS) as eligible for GHG mitigation credits.

The project will require extensive monitoring of the storage site and overburden using a range of existing and novel technologies, including repeat 3D seismic, well-bore aquifer and surface monitoring, plus extensive modelling of the whole system. An observation well will be considered. In addition there would be comprehensive risk analysis and modelling of the storage system and leakage risks. State of the art visualization tools will be developed which will input to an extensive outreach programme.

Monitoring at In Salah Gas will serve a number of purposes:

- To enable optimization and management of hydrocarbon production (rates and reserves over time) by quantifying the impact of CO<sub>2</sub> re-injection and reducing uncertainties over time.
- To develop a detailed understanding of the behaviour of the CO<sub>2</sub> storage at In Salah with a view to reducing uncertainties in predictions of long term storage performance.
- To test and demonstrate the technologies necessary for early detection of seepage of CO<sub>2</sub> out of the primary containment to enable intervention and maintain the integrity of long-term storage.

A five year Joint Industry Project is being launched to address these issues. The project will commence during 2004 with initial acquisition of baseline data and be followed by a detailed monitoring programme once CO<sub>2</sub> re-injection has commenced in mid year.

It is proposed that the JIP work programme will comprise the following elements:

- Project Management
- Establishing a Project Baseline
- Imaging CO<sub>2</sub> Migration
- Well Based Monitoring
- Rock / Fluid Interactions
- Detecting Surface (Geologic) Seepage
- Integration and Risk Assessment
- Communications

The JIP data elements will build on the key project needs and will provide a comprehensive understanding of the CO<sub>2</sub> injection process in an active field environment, enabling project learning to be transferred easily to other similar oil and gas field operations or storage opportunities.

## REFERENCES

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2. Riddiford, F, Tourqui, A, Bishop, C, Taylor, B and Smith, M. 2002. A Cleaner Development. The In Salah Gas Project, Algeria. *GHGT6* Kyoto.

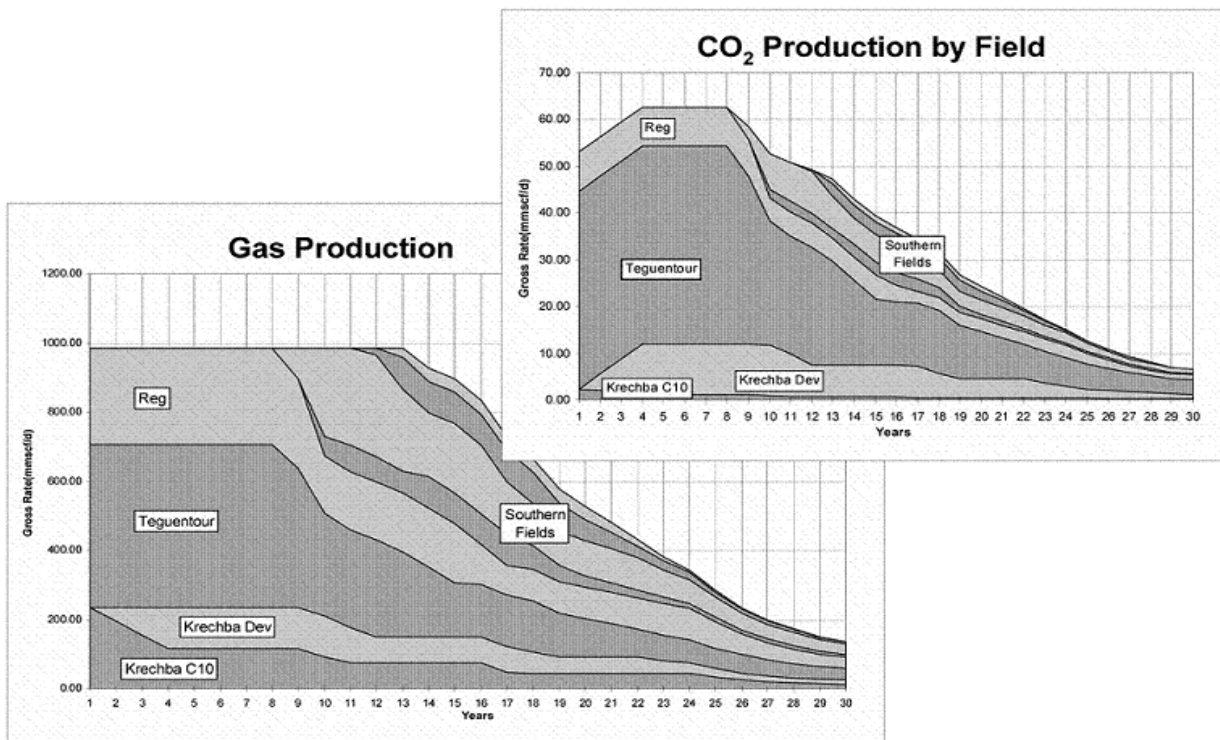


Figure 1: In Salah gas production and CO<sub>2</sub> injection profiles.

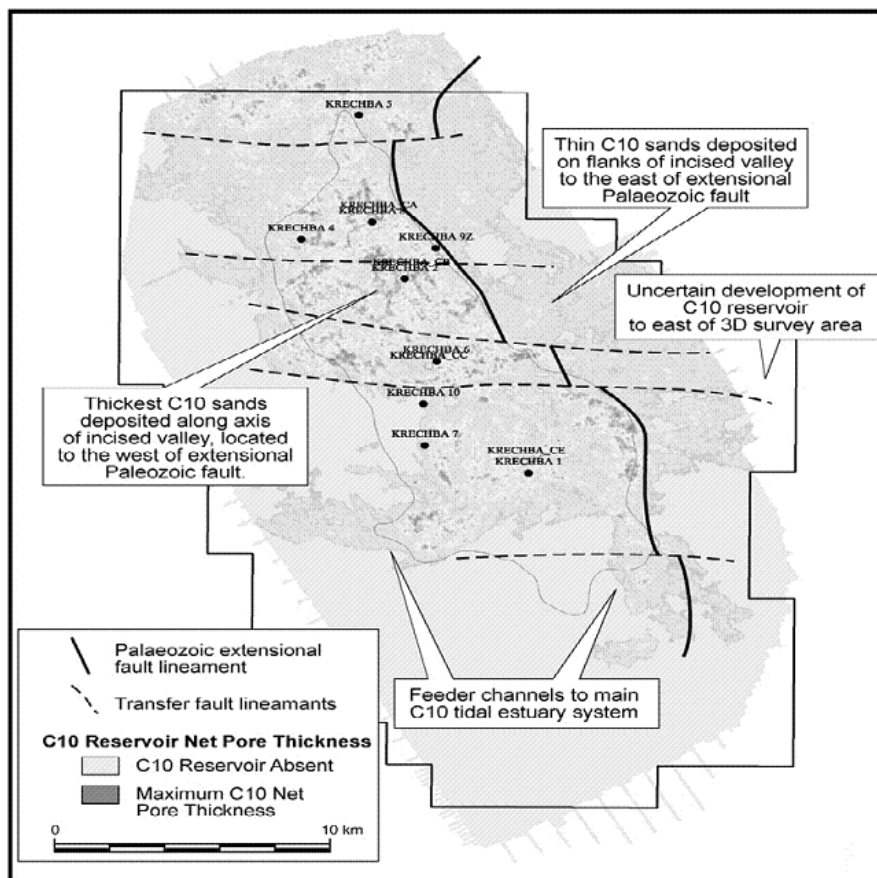


Figure 2a: Net pore thickness C10 reservoir

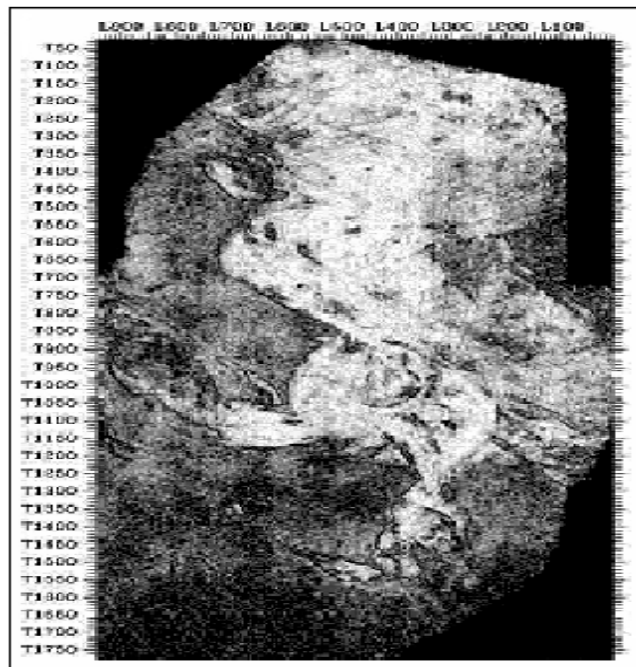
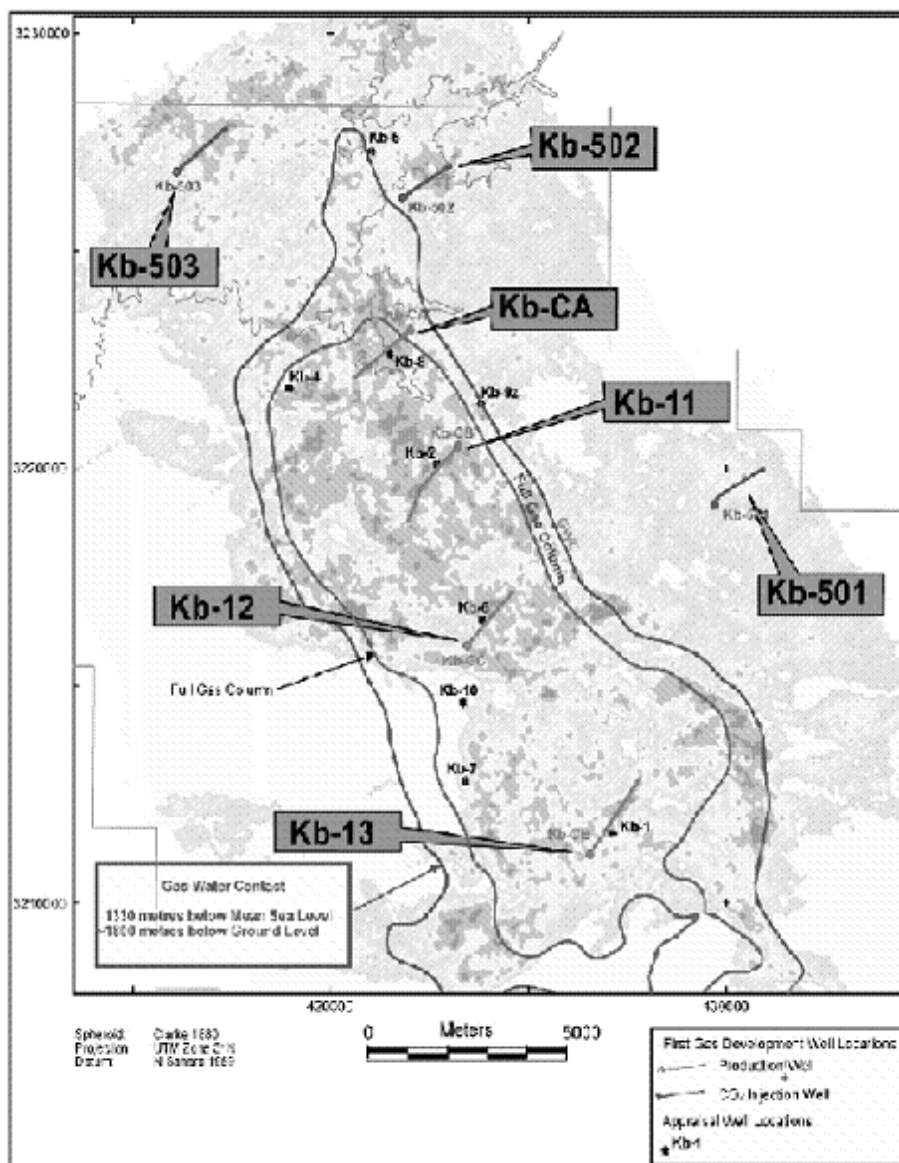


Figure 2b: Coherency displays C10 reservoir



**Figure 3:** Krechba field layout showing CO<sub>2</sub> injectors and producers