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Options for CO_2 sequestration in Kuwait

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Abstract

In preparation for future requirements to abate CO_2 emission levels, a CO_2 storage feasibility study was carried out for the country of Kuwait. At present, no definite plans exist to install capture facilities at the larger emission points in the country; the study presented is one of the first steps to prepare the country for a low-carbon future. The first step was to investigate formations for potential CO_2 storage capacity in a country-wide screening. Two regions within Kuwait were shortlisted for subsequent evaluation; one site was selected for detailed characterization and assessment. The main result of the study was that the Kra Al-Maru Trend is likely to be a first-class CO_2 storage site. Pending verification of the findings we conclude that the Kra Al-Maru Trend provides the storage capacity of at least 440 Mt, which is equivalent to the CO_2 produced in a period of 40 years by the Doha East and Doha West power plants combined. The subsurface of the Kra Al-Maru Trend can store this CO_2 at the rate that is currently emitted to the atmosphere by the two power plants. No showstoppers were discovered to safe and secure storage of CO_2. Storing CO_2 in the subsurface of the Kra Al-Maru Trend offers the possibility of future back-production of the CO_2 stored. Verification of these conclusions is required, through a dedicated appraisal well that targets the Cretaceous interval at depths between about 2000 m and 3000 m (6000 - 9000 ft).

Keywords: geological storage; CCS; Kuwait; Doha East; Doha West; Kra Al-Maru.

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1. Introduction

In the context of global climate change the reduction of greenhouse gases emission is needed. In Kuwait, effects of climate change are already apparent, as summer temperatures in the region are rising to the highest levels measured on the planet [1]. The country is also vulnerable to sea level rise, as much of the countries' populations and industries reside in coastal areas. As the need for climate actions is apparent, the State of Kuwait ratified the UNFCCC on March 28th 1995, ratified the Kyoto Protocol on March 11th 2005, and recently signed the Paris Agreement.

The Intergovernmental Panel on Climate Change and the International Energy Agency have identified CCUS as a key mitigation technology [2, 3]. Integrated demonstration projects are currently being developed worldwide to prove the feasibility of CCS [4].

In the Gulf Cooperation Council (GCC) region, the first large-scale carbon capture project is located in Saudi-Arabia and is combined with enhanced oil recovery (CO_2-EOR) [5]. The United Arab Emirates have another EOR project under construction in Abu Dhabi [6]. These projects test the feasibility of capturing and utilizing CO_2 and may lead the way to significant greenhouse gas emission reductions in the GCC region, by injecting and storing the CO_2 into the subsurface.

This paper reports on a study into the potential storage capacity of the Kuwaiti subsurface for CO_2. The paper presents the results of an assessment of the total storage capacity for CO_2 in Kuwait and shows in some detail one of the best candidate storage sites, the Kra Al-Maru Trend.

Activities started with a study of the regional geology of Kuwait. Formations and structures were investigated for potential CO_2 storage capacity in a country-wide screening. Two regions were shortlisted for further evaluation and subsequently a single site was characterized and analyzed in more detail. The study included an assessment of the feasibility of back-producing stored CO_2 for potential future use, setting up monitoring and contingency plans, as well as a first-order assessment of the cost of transporting and storing CO_2.

2. Regional geology in relation to CO_2 storage

Between 1938, when oil was first discovered in Kuwait, and 1975, when the Kuwaiti oil industry was nationalized, all oil discoveries were limited to the Cretaceous and Tertiary reservoirs. After 1975, a number of deep exploration wells discovered oil in other reservoirs within the Jurassic section [7]. These hydrocarbons are mainly found in structural and stratigraphic traps usually elongated north-south [8]. For screening purposes it was assumed that these traps can also hold CO_2.

Due to the relative tectonic stability of the region, mainly primary porosity and permeability of the reservoir rocks play a role in providing reservoir space. Regarding seals, anhydrite forms one of the best seals, and several widely distributed formations in Kuwait consist of this lithology. They include, e.g., the Rus, Hith, Gotnia, and Jilh Formations (Fig. 1). However, some shaley and marly formations such as the Ahmadi or Ratawi Formations can also act as effective seals due to the increasing burial depth [9].

Many of the Cretaceous reservoirs are sealed by the Ahmadi Formation, a regional shale ranging in thickness from 170 ft in the west to 420 ft in the east. The reservoirs in the Jurassic are sealed by the Gotnia Formation which consists of salt and anhydrite and ranges between 300 ft and more than 1500 ft [10].

3. Country wide screening

An inventory of potential CO_2 storage locations in saline aquifer structures was created by constructing a regional geological model of Kuwait and identifying structural features that could hold and trap CO_2. The Jurassic was not considered a target for a potential CO_2 storage project, because the Jurassic is known to be over-pressured and potentially less permeable compared to some overlying younger formations. Even more important, however, is the probability of undesired interference of CO_2 storage with current oil production, which predominantly takes place from Jurassic formations. The focus was, therefore, on the selection of closures in Cretaceous and Tertiary formations. However, while the available 3D geological model was reliable for Jurassic formations, little structural control was available for the shallower formations; trap volumes derived from the model were likely to overestimate storage capacity for Cretaceous and Tertiary formations. The result is shown in Fig. 2, for the Burgan formation.

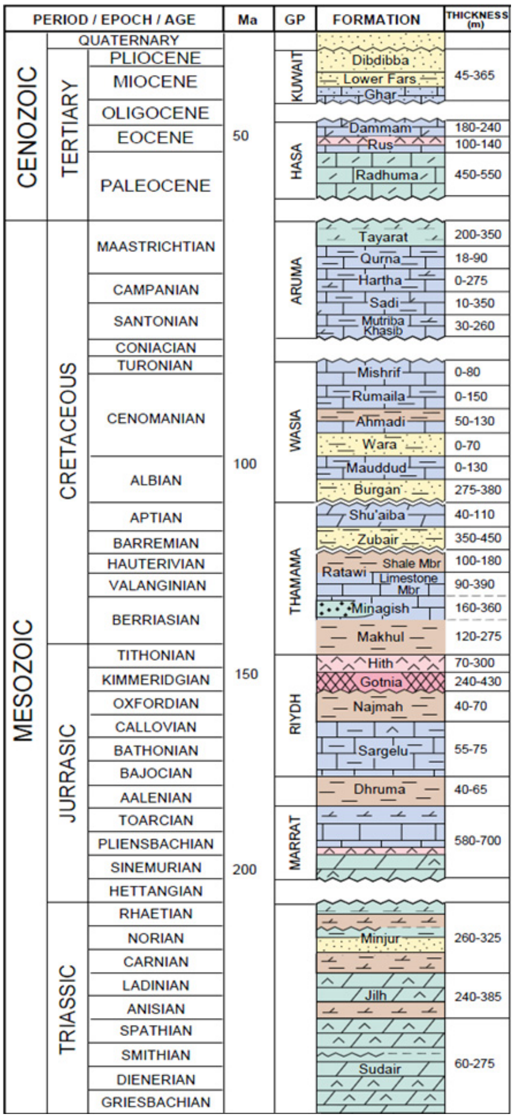

Figure 1. Chronostratigraphic column and tectonostratigraphy of onshore Kuwait (after [11]).

The criteria listed in Table 1 were applied in a country-wide inventory of storage options. Extensive discussion and weighing of the criteria, in which data availability and not interfering with oil and gas production were dominant, resulted in the shortlisting of two structures (Fig. 2):

- Kra Al-Maru trend, which includes the Kra Al-Maru (KM) and Kahluhlah (KL) fields.
- Rahiyah structure, which includes the Rahiyah (RH), Um Ross (UR) and Kabd (KB) fields.

High-level estimates indicate significant storage capacities for these two structures. Analyses of potential CO_2 sources also indicated the proximity of two such sources: the Doha East and Doha West power stations, emitting about 4.6 Mtpa and 7.7 Mtpa of CO_2, respectively.

Table 1. Criteria for selecting potential CO_2 storage sites in Kuwait, applied in the country-wide storage capacity screening.

Criteria	Explanation
Reservoirs deeper than 1000 m	To optimize pore space utilization, CO_2 must be in dense phase. Therefore, only reservoirs at depths greater than 1000 m were considered.
No interference with hydrocarbon production activities	Most oil fields produce from Jurassic formations. The storage reservoir should preferably be located above the youngest known oil bearing reservoir in its vicinity.
Fresh water bearing reservoirs not to be affected	Risk to the Dammam and Fars Formation is to be minimized.
Avoid over-pressured Jurassic formations	Formations below the Hith Formation tend to be over pressured. This is potentially undesirable for CO_2 injection.
Preference for structural traps	This is related to the wish to have the option of future back-production of the CO_2.

3.1. Initial risk assessment and evaluation

An initial risk assessment identified the following key risks for the areas:

- plume migration within the reservoir formations;
- integrity of operational legacy wells in the area;
- integrity of abandoned wells in the area;
- good cap rock quality;
- re-activation of existing faults;
- migration along faults.

Evaluation of Cretaceous structures in a local geological model derived from 3D seismic data proved that these structural closures were indeed less pronounced than those in Jurassic formations. The Rahiyah structure, while having closures in the Jurassic, did now show closures in the Cretaceous, but has an updip slope towards the Minagish field. Closures were found for the Kra Al-Maru Trend, as well as a suitable cap rock, likely to be able to hold CO_2 for future re-production. Interference with ongoing oil production is considered to be minimal in both regions, as most of the fields in the regions are not being produced yet. These results led to the selection of the Kra Al-Maru Trend for a detailed CO_2 storage feasibility study.

4. Detailed characterization of the Kra Al-Maru Trend

The detailed characterization of a storage site aims to identify, quantify and manage risks in various disciplines. In the quest to determine the conditions under which CO_2 can be injected and stored safely, and trying to identify the weak spots of the storage system, an iterative and interdisciplinary approach is required. This means that geologists, reservoir engineers, geomechanical engineers, geochemical engineers and well engineers worked closely together, constantly updating their various simulation models based on discussions and outcomes of others models. The workflow developed in the EU FP7 SiteChar project was used [12].

For the storage site in the Kra Al-Maru Trend a refined static geological 3D model was set up, to be down-scaled or modified to sizes and shapes as required by various disciplines (dynamic flow modelling, geomechanical modelling, geochemical analysis, etc.).

The characterization resulted in a detailed understanding of the behavior of the CO_2 in the storage formations, the pressure increases induced by the injection process and potential migration or leakage paths. This provided the basis for a more detailed definition of risks.

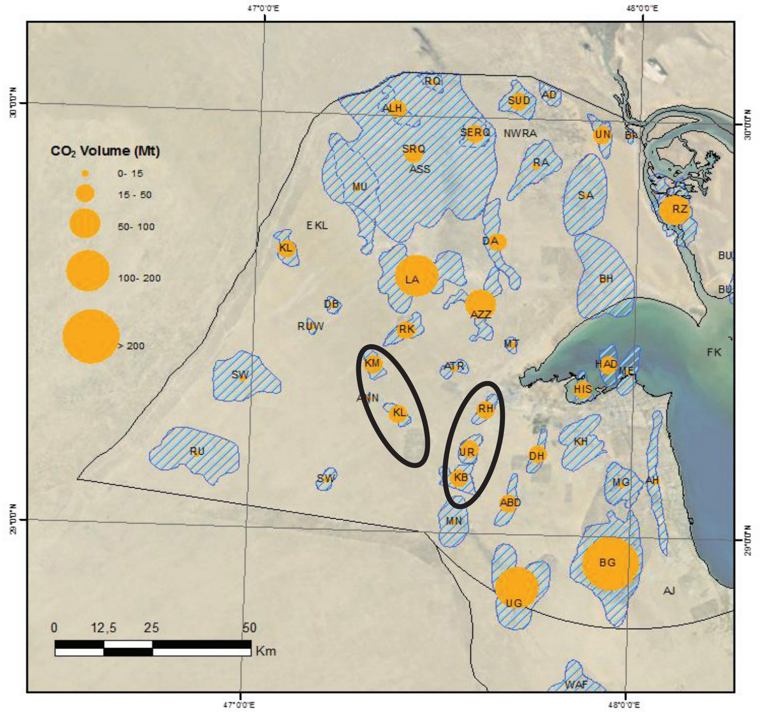

Figure 2. Map of Kuwait, with superimposed the assumed Cretaceous structural closures (blue, hashed outlines) and their volume in terms of CO_2 capacity (orange disks); volumes shown apply to the Burgan formation. All of the closures are associated with oil fields, especially in formations of Jurassic age; field names are given in abbreviations. Due to lack of structural control for Cretaceous and Tertiary formations, the closure volumes are (sometimes significantly) overestimated. The ellipses indicate the areas that resulted from the shortlisting: the Kra Al-Maru Trend in the western ellipse; the Rahiyah structure in the eastern ellipse.

4.1. The storage location

The Kra Al-Maru Trend is a north west trending elongate subsurface ridge which is roughly 40 km long and 8 km wide. The Kra Al-Maru Trend has subtle expressions as the Kra Al-Maru subsurface anticline of about 20 m elevation. Other rises occurring along this trend are Umm Rijim, Khashm Al Afri, and Khaluhah. The Kra Al-Maru Trend closes up abruptly to the northwest suggesting some fault control. Oil was found in Ratawi (Lower Cretaceous) and Najma/Sargelu (Jurassic) reservoirs at Kra Al-Maru in October 1995 [11].

The current emission levels from the Doha East and Doha West power plants were used as the target injection rate (this implies the assumption of full-scale capture plants at both locations). This rate is about 11 $MtCO_2$/yr. It was further assumed that the capture plants have a lifetime of 40 years. The total volume of CO_2 to be stored amounts to 440 Mt.

4.2. Potential reservoir formations

Three potential storage formations were identified in the Cretaceous interval: the Wara formation, the Burgan formation and the Zubair formation (Fig. 1). These sandstone formations all have good to excellent reservoir quality and together span several hundred meters of thickness. Intermediate shaley or carbonate formations are not considered to contribute significantly to storage capacity, but could act as intermediate (low-quality) seals.

4.3. Dynamic simulations

Various simulations of CO_2 injection scenarios indicate that injecting significant amounts of CO_2 is feasible; average formation pressure is below 10% above hydrostatic, which was used as the safe limit. This is due to the assumption of large horizontally connected reservoir formations, in which pressure can dissipate over distances of hundreds of kilometers. This assumption requires verification, although it is supported by observations during oil production from the same formations [13].

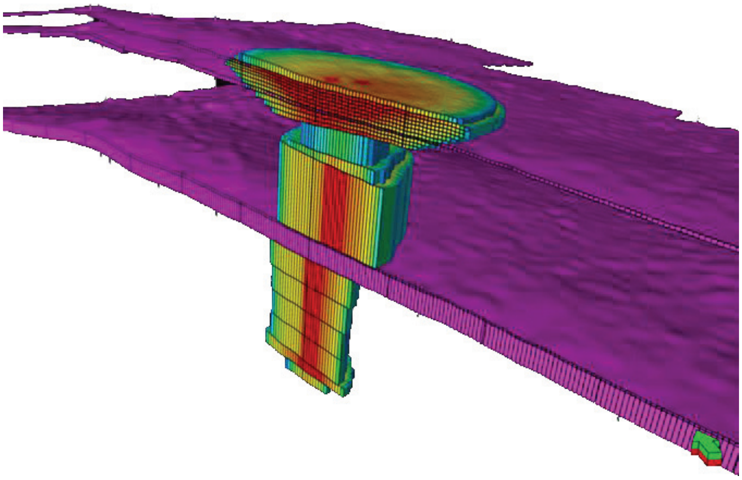

Figure 3. 3D reservoir model with simulation results of the CO2 injection superimposed. Intermediate shale or carbonate formations are shown in purple. Permeable reservoirs (Zubair, Burgan, and Wara Fms) are not shown. The topmost Ahmadi shale, was omitted from this display. The diameter of the top of plume, after 40 years of injection (440 Mt) is about 10 km.

There remains, however, a need for site-specific core material, to verify assumed formation properties, as well as for an injection test, to measure and confirm feasible injection rates and storage capacity.

Available data suggest that the CO_2 is unlikely to migrate away from the injection location. A risk identified in early stages of the study was the potential migration towards the Minagish oil field. Reservoir modelling results suggest that the CO_2 plume will not migrate away from the injection location, even in the ambitious storage scenario used.

4.4. Cap rock

Although data obtained from site-specific core material was not available, the Ahmadi shale can be considered to be a regional seal of approx. 200 feet in thickness at the Kra Al-Maru Trend. Analysis of regional data showed that the shaley character of the formation renders it likely to represent good-quality cap rock. The Ahmadi shale is a seal for oil in the Burgan field, retaining a significant column of oil [14]. There is no reason to believe that the Ahmadi Shale in the Kra Al-Maru Trend is very different from the Burgan field. However, there is a clear need for cap rock core material collected at the potential storage site, to confirm the quality of the Ahmadi as a seal.

4.5. Faults

Available data suggest an absence of large faults (although sub-seismic faults cannot be ruled out). This implies that large, connected reservoir volumes are available to absorb the pressure increase that results from injection of CO_2. Analysis of effects of injection on stress fields was performed to derive limits for safe injection and storage.

4.6. Seismicity

Analysis of regional pressure fields and the effects of large-scale storage suggests that storage, even at the ambitious scale described above, is unlikely to lead to activation (or, in case faults do exist, re-activation) of faults. The risk of seismicity is assessed to be small. Formation properties measured on core material collected at the site are needed to confirm the safety limits and the likelihood of fault (re-)activation.

4.7. Wells

Only two wells are expected to come into contact with the CO_2 plume, although more will be subject to a pressure increase. Well completion standards at KOC are such that a good quality cement sheath can be assumed to be in place; the quality of the cement sheath and the current status of the casings in the two wells remains to be verified from log data. One abandoned well appears to have an open hole section at the depth interval of interest. Until confirmation of well quality is available, the wells are assessed to be a high, but manageable, risk.

4.8. Using the Kra Al-Maru Trend as a CO_2 buffer storage

Simulations indicate that the CO_2 remains in the proximity of the injectors. Several different scenarios of potential back production of the CO_2 were set up. Results showed, depending on a water production constraint, in the case of shorter injection, production of only a limited rate can be maintained and only for a few years. This suggests that back production of the stored CO_2 becomes more feasible when preceded by a more extensive period of CO_2 injection. Recovery factors resulting from our simulations ranged from a low 20% up to 40%, which is in line with a recent study[15].

5. Risk assessment

Fig. 3 shows both initial (left) and final risk assessment (right) of the Kra Al-Maru Trend. The detailed characterization has led to a better understanding of the site and of the risks involved in storing CO_2 and most of the risks in the final assessment are closer to or even inside the green low-consequence / low likelihood zone. The one exception is associated with the abandoned wells in the area, for which, as mentioned above, no detailed data was available.

The overall conclusion on the feasibility of storing significant amounts of CO_2 at the Kra Al-Maru Trend is that the structure, with its Cretaceous formations is likely to be a first-class CO_2 storage site (see Table 2).

6. Project cost

A preliminary analysis of the cost of CCS in Kuwait suggests that the total cost of capture, transport and storage lies in the range of 50 – 65 USD/tCO_2 (level 2016). In this case, both storage and transport costs are at the lower end of the spectrum of costs that have been reported in the literature (e.g., [16]), due to the storage site being onshore and relative proximity to the capture location. Capture costs are estimated to be in range with other, recently reported figures. The analysis did not cover local issues, such as labor costs, or the detailed lay-out of the specific power plants that were taken as the likely capture locations.

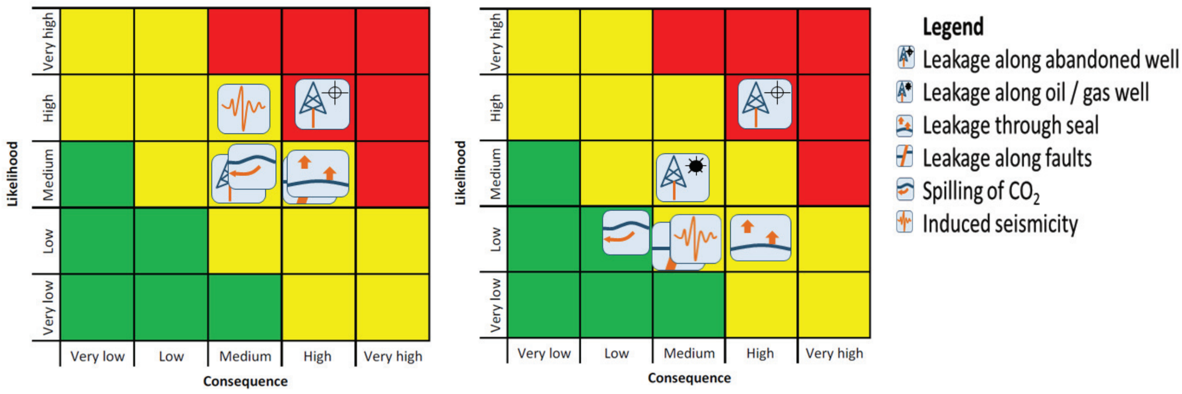

Figure 3. Initial risk matrix (left) and final, updated risk matrix (right).

Table 2. Summary of the results from the detailed characterization of the Kra Al-Maru Trend for the feasibility of CO_2 storage.

Aspect	Score	Uncertainty	Comment
Storage capacity	Excellent	Low	Cretaceous sands are of good quality There is significant spare storage capacity
Injection rates	Excellent	Low	Cretaceous sands: good quality There is significant spare capacity for injection rate
Containment – caprock	Good	Low	Evidence for seal in logs Site specific evidence for seal quality required
Containment – wells	Medium	Medium	There are two abandoned wells that need to be checked The available CBL shows poor cement in places However: well integrity is manageable

7. Conclusion and next steps

The knowledge and understanding of the Kra Al-Maru Trend collected during the detailed characterization results in the basis for further development of the site as a CO_2 storage location.

Further work is needed to validate the integrity of the Kra Al-Maru trend as a storage site. The first activities should be to assess the integrity of the wells mentioned above. This will remove the uncertainty about the quality of the legacy wells. With this information, a better estimate can be made of the effort and cost involved in developing a storage site in the Kra Al-Maru Trend. This will form the basis for decision to drill an appraisal well.

After a positive decision, the next step is to drill a well that targets the Cretaceous interval of potential storage formations. This will produce cores and logs of the Cretaceous interval of interest at the most likely location of injection. A well test is required to confirm feasible injection rates. The next step would be to confirm the findings obtained in the detailed characterization study with the logs and cores from the exploration well.

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