76046

Hashemite Kingdom of Jordan

Carbon Capture and Storage (CCS) Capacity Building Technical Assistance

Final Report

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World Bank
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Table of Contents

Abbreviations

Atm:	Atmospheric pressure
BP:	British Petroleum
CCS:	Carbon Capture and Storage
CDM:	Clean Development Mechanism
CO_2:	Carbon dioxide
EU:	European Union
GHG:	Greenhouse Gases
Mt:	Million metric tons
NPC:	National Petroleum Company
NRA:	Natural Resources Authority
OECD:	Organization of Economic Cooperation and Development
ppm:	parts per million
UNFCCC:	United Nations Framework Convention on Climate Change
US EPA:	United States Environmental Protection Agency
USTDA:	United States Trade and Development Agency

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Executive Summary

This study was funded by the Carbon Capture and Storage Capacity Building Trust Fund, and administered by the World Bank. The main objectives of the study were 1) to build or enhance Jordan's institutional capacity to make informed policy decisions on carbon capture and storage (CCS) technology and applications; 2) to assess the potential application of CCS technology in Jordan; and 3) to identify barriers—legal, regulatory, financial and others—to CCS activities in Jordan and recommend ways to address those barriers.

Jordan's Official Policies Related to CCS. At the international level, Jordan has been supporting the proposal to include CCS as a Clean Development Mechanism (CDM) instrument under the United Nations Framework Convention for Climate Change (UNFCCC). The UNFCCC's recent 17th Conference of the Parties (COP17) in South Africa (November – December 2011) indeed approved CCS as an eligible CDM option. Within Jordan, however, there is no specific governmental policy either supporting or prohibiting CCS.

Potential Application of CCS in Jordan. Jordan's greenhouse gas footprint is relatively quite small. In 2010 Jordan released approximately 30 million tons of greenhouse gases (GHG), of which 85 percent were CO_2; this was less than 0.07 percent of total global GHG emissions. However, Jordan could experience a step increase in GHG emissions following the implementation of several oil shale power plants and new cement plants, together with other industrial activities that are currently planned. One 500-600 MW oil shale power plant alone could add 3-4 million tons of CO_2 a year to Jordan's current release level.

Over the Short Term, Capacity-Building may be more Appropriate than Capital Investment. During the course of this study, the study team concluded that Jordan may benefit from following the evolution of carbon capture and storage technology via publicly available information. Similar CCS studies are being carried out in Egypt, Morocco and Tunisia, and Jordan could benefit from a regional knowledge exchange event when those studies are concluded. However, given Jordan's other national priorities, tight government fiscal situation and limited CO_2 emissions, the CCS team that authored this report believes that it is not in the interest of Jordan to pursue capital investment related to CCS in the short-term.

In the short- to medium-term, Jordan could consider the following activities that would serve to further build its internal capacity to manage future CCS projects or programs:

1. Undertake a comprehensive geologic assessment of the Wadi Sirhan Basin in the desert area of eastern Jordan to analyze its potential for long-term secure storage of CO_2;
2. Conduct a rigorous reservoir characterization and CO_2 injectivity pilot in the deep Disi Sandstone of the Hamad Basin near Risha in the north-eastern part of the country; and
3. Support CO_2 capture and storage conceptual design, a feasibility study and a pilot activity to be carried out at the country's planned power plants, especially the planned oil shale power plant.

The first two activities would build on and deepen the existing scoping-level geologic study of Jordan's potential for storing CO_2. The third recommended activity would leverage Jordan's unbundled and commercial power sector in attracting international CCS investment in larger-scale CO_2 capture and storage pilot activities. This final activity could make progress toward achieving two parallel objectives: developing Jordan's domestic energy sources and controlling its GHG emissions.

Over the longer-term, the study team recommends that Jordan consider two additional activities:

4. Pursue regional opportunities for transporting and productively using Jordan's captured CO_2 emissions for enhanced oil recovery in neighboring Egypt, Iraq and Saudi Arabia; and

5. Further evaluate the use of CO_2 injection for enhancing the production of geothermal water for moderate-temperature power production.

For any future CCS projects in Jordan, emphasis must be given to protecting the country's potable water resources. Any discussion or implementation of CO_2 storage must address how the selection and design of such storage would protect and assure the safety of Jordan's potable groundwater and aquifer system.

Barriers to CCS in Jordan. There are currently no significant country-specific barriers that explicitly impede the application of CCS in Jordan. CCS is a new technology for Jordan, and as such, there are no laws or regulations that explicitly support or prohibit the approach. Existing regulations could be expanded or modified in order to manage and oversee CCS activities or project; this is especially true for regulations that would relate to CO_2 capture and transport. However, because the technology has not yet been implemented in Jordan, new regulations related to CO_2 storage and/or sequestration would need to be introduced. In addition, while financing for high-cost CCS technologies currently represents a barrier in Jordan, this barrier applies to all countries equally. As a next step, Jordan could take a project-specific approach in addressing these domestic barriers—should Jordan decide to move forward on CCS—instead of a macro- or country-level approach. The project-specific approach could be subsequently scaled up if necessary.

Capacity Building for CCS in Jordan. No matter the next steps taken, it is clear that Jordan would benefit from increased awareness about CCS as an evolving technology that could help control GHG emissions. Jordan has an adequate cadre of qualified professionals that can study and follow evolving CCS technologies, including trained geologists, engineers, chemists and others. Jordan has a satisfactory track record in introducing and adopting new and advanced technologies into the country; the same approach can be adopted with CCS technology.

This study, therefore, hopes to represent one step toward raising the awareness of CCS technology among Jordanian policy makers, professionals and academics. The CCS Capacity Building Trust Fund is prepared to provide limited financial support to a team of Jordanian researchers for an exploratory study on the potential for CCS within Jordan. Such a study should further increase awareness of CCS in Jordan and create a body of knowledge within the country that could support next steps on CCS consideration by policymakers, or actual project implementation.

The CCS Capacity Building Trust Fund is also keen to receive proposals from Jordanian organizations that wish to explore larger-scale studies, such as the above mentioned short- to medium-term geologic studies for strengthening the country's internal CCS knowledge and capacity.

1. Introduction

1. In September 2010, the Carbon Capture and Storage Capacity Building Trust Fund agreed to fund a technical assistance activity that would produce a study on carbon capture and storage (CCS) for Jordan. The main objectives of the study were 1) to build or enhance Jordan's institutional capacity to make informed policy decisions on CCS technology and applications; 2) to assess the potential application of CCS technology within Jordan; and 3) to identify barriers—legal, regulatory, financial and others—to CCS activities in Jordan and recommend ways to address those barriers.
2. As of 2010, Jordan emits a total of 30 million metric tons (Mt) of greenhouse gases (GHG) per year, with 74 percent of that number being CO_2 emissions from energy activities. The main sources of Jordan's CO_2 emissions are power plants burning natural gas or oil, the country's sole oil refinery and a few industrial plants such as cement and fertilizer production facilities. Most of these facilities are located in the Amman metropolitan area and in Aqaba in the south. Jordan's CO_2 emissions are a very small percentage of the global total (0.066 percent in 2009); however, there is a strong possibility that these emissions could increase in the coming years. Jordan continues to build power plants (mostly natural gas-fired) and the country plans to construct a number of cement production facilities and oil shale power plant(s). Jordan is active in the UNFCCC deliberations and is interested in exploring ways to reduce its carbon footprint.
3. This report includes the key findings of the study funded by the Carbon Capture and Storage Capacity Building Trust Fund, as well as conclusions and recommendations for next steps. The report is divided into four sections (in addition to the Introduction):
   - Section 2. Assessment of CCS Potential and Geological Aspects
   - Section 3. Identification of Barriers to CCS
   - Section 4. Assessment of Jordan's Capacity Related to CCS
   - Section 5. Concluding Remarks
4. In addition to the main body of the report, supplemental information is included in the annexes:
   - Annex 1: CO_2 Point Sources in the Amman-Zarqa and the Qatrana Areas
   - Annex 2: Documents Collected and References
   - Annex 3: Report on Options for CO2 Transportation and Storage for Jordan
   - Annex 4: Laws, Regulations and International Conventions of Jordan which May Relate to CCS
   - Annex 5: Global CCS Regulations Update

2. Assessment of CCS Potential and Geological Aspects

2.1 CO_2 emission sources and potential for capture

5. The majority of Jordan's industrial facilities that emit greenhouse gases are in the Amman Metropolitan area and in Aqaba (see Figure 1).

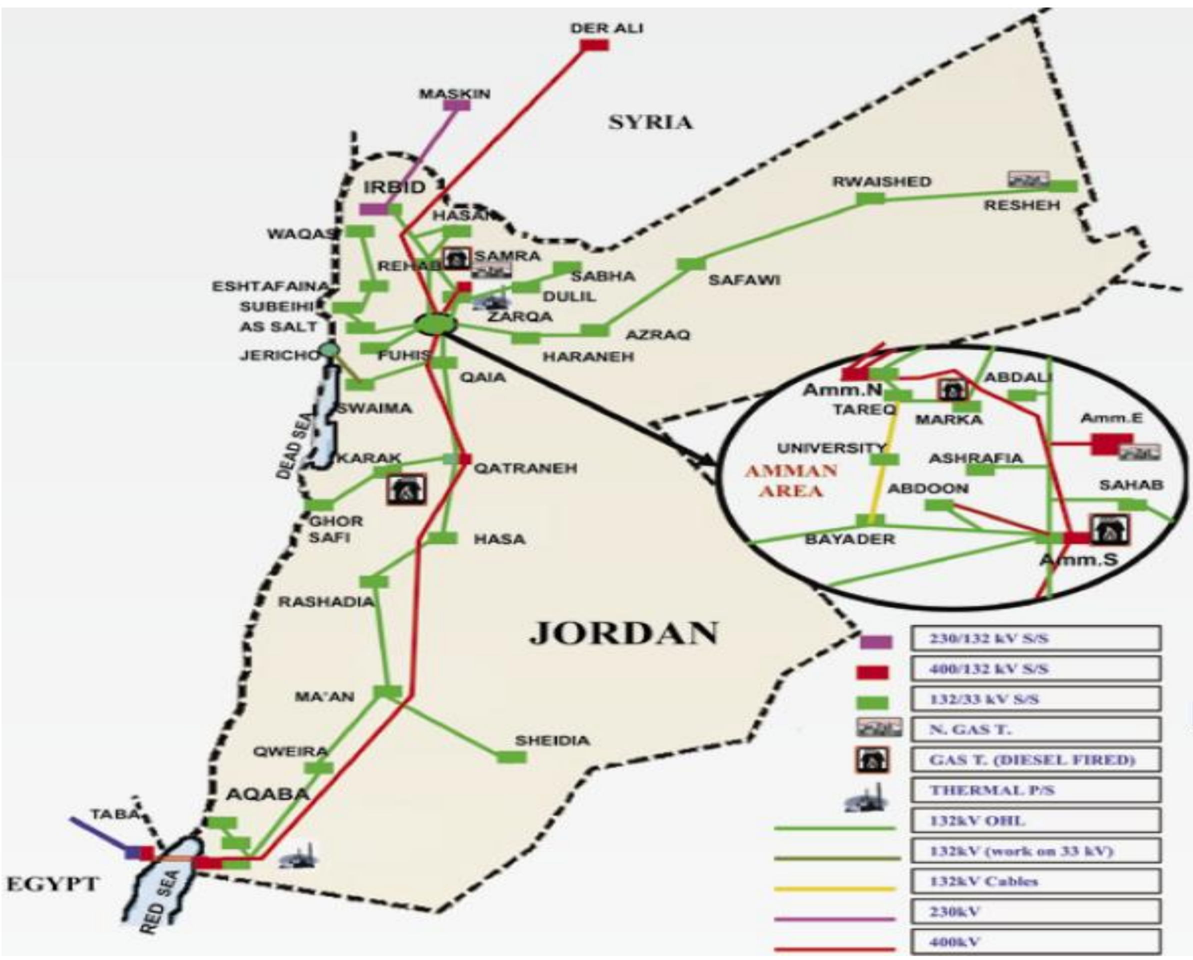

Figure 1. Map of Jordan indicating major energy facilities and transmission lines

6. After reviewing the country's existing and planned energy facilities, the most suitable for CCS were identified in the Amman-Zarqa and Karak-Qatrana areas. The facilities identified are the largest and are likely to be operating for at least another 20 years. Table 1 lists the facilities identified along with their production capacity and annual CO_2 release. The data presented are for the year 2013, when the Samra power plant is expected to be expanded to 1,020 MW.

Sources of CO2	MW 2013		GWh/y 2013	Mt CO2/y 2013
Power plants				
- Amman East (CCGT)	370		2,269	0.84
- Rehab (CCGT)	300		1,840	0.68
- Samra/SEPGCO (CCGT)	1,020		6,255	2.31
Refinery	90,400	bbl/d		0.68
Cement Plants in Amman Area				
- Fuheis (JCFC)	3	Mt/y		1.20
- Muwaqar (NCo)	1	Mt/y		0.40
Cement Plants in Qatraneh Area				
- Karak (Arabian Cement)	2	Mt/y		0.80
- Qatrana (MCM)	1.2	Mt/y		0.48
Oil shale power plant	600		3,679	4.05
TOTAL				**11.44**

Table 1. Key sources of CO2 in the Amman-Qatrana Areas

7. All facilities shown in Table 1 are existing facilities, except for the oil shale plant which was added to illustrate its impact on CO_2 release volumes. Without the oil shale plant, the power plants together with the oil refinery and four cement production plants release roughly 7 million tons of CO_2 per year. A 600 MW oil shale plant could add approximately 4 million tons of CO_2 per year to that total.

8. For illustrative purposes, the above facilities were analyzed using the assumption that they were equipped with CO_2 capture equipment capable of removing 90 percent of the CO_2 released. The estimated cost ranged from \$52 to \$74 per ton of CO_2 removed, including the capture equipment. Also, water requirements for CO_2 capture were estimated at 23.5 million m^3 per year. More details on this preliminary assessment are provided in Annex 1 of this report.

9. The remainder of this section summarizes the findings of the CO_2 transport and storage assessment, which was carried out by Advanced Resources International Inc. The assessment explored options for the productive use of CO_2, as well as the potential for geological sequestration for long-term CO_2 storage. The complete assessment is included as Annex 3 of this report

2.2 Productive Use of Captured CO_2 Emissions

10. The transport and storage study identified two primary options for productively using Jordan's captured CO_2 emissions from power, refinery, shale oil and cement plants:

- Use of CO_2 for enhanced oil recovery in the surrounding large oil fields of Egypt, Iraq and Saudi Arabia.

- Use of CO_2 for enhancing the production of geothermal ("hot") water for moderate temperature power production.

11. These two options are further discussed below. Note that the information on the potential for productive use of CO_2, such as the estimated CO_2 demand by the various oil fields and the feasibility and economic potential for producing "hot" water, is at a very preliminary scoping level. Establishing the technical and economic feasibility of pursuing these two options for productively using Jordan's captured CO_2 would require additional, and significant, site-specific assessments.

2.2.1 Use of CO_2 for Enhanced Oil Recovery

12. An alternative to storing CO_2 in saline formations is to transport and sell captured CO_2 for use by facilities using CO_2 enhanced oil recovery (CO_2-EOR). Similar productive use of CO_2 is underway in the U.S., Canada, Turkey and a few other countries. (More information on this topic is provided in Annex 3: Report on Options for CO_2 Transportation and Storage for Jordan.)

13. Given the potential locations of CO_2 capture plants in Jordan and the locations of the region's oil fields, three options exist for transporting and selling CO_2 for CO_2-EOR:

    - Short-distance transport of the captured CO_2 south to the Red Sea Basin oil fields of Egypt.

    - Short-distance transport of the captured CO_2 east to a large Mesopotamian Foredeep Basin oil field in western Iraq.

    - Long-distance transport of the captured CO_2 to numerous oil fields in Iraq, Kuwait, Saudi Arabia and other Gulf countries.

Table 2 provides a summary list of the large oil fields surrounding Jordan that may be potentially favorable for miscible CO_2-EOR. Figure 2 provides a location map for these oil fields.

Table 2. Proximate to Jordan Oil Fields Potentially Favorable for Miscible CO_2-EOR

Distance and Geologic Province	Number of Oil Fields	Ultimate Primary/Secondary Recovery (MMBbls)	Average Depth (Ft)	Maximum Depth (Ft)	Minimum Depth (Ft)
Fields Within 500 Miles (800km)					
Mesopotamian Foredeep Basin	1	16,000	10,000	10,000	10,000
Red Sea Basin	6	4,804	8,631	12,050	5,750
Totals	**7**	**20,804**			
Fields Within 500 - 1,000 Miles (800km-1,000km)					
Mesopotamian Foredeep Basin	57	355,554	8,032	14,609	3,900
Zagros Fold Belt	16	103,468	7,152	15,420	3,500
Greater Ghawar Uplift	5	98,270	7,618	13,500	5,550
Interior Homocline-Central Arch	7	22,529	8,352	13,720	4,760
Widyan Basin-Interior Platform	7	5,950	9,873	10,760	8,200
Totals	**92**	**585,771**			

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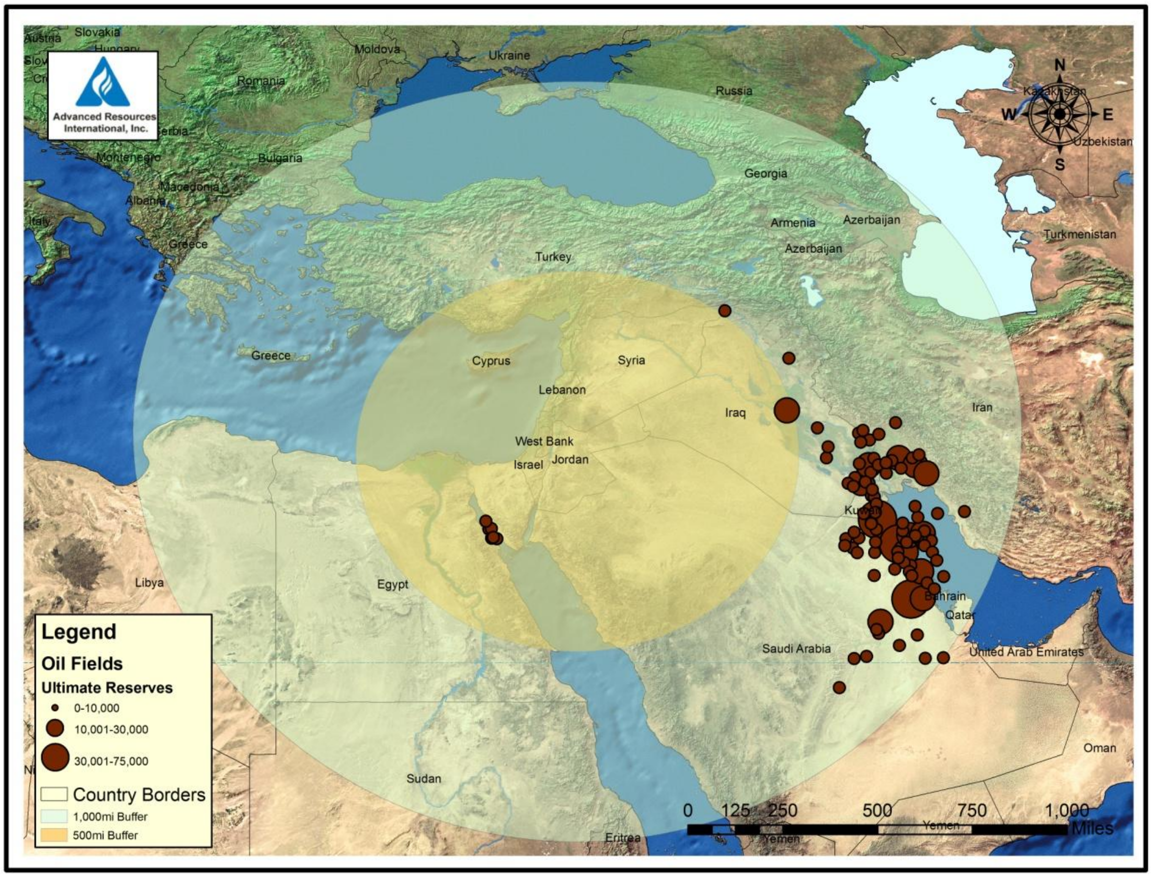
Figure 2. Large Oil Fields With CO_2-EOR Potential Near Jordan.



14. ***1. Short Distance Transport of Captured CO_2 South to Egypt.*** Six oil fields in the Red Sea Basin of Egypt may be technically feasible locations for CO_2-EOR. These six oil fields are approximately 300 miles (500 km) from Amman and approximately 240 miles (400 km) from Qatrana.

- The six Egyptian oil fields are sufficiently deep for application of miscible CO_2-EOR, with depths averaging 8,630 feet (2,610 m); the actual range of depths is from 5,750 feet (1,740 m) to 12,050 feet (3,650 m).

- The estimated primary/secondary (P/S) oil recovery for these six oil fields is 4.8 billion barrels. Assuming 40% P/S oil recovery efficiency, the original oil in-place (OOIP) in these six oil fields is estimated at about 12 billion barrels. With $\pm$15% recovery of OOIP, the CO_2-EOR target is nearly 2 billion barrels.

15. The anticipated CO_2 requirements for these six oil fields, assuming 0.4 metric tons of purchased (net) CO_2 per barrel of recovered oil, would be about 800 million metric tons over a period of 30 to 40 years.

16. ***2. Medium Distance Transport of Captured CO_2 East to Iraq.*** One very large Mesopotamian Foredeep Basin oil field in western Iraq may be a technically feasible site

for CO_2-EOR. This oil field is approximately 500 miles (800 km) from central Jordan.

- This large oil field, with a depth of 10,000 feet (3,030 m), is sufficiently deep for considering the use of miscible CO_2-EOR. (A second oil field in this area, with a depth of 2,385 feet [727 m] may only be attractive for near-miscible CO_2-EOR and is not included in our analysis).

- The reported primary/secondary (P/S) oil recovery for the one deeper Mesopotamian Foredeep Basin oil field is 16 billion barrels. Assuming 40% P/S oil recovery efficiency, the original oil in-place (OOIP) in this oil field is estimated at about 40 billion barrels. With $\underline{+}$15% recovery of OOIP, the CO_2-EOR target is 6 billion barrels.

17. The anticipated CO_2 requirements for this large oil field, assuming 0.4 metric tons of purchased (net) CO_2 per barrel of recovered oil, would be 2,400 million metric tons over a period of 30 to 50 years.

18. ***3. Long Distance Transport of Captured CO_2 to the Arabian Gulf Region.*** A large number of oil fields in the Mesopotamian Foredeep Basin (the Zargos Fold Belt, the Greater Ghwar Uplift plus other basins of Iraq, Kuwait and Saudi Arabia and various Gulf countries) may also be technically feasible locations for CO_2-EOR. These oil fields are located 500 miles (800 km) to 1,000 miles (1,600 km) from central Jordan.

- A total of 92 of these oil fields, with depths of 3,500 feet to 15,420 feet (1,060 m to 4,670 m) appear to be sufficiently deep for considering the use of miscible CO_2-EOR.

- The reported primary/secondary (P/S) oil recovery for these 92 oil fields is nearly 586 billion barrels. Assuming 40% P/S oil recovery efficiency, the original oil in-place (OOIP) in these oil fields is estimated at about 1,465 billion barrels. With $\underline{+}$15% recovery of OOIP, the CO_2-EOR target is nearly 220 billion barrels.

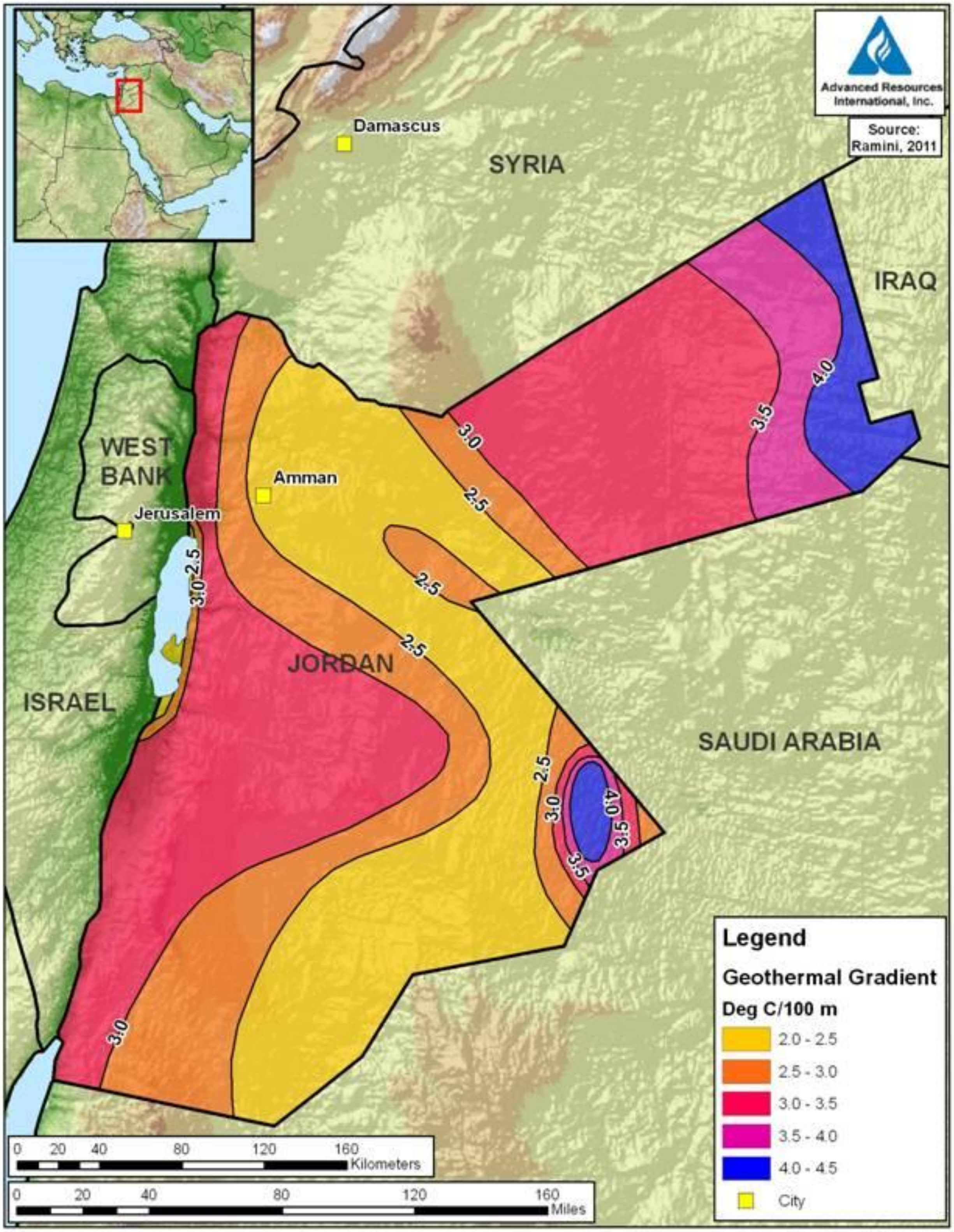
19. The anticipated CO_2 requirements for these 92 large oil fields, assuming 0.4 metric tons of purchased (net) CO_2 per barrel of recovered oil, would be 88,000 million metric tons over a period of 50 to 100 years.

2.2.2 Other Options for Productively Using Captured CO_2

20. ***a. Use of CO_2 for Producing Moderate Heat Content Water.*** Significant portions of Jordan, particularly in the Hamad Basin, are underlain by areas of high geothermal gradients of 3.5°C to 4.5°C per 100 meters (1.9°F to 2.5°F per 100 feet), Figure 3. As such, the subsurface waters in the Paleozoic (Cambrian/Ordovician) formations, such as the Disi and Dubeidib sandstones at depths of 11,500 to 13,200 feet (3,500 to 4,000 meters), hold water with temperatures of 135°C to 200°C (280°F to 390°F).

21. In the past, geological investigators have suggested that it may be possible to produce these waters and use their heat content for moderate-temperature production of electric power. The constraints to this option have been the high electricity power costs of pumping the water to the surface and previously-reported lower water heat content measures.

Figure 3. Geothermal Gradient Map of Jordan



22. However, the injection of CO_2 into a bounded saline formation containing geothermal heat content waters could result in over-pressured conditions and artesian flow of water to the surface. The possible combination of freely flowing water, higher than previously expected water temperatures,[1] and new heat recovery systems for power production, possibly using advanced heat transfer fluids, suggest that this additional option for productively using CO_2 injection requires further investigation.

23. ***b. Use of CO_2 for Enhanced Gas Recovery.*** At this time, the study team considers the use of CO_2 for enhanced gas recovery in Jordan to be speculative and outside the scope of this report. Additional in-depth study of this option would be required to understand the full scope of its technical and economic feasibility in Jordan.

2.3 Geological Aspects of CCS in Jordan

24. Two areas of Jordan, underlain by deep saline formations, appear to be favorable for storing CO_2. These are the Hamad Basin in northeast Jordan and the Wadi Sirhan Basin in east-central Jordan, Figure 4.

25. For the Hamad Basin, the first priority formation for storing CO_2 is the Disi Formation within the larger Ram Group of Cambrian/Lower Ordovician formations. As discussed further below, the Disi is a deeply buried, thick sandstone with highly saline formation waters overlain by a caprock (seal) provided by the Hiswa Shale and other overlying shales. Because of its substantial depth, only limited information is available on the reservoir properties that are important for establishing CO_2 storage capacity and injectivity in the Disi Formation in the Hamad Basin.

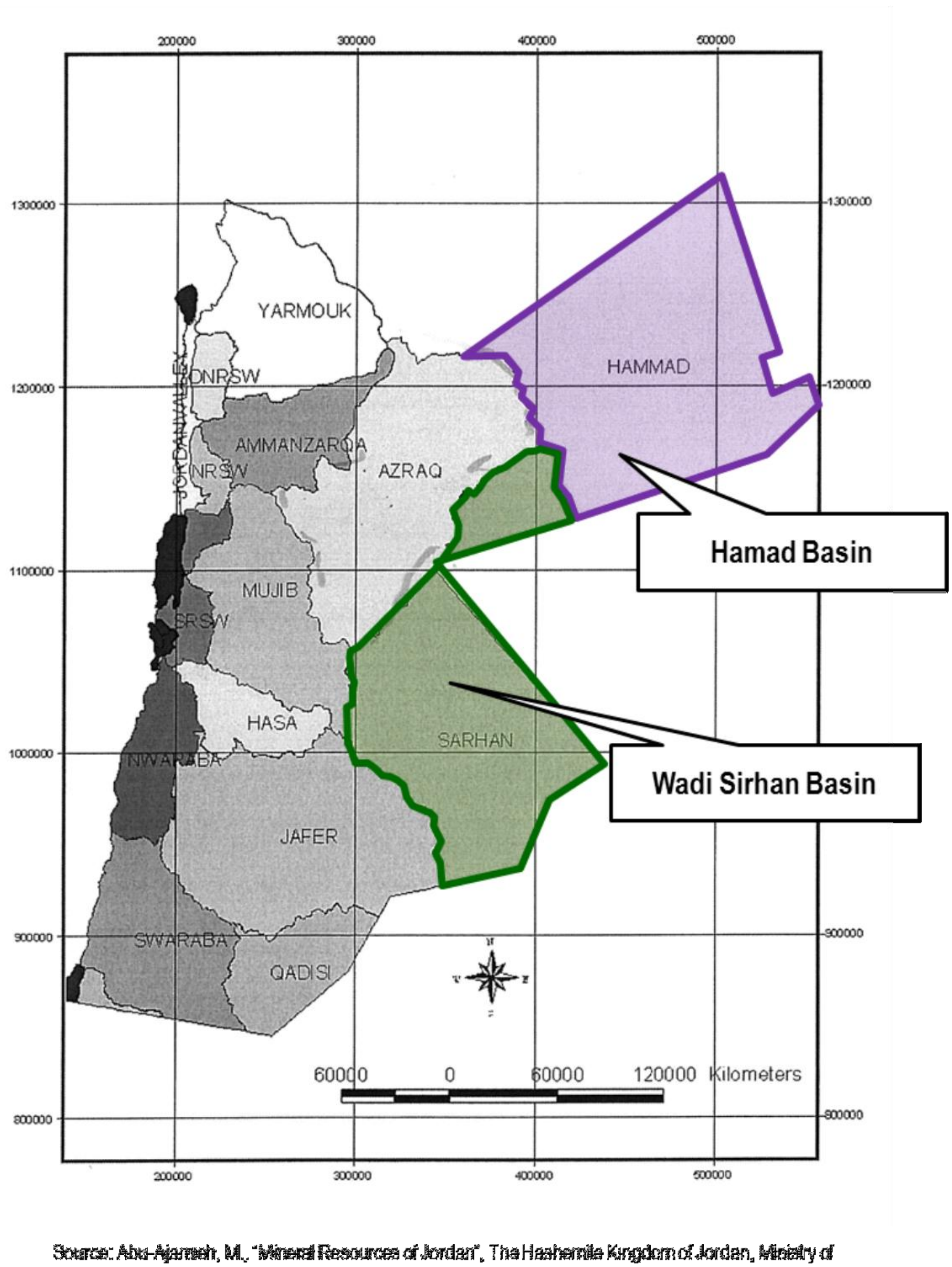
26. The second priority formation for storing CO_2 in the Hamad Basin is the thick Dubeidib Formation within the larger Khreim Group of Middle Ordovician/Silurian formations. However, the upper portion of the Dubeidib Formation contains the gas-saturated Risha Unit which is the source for the Risha Gas Field. Further reservoir characterization would be required to determine what (if any) portions of the Dubeidib Formation could serve as favorable intervals for storing CO_2.

27. In the Wadi Sirhan Basin, although little information exists on the characteristics of the deep Disi Formation, both the Disi and the Dubeidib are the priority formations for potentially storing CO_2 in this basin. The Hiswa Shale serves as the caprock for the Disi Formation and the thick, regionally extensive Mudwwara Shale provides the caprock/seal for the Dubeidib Formation.

28. These geological options for storing CO_2 are further developed and quantified in the remainder of this Chapter.

[1] New research by Foster, et al (2007) calculated a subsurface heat flow for southern Jordan of 60 mWm^{-2} compared to previously reported values of 45 mWm^{-2}.

Figure 4. Priority Basins for Storing CO_2 in Saline Formations of Jordan



Source: Abu-Ajameh, M., "Mineral Resources of Jordan", The Hashemite Kingdom of Jordan, Ministry of Energy and Mineral Resources, Natural Resources Authority, 1989.

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2.3.1 Hamad Basin

29. The first priority basin for storing CO_2 is the Hamad Basin in the northeastern part of Jordan (Figure 4). The basin is bounded on the north by Syria, on the east and south by Iraq and Saudi Arabia, and on the west by the Azraq and Wadi Sirhan basins.

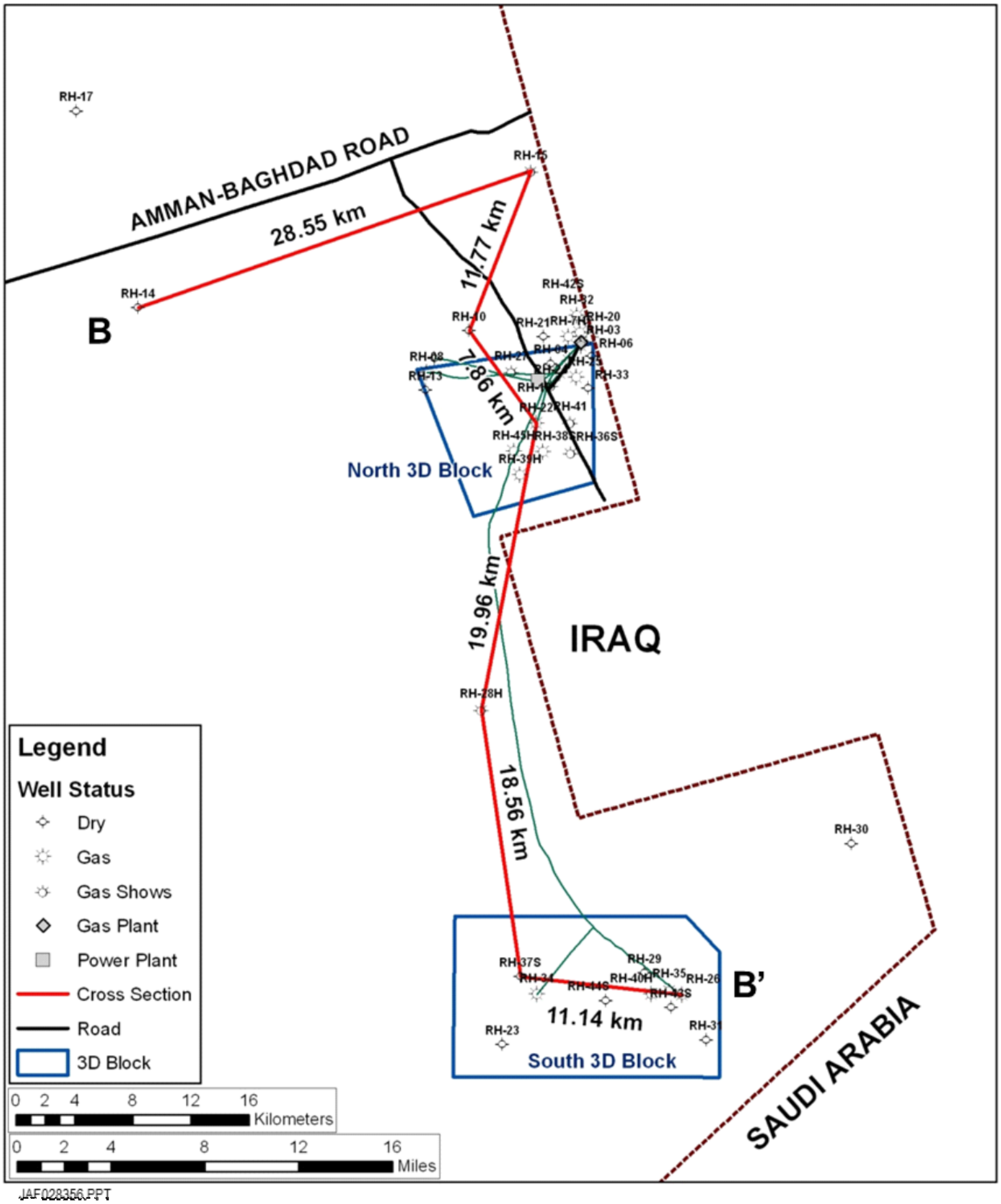
30. The Hamad Basin covers an area of 7,450 square miles (19,300 square kilometers) and is underlain by numerous Paleozoic- and Mesozoic-age formations. The younger, Tertiary-age Rijam and Wadi Shallala formations, plus basalts, form the surface units of the Hamad Basin.

31. The depth to the basement in the Hamad Basin deepens from about 13,000 feet (4,000 meters) on the west to 23,000 feet (7,000 meters) on the east (see previous Figure 3). The Ram Group (particularly the Disi Sandstone), and the Khreim Group (particularly the Dubeidib Sandstone) would provide the primary saline formations for storing CO_2 in this basin.

32. Regional Cross Section #1, shown below, depicts the eastern portion of the Hamad Basin and illustrates the lateral continuity of the formations for a 60 mile (100 km) segment of the Hamad Basin (see Figure 5). The base formation in Cross-Section #1 is the Hiswa Shale, the lower most unit of the Khreim Group that serves as the caprock (seal) for the Ram Group of formations. The Hiswa Shale has a depth (to top of formation) of 9,800 feet (3,000 meters) below sea level and approximately 13,000 feet (4,000 meters) below surface. The regionally continuous Hiswa Shale in this portion of the Hamad Basin is approximately 1,600 feet (500 meters) thick.

33. Below the Hiswa Shale is the Ram Group and its five distinct formations. Only limited deep well data is available on the deep Ram Group and its dominant formation, the Disi Sandstone. However, geological mapping and analog information from other basins help provide sufficient data for a first-order characterization of the Disi Sandstone.

Figure 5. Location of the Regional Geologic Cross-Section #1: Hamad Basin



[Regional Geologic Cross-Section #1 in Eastern Hamad Basin appears in the full report]

(i). Disi Sandstone.

34. The Disi Sandstone underlies much of Jordan as well as the larger Arabian Peninsula. In the southern part of Jordan, the Disi Sandstone crops out (is at the surface) and serves as an important source of freshwater. The freshwater in the Disi Sandstone in the south is from the capture and storage of rainwater (recharge) over millions of years, enabled by the surface exposure of the permeable Disi Sandstone in this area.

35. In the Hamad Basin of northeast Jordan, the Disi Sandstone is deeply buried at a depth of 10,000 to 16,000 feet (3,000 to 5,000 meters). It is also physically and areally separate (due to an extensive basaltic dyke) from the southern recharge area. Preliminary information, which should be further defined, indicates that the salinity of the waters in the Disi Sandstone in the Hamad Basin make them non-potable; the waters have a TDS in excess of 50,000 ppm (as a point of reference, seawater has a salinity of about 30,000 ppm).

36. The Disi Sandstone (as defined in the outcrop and near-surface area of southern Jordan) contains about 1,000 meters of predominantly fine-to-coarse grained sandstone. Prior aquifer modeling of the shallow Disi Sandstone in the south of Jordan has established a regional coefficient of permeability of 0.6 to 1.0 m/d with the vertical and horizontal coefficients of permeability being generally similar (Humphreys, 1968). However, the permeability of the deeply buried Disi Sandstone in the Hamad Basin will be considerably less and has yet to be defined.

37. In the Hamad Basin, the Disi Sandstone has an estimated thickness of 3,300 to 6,600 feet (1,000 to 2,000 meters), which accounts for approximately half of the thickness of the Ram Group. The Disi Sandstone extends under the entire Hamad Basin and thus covers an area of 7,400 mi^2 (19,300 km^2). For calculating CO_2 storage capacity, we estimate a porosity of 8%, a temperature gradient of 1.9 ^oF per 100 feet (3.5^oC per 100m) and a hydrostatic pressure gradient for the Disi Sandstone.

38. Information from deep oil and gas exploratory wells in other analog basins of Jordan, drilled by the Natural Resources Authority and the National Petroleum Company of Jordan, was assembled and evaluated to define the suitability of the Disi Sandstone for storing CO_2. This includes estimating its CO_2 storage capacity and its seals. No information is available on the permeability or the CO_2 injectivity of the Disi Sandstone in the Hamad Basin.

(ii). Dubeidib Formation

39. The Dubeidib Formation of the Khreim Group overlies the Disi Sandstone. In the eastern part of the Hamad Basin, the upper 330 feet (100 meters) of the Dubeidib Formation, defined as the Risha Member, is gas-saturated. But elsewhere in the basin, the technical literature indicates that the Dubeidib is fully or partly saturated by water. Based on regional cross-sections prepared by the study, a series of shale and siltstones separate the Upper Risha Member from the other sandstones within the Dubeidib Formation, preserving the potential for the lower portion of the Dubeidib Formation to serve as a CO_2 storage

option.

40. A closer look at the Dubeidib Formation (and Khreim Group) is provided in the three parts of Regional Cross-Section #1. Part 1 defines the lithologic units of the Dubeidib Formation in the southeast portion of the Hamad Basin, (see Figure V-4 of Annex 3). In addition to siltstone and shale, the cross-section identifies a 160-foot (50-meter) water-bearing, fine-grained sandstone interval in the middle of the Dubeidib Formation. Part 2 of this cross-section is in the central-east portion of the Hamad Basin (see Figure V-5 of Annex 3), and shows the continuation of the internal units of the formation, including the water bearing zone in the middle of the Dubeidib Formation. Part 3 of this cross-section, (see Figure V-6 of Annex 3) is along the northern edge of the Hamad Basin and shows the westward thinning of the Dubeidib Formation, the increasing presence of volcanics and the westward thickening of the overlying Triassic and Cretaceous (Kurnub) formations.

41. Additional information is available in Table 3 on the Dubeidib Formation and its Risha Member from deep exploration wells drilled in the Risha area.

Table 3. Dubeidib Formation Reservoir Properties from Deep Wells Drilled in the Hamad Basin

	North Area	South Area
Well Name	RH-3 (Discovery Well)	RH-28 (50 km South of RH-3)
Date	July, 1987	May, 1993
Reservoir	Risha Member	Risha Member
Unit	Unit #3	Unit #1
Depth	8,600 ft (2,611 m)	8,850 ft (2,702 m)
Thickness		
Unit #1	(53 m, Sandstone)	(22 m, Sandstone)
Unit #2	(21 m, Siltstone)	(24 m, Siltstone)
Unit# 3	(31 m, Sandstone)	(39.5 m, Sandstone)
Total	346 ft (105 m)	282 ft (85.5 m)
Porosity	6 to 8%	8%
Pressure	3,354 psi (0.39 psi/ft)	3,363 psi (0.38 psi/ft)
Temperature (Bottom Hole)	n/a	300 ^{o}F
Resitivity of Water (R_w)	n/a	0.035

42. The Dubeidib Formation is at a depth of 8,000 to 10,000 feet (2,500 to 3,000 meters) and has a gross interval thickness of 3,000 to 4,000 feet (900 to 1,200 m) in the Hamad Basin. A series of six water samples from the RH-27 well in the upper portion of the Dubeidib Formation at 8,800 feet (2,680 m) had salinities of 42,250 to 55,046 mg/l , confirming that the waters in this formation are non-potable. The Dubeidib Formation extends under the entire Hamad Basin and thus covers an area of 7,400 mi^2 (19,300 km^2). Based on the information from the two exploration wells in Table 3, we estimate porosity for the Dubeidib Formation of 8%, a pressure of 3,360 psi, and a bottomhole temperature of 300^{o}F.

43. Interpreted core information from the RH-5 exploratory well provided useful information on the permeability of the lower portions of the Dubeidib Formation. For example, core #9, with nine plugs from 10,592 to 10,605 feet (3,229.2 to 3,233.2 m) had porosities that ranged from 7.8% to 19.0% and permeabilities that ranged from 0.8 md to 61 md. A series of samples from cores #6, #7 and #8, from 9,668 to 10,075 feet (2,947.7 to 3,071.7 m) had much lower, single digit porosities and permeabilities, generally less than 1 md.

(iii). The Zarqa and Kurnub Groups

44. The Triassic-Jurassic age Zarqa Group forms a sandstone aquifer system which extends across all of Jordan except the Southern Desert. The Zarqa Aquifer System has been tested in the Tureibil area of the Hamad Basin. In the deep center of the area, the Zarqa aquifer water was measured to have 5,800 ppm (TDS) at 1,062 meters (below ground level) and 20,640 ppm (TDS) at 1,407 meters (below ground level), as established in one of the deep Risha gas wells (RH-1).

45. The Lower Cretaceous-age Kurnub Sandstone Formation extends over most of Jordan, except for the eastern portion of the country in the Hamad Basin. In general, where both the Kurnub Group and the underlying Zarqa Group are present, the two form a single regional aquifer system.

46. Because of the lower salinity of the Zarqa Group of formations and the potential for fluid connectivity between the Zarqa and the Kurnub formations, we have excluded these formations from consideration for CO_2 storage.

2.3.2 Wadi Sirhan Basin

47. The second priority basin for storing CO_2 in Jordan is the Wadi Sirhan Basin in the east-central part of the country, Figure 4. The basin is bounded on the north and west by the Azraq Basin, on the south and west by the Jafr Basin, and on the east and south by Saudi Arabia.

48. The Wadi Sirhan Basin covers an area of 4,860 mi^2 (12,600 km^2) and is underlain by a thick sequence of Paleozoic (Cambrian through Silurian) formations. The depth to basement in the Wadi Sirhan Basin ranges from 13,000 feet (4,000m) on the east to 20,000 feet (6,000m) on the west. The saline formations in this basin with the highest potential for storing CO_2 include: (1) the numerous formations within the Ram Group with the Disi Formation ranked highest; and (2) potentially the Dubeidib Formation within the Khreim Group.

49. The sub-surface geology of the Wadi Sirhan Basin has been assembled from two regional geologic cross-sections. Regional Cross-Section #2, north to southeast in the eastern Wadi Sirhan Basin, provides a 90-mile-long (150 km) display of the upper formation of the Ram Group (Umm Sahm Formation) and the four formations of the Khreim Group in this portion of the basin (see Figures V-7 and V-8 of Annex 3). In general, the wells drilled into this basin stopped at the Dubeidib Formation of the Khreim Group with one deep, 10,930 foot (3,331 m) well (WS-2 on the northeastern portion of the Wadi Sirhan Basin) penetrating the underlying Ram Group's Umm Sahm and Disi formations.

50. Regional Cross-Section #3, from southwest to northeast, provides a 66-mile-long display of four formations in the Khreim Group as well as considerable information on the lateral extent of the Disi Sandstone and other Ram Group formations in the south and central portions of the basin (see Figure V-7 and V-9 of Annex 3). Two deep wells of this cross-section, well WS-3 in the center of the Wadi Sirhan Basin and well WS-10 on the far

eastern border of the Wadi Sirhan Basin, penetrate the Ram Group formations. These two wells provide valuable data on the thickness, depth and lateral continuity of the important Disi Sandstone. Based on the information from regional Cross-Section #3, the Disi Sandstone in this part of the Wadi Sirhan Basin is buried at a depth of 6,500 to 8,000 feet (2,000 to 2,400 meters) and has a gross thickness of about 3,300 feet (1,000 meters).

51. The following properties have been assembled for characterizing the CO_2 storage potential of the Disi Sandstone in the Wadi Sirhan Basin:

1. Seals and Caprocks. The Hiswa Shale provides a 330 feet (100 m) seal for the Disi Formation in the Wadi Sirhan Basin. The thick 1,650 feet (500 m) Mudawwara Shale, overlying the Dubeidib Formation, provides a thick secondary seal and caprock.

2. Thickness and Areal Extent. The Disi Formation thickness ranges from 3,300 feet (1,000 m) on the east to about 2,000 feet (600 m) along the western edge of the Wadi Sirhan Basin. The net thickness of the Disi Formation within the 4,865 mi^2 (12,600 km sq) Wadi Sirhan Basin, is assumed to average 660 feet (200 m), using a net to gross ratio of 0.25.

3. Other Reservoir Properties. Very little publically available information exists on the other reservoir properties of the Disi Formation in the Wadi Sirhan Basin, particularly its porosity, permeability and pressure. In the south of Jordan, where the Disi Formation is shallow or visible in outcrops, the sandstone porosity has been measured at 17% to 24%.

For purposes of calculating CO_2 storage volume for the Dubeidib Sandstone Formation in the deeper subsurface, the study team assumed that porosity is reduced to an average of 8%. We also assumed that the temperature gradient is 1.4 ^oF per 100 feet (2.5^oC per 100 m). For depth, we used the data from the cross-section showing that, in general, the depth to the top of the Disi Formation is about 6,500 feet (2,000 m) below surface. Assuming that reservoir pressure is hydrostatic, we estimated an average reservoir pressure of about 2,800 psi.

(ii). Dubeidib Formation

52. Because of the reported lower water salinities for the Dubeidib Formation, at least in the southern portion of the Wadi Sirhan Basin, we have lowered the priority of this saline formation for CO_2 storage in Jordan. However, should additional data on water salinity become available, it would be most valuable for further assessing the suitability of this large and extensive saline formation for storing CO_2.

2.3.3 Estimating CO_2 Storage Capacity

(i). Introduction

53. The estimates of CO_2 storage capacity is set forth below for the Disi and the Dubeidib formations in the Hamad Basin, and for the Disi Formation in the Wadi Sirhan Basin.

54. The CO_2 storage estimates use the reservoir properties developed for these formations as input to the modified U.S. DOE methodology for calculating CO_2 storage in deep saline formations:

$$\mathbf{M_{CO2} = A * h * \Phi * 7{,}758 * C_1 * C_2 * E}$$

Where:

M_{CO2}	=	Storage of CO_2 in Mcf or in metric tons (mt)
A	=	Area, in acres
h	=	Average thickness, in feet
Φ	=	Porosity, dimensionless
7,758	=	Conversion factor for barrels of pore space per acre-foot
C_1	=	Conversion factor for volume of dense phase CO_2 in one barrel of reservoir pore space ($\pm$ 2 Mcf/barrel)
C_2	=	Conversion factor for density of CO_2 ($\pm$18.9 Mcf/metric ton)
E	=	Storage efficiency ($\pm$ 2%)

(ii). CO_2 Storage Capacity in the Hamad Basin

55. ***a. Disi Formation.*** The following average reservoir properties are used to calculate the CO_2 storage capacity of the Disi Formation in the Hamad Basin.

A	=	Use 19,300 km^2 (7,450 mi^2; 4.77 * 10^6 acres) for basin area
h	=	Assume 1,000 feet
Φ	=	Assume 8%
C_1	=	Use 2 Mcf/B
C_2	=	Use 18.9 Mcf/metric ton
E	=	Assume 2%

56. Based on the above reservoir properties, the CO_2 storage capacity of the Disi Formation in the Hamad Basin is approximately 6 billion metric tons, as calculated below.

M_{CO2} (Mcf) $(4.77 * 10^6 \text{ acres} * 10^3 \text{ feet} * 0.08) * 7{,}758 \text{ B/AF} * 2 \text{ Mcf/B} * 0.02 = 118 * 10^9 \text{ Mcf}$

M_{CO2} (mt) $(118 * 10^9 \text{ Mcf}) / 18.9 \text{ Mcf/mt} = 6.2 * 10^9 \text{ metric tons}$

57. ***b. Dubeidib Formation.*** For the Dubeidib Formation in the Hamad Basin, we used the same area porosity and conversion factors as for the Disi Formation, except we targeted only the 160-foot (50 meters) water-bearing interval in the center of the Dubeidib Formation in order to avoid contact with the overlying gas-saturated Rishi Formation. Based on these parameters, the CO_2 storage capacity of the Dubeidib Formation in the Hamad Basin is estimated to be approximately 1 billion metric tons:

M_{CO2} (Mcf) = $19 * 10^9$ Mcf

M_{CO2} (mt) = $1 * 10^9$ metric tons

(iii). CO_2 Storage Capacity in the Wadi Sirhan Basin

58. ***a. Disi Formation.*** For the Disi Formation in the Wadi Sirhan Basin, we used the same conversion factors as for the Hamad Basin, with the following differences in reservoir properties and area:

A	=	Use 12,600 km^2 (4,860 mi^2; 3.11 * 10^6 acres) for basin area
h	=	Assume 660 feet
Φ	=	Assume 8%

59. Based on the above values for area and net pay, the CO_2 storage capacity of the Disi

Formation in the Wadi Sirhan Basin is estimated to be approximately 2.7 billion metric tons.

$$M_{CO2}\,(Mcf) = 51 * 10^9 \text{ Mcf}$$

$$M_{CO2}\,(mt) = 2.7 * 10^9 \text{ metric tons}$$

60. ***b. Dubeidib Formation.*** Because of the reported lower water salinities for the Dubeidib Formation, in the Wadi Sirhan Basin, we did not estimate CO_2 storage capacity for this formation

2.3.4 Transporting Captured CO_2 Emissions to Saline Formation Storage Sites

61. The assessment undertaken as part of this study explored two scenarios for transporting and storing captured CO_2 emissions in the saline formations of Jordan:

- ***Scenario #1***: Pipeline transportation of CO_2 captured in the Amman-Zarqa area for storage in the Hamad Basin.

- ***Scenario #2***: Pipeline transportation of CO_2 captured in the Qatrana-Karak area for storage in the Wadi Sirhan Basin.

For both scenarios, the assessment assumed that CO_2 capture will take place at each plant (at the source of CO_2). While site-specific considerations and requirements are expected to affect the design and cost of CO_2 capture, preliminary estimates are that levelized costs would be in the range of: US$52-74 per ton of CO_2 removed (see Annex 1).

62. ***Scenario #1. Zarqa-Hamad Basin***. The annual volume of captured CO_2 in the Amman-Zarqa area is estimated at 5.8 million metric tons (90% capture of 6.5 million mt from the power plants and cement plants in the Amman metropolitan area and the oil refinery located in Zarqa). For CO_2 pipeline planning and storage purposes, this is equal to 300 million cubic feet of CO_2 per day.

63. The CO_2 would be transported by a 20-inch diameter pipeline for a distance of 150 miles (250 km) to the center of the Hamad Basin. The CO_2 would then be injected into and stored in the Disi Formation at a depth of about 12,000 feet (3,650 meters).

64. Our preliminary, scoping-level estimate for the capital, annual operating and transportation costs per ton of CO_2 are set forth below and in Figure 6.

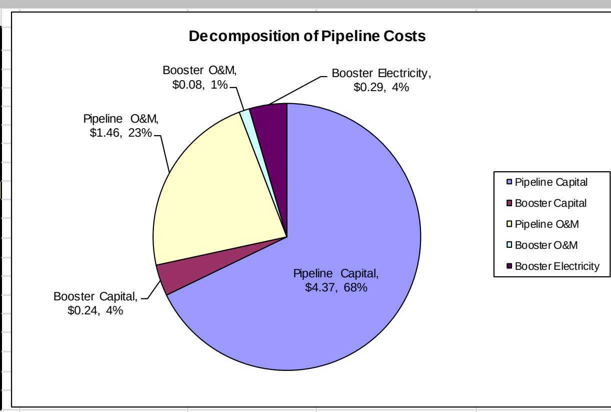
• Capital Costs	$178 million
• O&M Costs (Annual)	$11 million
• Est. CO_2 Transportation Costs	
– 15% Capital Recovery Factor	$6.15/mt of CO_2
– 10% Capital Recovery Factor	$4.61/mt of CO_2

Figure 6. Scoping Level Estimates of CO_2 Transportation Costs: Scenario #1. Zarqa-Hamad Basin, 15% Capital Recovery Factor

Pipeline

Costs

Capital Costs	Total	Annualized	Per Tonne CO2	Per Mile
Pipeline				
Materials	$39,802,336	$5,970,350	$1.03	$265,349
Labor	$75,013,008	$11,251,951	$1.94	$500,087
Miscellaneous	$34,216,661	$5,132,499	$0.89	$228,111
Right of Way	$19,711,259	$2,956,689	$0.51	$131,408
Total	$168,743,264	$25,311,490	$4.37	$1,124,955
Booster Stations	$9,408,461	$1,411,269	$0.24	
Total	$178,151,725	$26,722,759	$4.61	
O&M Costs	Present Value/Project Life			
Pipeline		$8,437,163	$1.46	
Booster Stations		$470,423	$0.08	
Booster Electricity		$1,691,417	$0.29	
Total		$10,599,003	$1.54	
Total Pipeline Costs	$178,151,725	$37,321,762	$6.15	



Requsite Data (Precalculated)		km
Total Distance of Pipeline (mi)	150.00	241.4016
CO2 Density ρ	897.1078641	
CO2 Viscosity μ	9.7476E-05	
Diameter (in)	20	
Horsepower Capacity of Booster Station	1,568	
Electricity Consumed by Booster Stations (kwh)	30,753,031	
Number of Booster Stations Needed	3	
Booster & Pipeline O&M as % of capital	5.00%	

Notes	
Distance Override On	
Annual CO2 Through Pipe	5,793,645

65. In addition to the CO_2 pipeline, there will be capital and O&M costs for constructing and operating the CO_2 storage site. The largest single cost will be for drilling and completing the CO_2 injection wells, although the number of injection wells depends on the permeability and CO_2 injectivity offered by the Disi Formation. For preliminary, scoping-level cost estimation purposes, the study team estimated the need for 30 CO_2 injection wells, assuming that each CO_2 injection well will be able to inject 10 million cubic feet per day of CO_2 and that each well, fully equipped, will cost US$5 million to drill and complete. We added 40% to these costs for related piping, monitoring and other capital for the CO_2 storage site. As such, our estimate for the capital costs of constructing the CO_2 storage site is $210 million.

66. Annual operating costs for the 30-well CO_2 storage site are relatively modest, estimated at $6 million per year($200,000 per well per year). Our preliminary, scoping-level estimate for CO_2 storage capital and operating costs is $4.66/mt (for 10% capital recovery factor) to $6.47/mt (for 15% capital recovery factor). Due to lack of data on reservoir permeabilities, considerable uncertainty surrounds these estimates of CO_2 storage costs.

67. ***Scenario #2. Qatrana-Wadi Sirhan Basin***. The annual volume of captured CO_2 in the Qatrana-Karak area is estimated at 4.6 million metric tons (90% capture of 5 million mt from the proposed shale oil plant near Qatrana). For CO_2 pipeline planning and storage purposes, this is equal to 240 million cubic feet of CO_2 per day.

68. The CO_2 would be transported by an 18-inch diameter pipeline for a distance of 90 miles (150 km) to the center of the Wadi Sirhan Basin. The CO_2 would then be injected and stored in the Disi Formation at a depth of about 7,500 feet (2,290 meters).

69. Our preliminary, scoping-level estimate for the capital, annual operating and transportation costs per ton of CO_2 are set forth below and in Figure 7.

• Capital Costs	$97 million
• O&M Costs (Annual)	$6 million
• Est. CO_2 Transportation Costs	
– 15% Capital Recovery Factor	$4.18/mt of CO_2
– 10% Capital Recovery Factor	$3.13/mt of CO_2

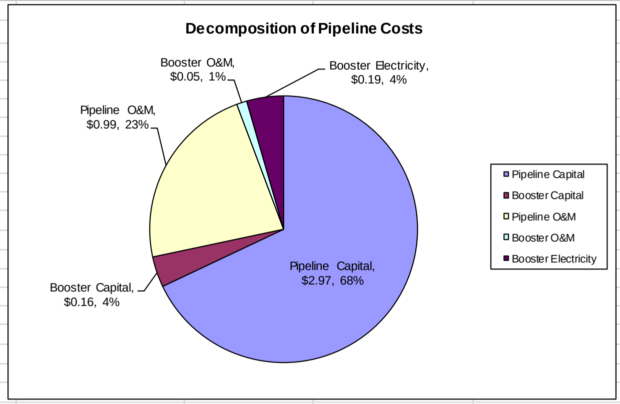
70. In addition to the CO_2 pipeline, there will be capital and O&M costs for constructing and operating the CO_2 storage site. The largest single cost will be for drilling and completing the CO_2 injection wells, although the number of injection wells depends on the permeability and CO_2 injectivity offered by the Disi Formation. For preliminary, scoping-level cost estimation purposes, we estimated the need for 40 CO_2 injection wells, assuming that each CO_2 injection well will be able to inject 6 million cubic feet per day of CO_2 and that each well, fully equipped, will cost $3 million to drill and complete. We added 40% to these costs for related piping, monitoring and other capital for the CO_2 storage site. As such, our estimate for the capital costs of constructing the CO_2 storage site is $168 million.

Figure 7. Scoping Level Estimates of CO_2 Transportation Costs: Scenario #2. Qatrana-Wadi Sirhan Basin, 15% Capital Recovery Factor

Pipeline

Costs

Capital Costs	Total	Annualized	Per Tonne CO2	Per Mile
Pipeline				
Materials	$20,249,692	$3,037,454	$0.66	$224,997
Labor	$41,227,154	$6,184,073	$1.33	$458,079
Miscellaneous	$18,620,562	$2,793,084	$0.60	$206,895
Right of Way	$11,700,996	$1,755,149	$0.38	$130,011
Total	$91,798,403	$13,769,761	$2.97	$1,019,982
Booster Stations	$5,017,688	$752,653	$0.16	
Total	$96,816,091	$14,522,414	$3.13	
O&M Costs	Present Value/Project Life			
Pipeline		$4,589,920	$0.99	
Booster Stations		$250,884	$0.05	
Booster Electricity		$902,060	$0.19	
Total		$5,742,865	$1.04	
Total Pipeline Costs	$96,816,091	$20,265,279	$4.18	



Requsite Data (Precalculated)		km
Total Distance of Pipeline (mi)	90.00	144.84096
CO2 Density ρ	897.1078641	
CO2 Viscosity μ	9.7476E-05	
Diameter (in)	18	
Horsepower Capacity of Booster Station	1,254	
Electricity Consumed by Booster Stations (kwh)	16,401,100	
Number of Booster Stations Needed	2	
Booster & Pipeline O&M as % of capital	5.00%	

Notes	
Distance Override On	
Annual CO2 Through Pipe	4,634,770

71. Annual operating costs for the 40-well CO_2 storage site are relatively modest, estimated at $6 million per year ($150,000 per well per year). Our preliminary, scoping-level estimate for CO_2 storage capital and operating costs is $4.92/mt (for 10% capital recovery factor) to $6.74/mt (for 15% capital recovery factor). Due to lack of data on reservoir permeability, considerable uncertainty surrounds these estimates of CO_2 storage costs.

Other Scenarios. Further analysis would be both required and useful for optimizing the capital and operating costs of the CO_2 pipeline and geological storage systems of Jordan.

3. Identification of Barriers to CCS Development

72. Jordan faces several barriers to CCS, some of which are global (applicable to all countries) and others which are country-specific, a situation shared with many other nations.

The most important global issues are:

- Readiness of CCS technologies;
- Financing available for CCS projects; and
- Lack of regulatory framework for climate change beyond 2012 (Kyoto period).

Jordan-specific issues and barriers include:

- Very limited awareness of CCS;
- Land and access right ownership and liability issues; and
- The need for regulations that would govern the approval, design, installation and operation of CCS-related facilities.

This section presents the key findings of the barriers to CCS study with detailed information provided in the annexes. The global issues are not discussed in detail as there are numerous existing publications which cover these issues in a comprehensive way; relevant references are provided below .

3.1 Jordan-specific Issues, Barriers and Potential Next Steps

3.1.1 Jordan-specific issues and barriers related to CCS

a. Limited domestic awareness of CCS

73. **There is limited information on and awareness of various aspects of CCS within Jordan,** including the potential need for CCS, technology options and the status, legal and regulatory aspects, financial issues, and other issues which surround this technology. However, at the policy level, Jordan – through the Ministry of Environment – has already made one significant policy decision on CCS in its support of a proposal to include CCS as a clean development mechanism (CDM) under the UNFCCC.

74. No CCS-related activity has been completed in Jordan to date and most domestic organizations interviewed as part of this study were not aware of CCS. Thus, the study team believes that a comprehensive capacity-building effort is needed in order to raise awareness and prepare the country to be in a position to follow the evolving CCS technology, make future policy decisions that are well-informed, and implement successfully any future CCS activities. More specifics on suggested capacity-building activities are provided in the next section of this report.

b. Ownership and liability issues

75. Ownership of potential underground storage areas rests with the Jordanian government,

eliminating thorny issues which are sometimes encountered when such ownership is in private hands. However, for CCS to succeed in Jordan, relevant ministries and agencies will need to coordinate closely. While ownership issues are legally clear, inter-governmental responsibilities must be carefully defined, as well as coordination between ministries and agencies with regard to decision-making authority on various aspects of CCS (for example, identification of storage sites; exploratory drilling; permitting; monitoring of storage sites; construction and operation of CO_2 pipelines; third-party access to CO_2 storage and pipelines; etc.).

76. Liability issues associated with potential CO_2 leaks need to be addressed for both the pipeline and the sequestration site. In addressing these issues, Jordan could draw on its own experiences with oil, gas and water pipelines; however, expertise from other countries would be needed to cover the issues unique to CCS. Safeguarding against leakage of CO_2 into both groundwater supplies and above ground (the latter potentially affecting people and animals, in extreme cases causing asphyxiation), and the framework for environmental and social impact management will need to be addressed. Jordan can also draw on the experience of the Trans-Arabian oil pipeline, the more recent Arab Gas pipeline and the pipeline associated with the Disi water conveyance project (under implementation) for general pipeline liability issues. Relevant work in OECD countries should also provide a good starting point for Jordan to analyze liability issues.

c. Legal and regulatory framework

77. Jordan will require a robust framework of laws and regulations governing all aspects of CCS-related activities; these can be introduced either by modifying existing laws and regulations or by creating new ones. When developing a CCS legal and regulatory framework, it is essential to have a thorough understanding of existing laws that may be relevant, as CCS may be most easily regulated by modifying frameworks that are already in effect. This generally occurs in jurisdictions with a history of oil and gas exploration and/or production, where some issues are similar to CCS, especially if enhanced hydrocarbon is a viable option. However, for most countries where CCS is a new approach, new laws and regulations are likely to be required, at least for some elements of CCS.

CCS-related activities which need to be covered in laws and regulations include, *inter alia*:

1. Broad regulatory issues
   - Classification of CO_2
   - Property rights
   - Trans-boundary movement of CO_2
   - The role of the environmental impact assessment (EIA)
   - Public participation in decision-making and approval processes
2. CO_2 capture

- Permits for design, installation and operation

3. Transportation of CO_2
   - Permits for design, construction and operation
   - Ownership and operation
   - Third-party access to transportation infrastructure
4. CO_2 storage
   - Authorization for exploration activities
   - Site selection
   - Permits for design, drilling, installation/construction and operation
   - Authorization of storage activities
   - Third-party access to CO_2 storage
   - Monitoring, reporting and verification requirements
   - Liabilities during project period
   - Long-term (post-closure period) liabilities
   - Enhanced hydrocarbon recovery using CO_2

78. A review of Jordan's existing laws and regulations (see Annex 4) indicates that some of the country's regulations currently in force could be amended to cover CCS-related activities. The laws and regulations that are potentially applicable for CO_2 capture facilities are:

- Regulation No. (37) of 2005/Environmental Impact Assessment Regulations
- Regulation No. (26) of 2005/Protecting the Environment from Pollution in Emergency Situations Regulations
- Regulations affecting the design/construction/operation of industrial facilities such as:
  - The environment protection law No. 52 of 2006
  - Regulation No. (28) of 2005/Regulations for the Protection of the Air
  - Ambient air quality standards
  - Standards for maximum allowable limits of air pollutants emitted from stationary sources
  - Emissions standards for electricity generation
  - Requirements for discharge of industrial effluents
  - Standards of heat levels allowed to be exposed to in work environment
  - Regulation of Hazardous Waste Management and handling
  - Industrial Wastewater JS: 202/1991 standards.

In addition to the modification of these existing laws and regulations, new laws and regulations will need to be enacted to cover CCS activities, especially for underground storage.

79. **Different countries have taken a variety of approaches to regulating CCS.** The most common strategy for regulating CCS appears to be the modification of existing laws that would cover the CO_2 capture and transport components, together with the introduction of a new regulation covering sequestration and storage. The U.S. is such an example: the U.S. Environmental Protection Agency (US EPA) developed a new class of injection wells called *Class VI*, established under EPA's Underground Injection Control Program; this new regulation covers all CO_2 sequestration issues (Code of Federal Regulations under 40 CFR 145.22 or 145.32). Elements addressing the unique nature of CO_2 sequestration include:

- *Site selection* based on geologic site characterization and risk assessment;
- *Requirements for the construction and operation of the wells* that include construction with injectate-compatible materials and automatic shutoff systems to prevent fluid movement into unintended zones;
- A process to address *injection depth* on a site-specific basis and accommodate injection into various formation types while ensuring that drinking water sources at all depths are protected;
- *Rigorous testing and monitoring* of each geologic sequestration site that includes testing of the mechanical integrity of the injection well, ground water monitoring, and tracking of the location of the injected CO_2 using direct and indirect methods; extended post-injection monitoring and site care to track the location of the injected CO_2 and monitor subsurface pressures until it can be demonstrated that drinking water sources are no longer endangered;
- Establishment of *monitoring areas* and periodic re-evaluation of the area around the injection well to incorporate monitoring and operational data and verify that the CO_2 is moving as predicted within the subsurface;
- Clarified and expanded *financial responsibility requirements* to ensure that funds will be available for corrective action, well-plugging, post-injection site care, closure, and emergency and remedial response;
- Considerations for *permitting wells that are transitioning from Class II enhanced recovery to Class VI.*

80. Other countries which have implemented new laws and regulations to cover CCS activities include:

- Australia has a comprehensive legislation at the federal level to cover off-shore CCS; in parallel, its States have introduced legislation for on-shore CCS.
- The European Union introduced the Directive on Geological Storage of CO_2, which establishes the legal framework for CO_2 storage; EU member countries were required to adopt the Directive into their respective national legal system by June

25th, 2011. At least 12 countries (Austria, Belgium, Denmark, Finland, France, Ireland, Latvia, Lithuania, Luxemburg, Romania, Spain and UK) did so on time. The remaining EU countries are expected to do so soon.

- The UK has established a temporary regulatory framework, primarily for CCS demonstration projects. The country has plans to introduce a more comprehensive framework after the demonstration projects are completed.
- Other countries which are in the last stages of formulating CCS laws and regulations include Canada, Japan and Norway. An update of global CCS regulations is provided in Annex 5.

81. There are numerous excellent sources that provide robust detail on these kinds of laws and regulations, as well as practical guidance on how a country could proceed to establish its own system. The most relevant sources are:

- Global CCS Institute (http://www.globalccsinstitute.com/key-topics/policy-legal-and-regulation)
- World Bank, " Carbon Capture and Storage in Developing Countries: a Perspective on Barriers to Deployment", June 2011
- IEA, "Carbon Capture and Storage Model Regulatory Framework", November 2010 (http://www.iea.org/ccs/legal/model_framework.pdf)
- IEA, "Carbon Capture and Storage/Legal and Regulatory Review", October 2010
- U.S. Carbon Sequestration Council, "CCS: Legal and Regulatory Framework – 10 Year Progress Report", November 2010. [This report reviews CCS regulatory developments in 15 countries]
- "Report of the Interagency Task Force (of the US Government) on Carbon Capture and Storage", August 2010
- "GSE briefing paper on CO_2 storage", September 2009
- "Legal design of carbon capture and storage/Developments in the Netherlands from an International and EU Perspective", ISBN 978-90-5095-801-1 (2009, published by Intersentia)
- Bellona, "Insuring energy independence/A CCS roadmap for Poland", 2011
- Anderson, A.S., "Carbon Sequestration in Oil and Gas Fields (in Conjunction with EOR and Otherwise) Policy and Regulatory Issues", July 23, 2010 (http://web.mit.edu/mitei/docs/reports/eor-css/anderson.pdf)

3.1.2 Potential next steps for Jordan related to CCS

82. Jordan may want to consider a CCS regulatory initiative which addresses issues associated with planning, implementing and operating CCS projects including environmental, social, legal, and other aspects.

On the appropriate timing of laws and regulations, there appear to be two primary schools of thought:

1) Laws and regulations should be amended or new ones introduced as soon as possible, because CCS is inevitable and is only a matter of time until the country in question needs to use it; alternatively,

2) Wait until large CCS demonstration projects around the world have been completed and the Post-Kyoto climate change framework has been finalized before discussing new legislation; another option for considering new legislation is when a CCS project is identified which seems to be moving toward implementation.

83. **The study team believes that the second approach is more appropriate for Jordan;** in other words, Jordan should focus on building its capacity to develop or modify the relevant regulatory framework. However, it terms of action, Jordan could wait until additional experience is accumulated in other countries and then amend existing laws or introduce new ones based on lessons learned from those experiences. In addition, Jordan could consider a micro-level or project-specific approach for CCS regulations (see Section 4.3.1 ***Multi-track approach to capacity-building***). The reasons for recommending this approach are the following:

- Jordan's GHG footprint is very small compared to other countries, both because of its size as well as the country's limited industrial sector. As mentioned above, in 2010 Jordan released approximately 30 million tons of GHG, of which 85 percent were CO_2 emissions; this figure represents less than 0.07 percent of the total global GHG emissions[2]. Jordan's main CO_2-producing industries are power plants (burning natural gas or oil), one oil refinery and a few fertilizer and cement plants.
- If oil shale activities are pursued in the future, they will add substantially to Jordan's total CO_2 emissions. Although such activities would substantially increase Jordan's CO_2 emissions in absolute terms compared to the baseline, the overall CO_2 footprint would remain relatively small at the global level. Nevertheless, Jordanian authorities may want to consider a pilot CCS project in parallel with the development of oil shale activities, as the simultaneous development of the two technologies may be complementary.
- Small commercial-scale CO_2 production facilities would not be able to take advantage of economies of scale and will result in high cost per ton of CO_2 being sequestered.
- Finally, CCS technologies, as with every new technology, still carry some risks. Thus, it is rational for Jordan to allow high-CO_2-emitting countries to implement and adapt these technologies first; as more CCS projects are implemented around the world, the CCS cost and project risks are likely to come down (due to the learning curve effect).

84. A regional approach could also be beneficial for Jordan. For example, Jordan may want to consider advocating for a regional CCS initiative which would link the major CO_2 producing facilities of the region to the many oil and gas wells of the Gulf Region (including Egypt, Saudi Arabia, Iraq, Kuwait, UAE, etc.) which would benefit from enhanced oil/gas recovery. Such a network could be developed in conjunction with a

[2] Jordan's Second National Communication to the UNFCCC, 2009 (Figure C2, page 162)

pipeline network which would bring oil and/or gas to energy-consuming countries (e.g., Lebanon, Jordan and Syria) and would take back CO_2 (two parallel pipelines) for enhanced recovery in energy-producing countries. Such a network would be mutually beneficial and should be considered at the regional level.

3.1.3 Institutional aspects to CCS regulation

85. Responsibility for Jordan's legal and regulatory framework is shared among several government ministries, so coordination will be needed in both the planning and enforcement stages of a national CCS strategy. The following GOJ ministries should have direct involvement: Ministry of Environment, Ministry of Energy and Mineral Resources, and Ministry of Water and Irrigation; other ministries may be involved as well. According to global experience, in the initial stages of a CCS strategy when laws and regulations are being planned and capacity-building activities are of the highest priority, an inter-governmental committee is usually set up to coordinate activity. In the case of Jordan, the arrangement for the existing National Committee on Climate Change could be an appropriate structure to perform this function (see Annex 7: Jordan – The National Committee on Climate Change).

3.2 Global Issues and Barriers Related to CCS

3.2.1 Readiness of CCS technologies

86. CCS technologies are commercially available, but they are often expensive. Across the industry, substantial effort is being made to reduce capital costs and auxiliary power requirements to make these technologies more affordable, and numerous demonstration projects are being implemented around the world. As mentioned above, Jordan will benefit from the results of these early applications and the lessons learned in other countries. The first demonstration projects are expected to be completed between 2015 and 2020. Enhanced hydrocarbon recovery options are closer to commercial application and could be pursued immediately, depending on site-specific requirements.

87. CCS includes three general steps:

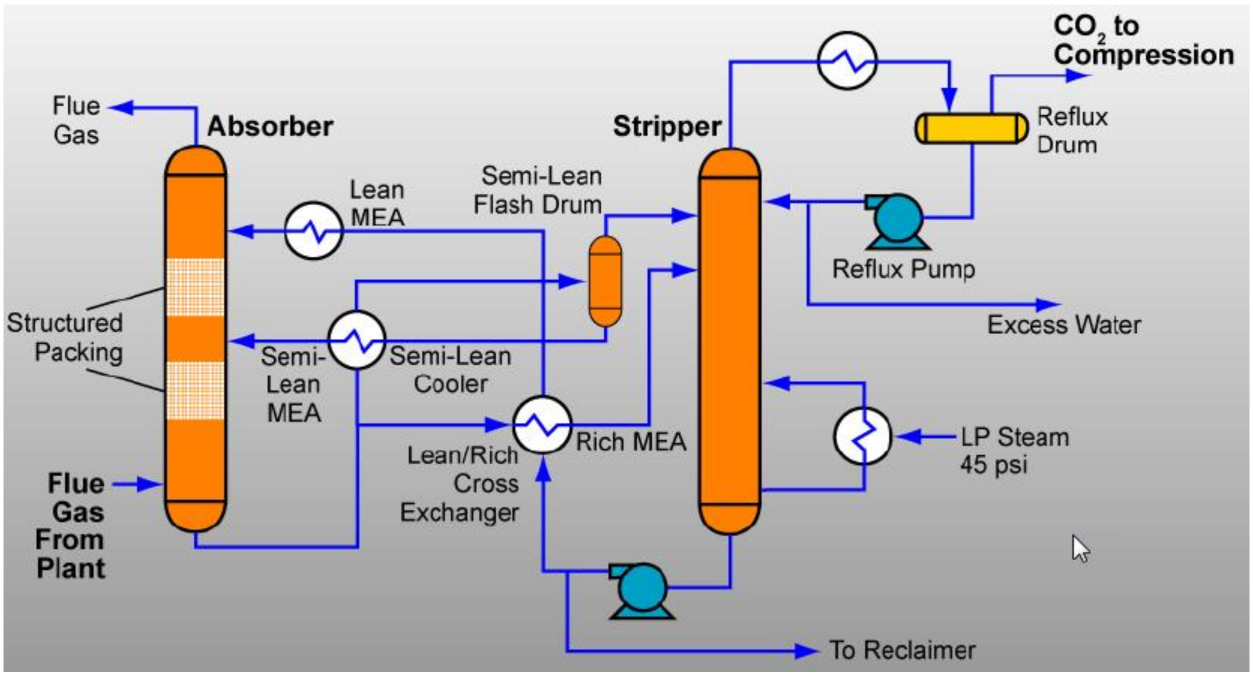
- Capture of CO_2 or separation of CO_2 from the other constituents of the flue gas;
- Transport; and
- Sequestration in saline aquifers, deep coal seams and oceans; also, CO_2 could be sequestered and/or used for enhanced oil and gas recovery.

88. CO_2 is transported using conventional pipelines with the CO_2 compressed to approximately 100 atmospheric pressure (atm). In the United States, there are approximately 3,500 miles of CO_2 pipeline in existence. These pipelines are similar to natural gas pipelines and there is no technological innovation needed to transfer large amounts of CO_2. However, the other two links of the CCS chain (capture and sequestration) require further research and technological development.

89. CO_2 capture (separation) from flue gas has been used in industrial applications, but the

process needs to be upgraded for power plants which are usually an order of magnitude larger (e.g., 5-20 times larger). Commercial CO_2 capture processes that are presently in use are based on chemical absorption with a monoethanolamine (MEA) solvent. A simplified process flow diagram is shown in Figure 8.

Figure 8. Simplified chemical absorption process diagram



Source: US DOE/NETL

90. While MEA processes are considered commercial, more experience with these processes is needed at larger scale and substantial industry effort is focused on reducing the auxiliary power required by the MEA process itself. For example if a modern combined cycle power plant (CCGT) has an overall efficiency of 56 percent; when CO_2 capture is added, the efficiency of the plant (CCGT with CO_2 capture) declines to approximately 48 percent. In addition, the capital costs of the plant double with the addition of the CO_2 capture. A recent publication[3] surveyed many studies on this issue and concluded that the addition of CCS on a CCGT will increase its capital costs by 82 percent (from $960/kW to $1715/kW) and the levelized cost of electricity by 33 percent; assuming 85 percent CO_2 capture, this results in cost of CO_2 avoided of $80/ton CO_2.

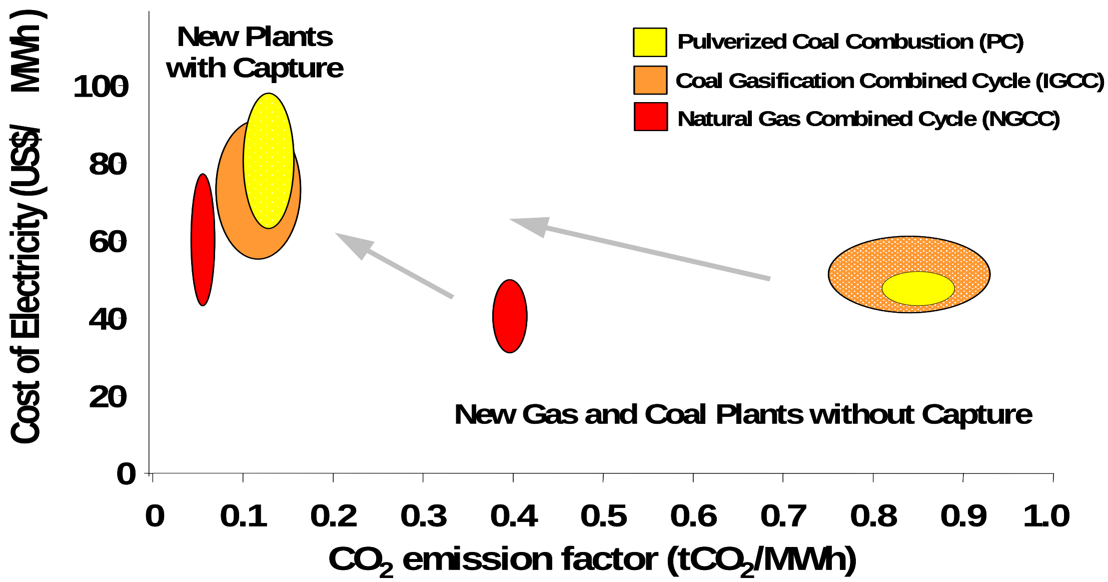
91. In general, the impact of CCS on fossil-fuel technologies is substantial. Figure 9 shows the impact of CCS on three different fossil-fuel processes (pulverized coal, integrated gasification combined cycle and CCGT). However, there is significant uncertainty associated with these estimates, a fact which is noteworthy.

92. As mentioned above, significant R&D effort is currently being devoted to simplifying and improving the MEA processes in order to lower capital costs as well as auxiliary power

[3] IEA, "Cost and Performance of Carbon Dioxide Capture from power Generation", 2011

consumption. In parallel, many new processes are being developed based on chemical absorption, physical sorbents and membranes. These technologies are very promising, but it will be at least 10 years until they have been fully tested and are available commercially.

Figure 9. Power Generation and Carbon Mitigation Costs of CCS



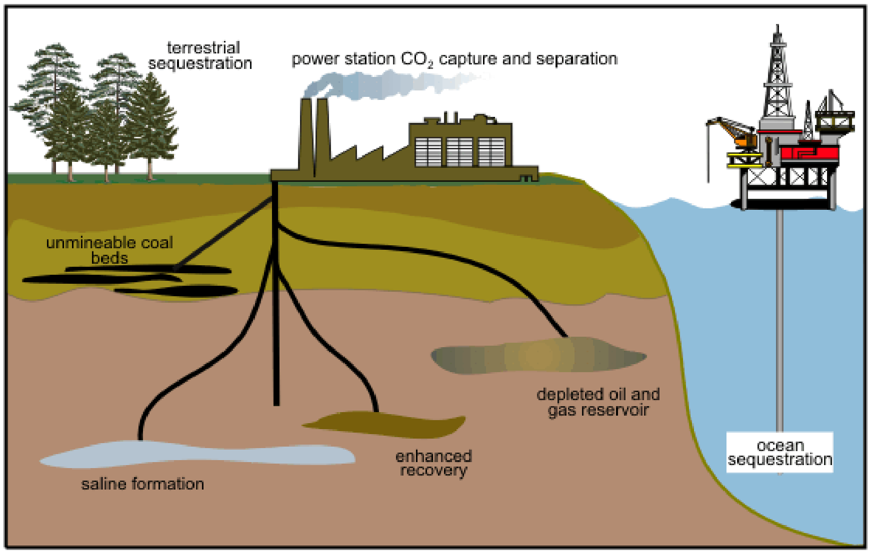
Source: IPCC Special Report on CCS (2005)

93. With regard to CO_2 sequestration, there are a number of alternatives, as shown in Figure 10. Underground storage of CO_2 is at depths of more than 1-3 km, where it is expected to stay for hundreds of years. The specific depth varies from location to location and depends on local geology, exploration history and settlement. The most important consideration for a storage site is that it has one or more layers of caprock that keeps the carbon deeply buried. For these reasons, suitable site selection is critical.

94. Pumping of CO_2 into depleted oil and gas fields to allow further extraction of hydrocarbons (oil and natural gas) has been practiced successfully for the past few decades in different regions across the world. CO_2 in deep coal mine beds allows for economical extraction of coal bed methane.

95. Sequestration deep in the ocean is theoretically feasible, as liquid CO_2 is heavier than seawater and has the potential to remain trapped for decades or even centuries. However, CO_2 could increase the ocean's acidity and have adverse -- and presently unknown-- consequences on marine life. For this reason, ocean sequestration faces a multitude of serious barriers to implementation and is not considered viable, at least for the time being.

Figure 10. Sequestration options



Source: World Bank, "CCS Status", 2008

96. Hence, the most common sequestration options being considered on a global basis are geological sequestration in coal beds, active and depleted oil/gas fields, deep aquifers and miner cavers/salt domes. Depleted oil/gas fields are the most promising near-term options, because of more favorable economics (resulting from enhanced oil/gas production).

97. Presently, there are nine CCS projects in operation worldwide, five involving CO_2 capture and sequestration and four involving enhanced oil recovery (EOR)[4]. Public funding for these and other projects currently being planned is estimated at US$26.6 – 36.1 billion[5]. Governments have announced plans to build somewhere between 19 and 43 additional CCS plants before 2020, but the global economic crisis may delay or cancel some of these projects.

98. Additional resources on CCS technologies are listed below:

- Global CCS Institute/The Global Status of CCS: 2011
- IEA, "Cost and Performance of Carbon Dioxide Capture from Power Generation", 2011
- "Cost and Performance Baselines for Fossil Energy Plants" US DOE, November, 2010 (http://www.netl.doe.gov/energy-analyses/baseline_studies.html)
- "Report of the Interagency Task Force (of the US Government) on Carbon Capture and Storage", August 2010
- "The future of coal" by MIT, 2007 (http://web.mit.edu/coal/)
- Herzog, H. "An Introduction to CO_2 Separation and Capture Technologies", MIT, 1999 (http://www.me.unm.edu/~mammoli/ME561_stuff/introduction_to_capture.pdf)

[4] World Bank, "CCS status", 2008
[5] IEA, "Progress of CCS must be speeded up", Carbon Capture Journal, Sept-Oct, 2010, pages 2-3

3.2.2 Financing of CCS projects

99. Financing of CCS projects is a major challenge, due to very high capital costs, increased auxiliary power and operating costs, and uncertainties associated with long-term liabilities. The only way to cover these expenses and risks is to have an adequately high value for the CO_2 emissions that are avoided due to the CCS process, a factor that does not yet exist. If captured CO_2 is used for enhanced oil or gas recovery, it should fetch a price which could improve the financial viability of CCS projects. However, in most cases, the price of CO_2 for EOR alone is not adequate to make a CCS project viable.

100. Proponents of CCS have proposed that it be included in the Clean Development Mechanism (CDM), which will result in a defined value for each ton of CO_2 that is avoided. At the last UNFCCC COP17 meeting (South Africa, November-December 2011) CCS was indeed approved as an eligible option under CDM. This allows CCS projects to compete with other GHG-reduction options for funding. In spite of this recent positive step, CCS financing continues to be a challenge.

101. In addition to costs and benefits, there are additional issues which impact CCS project financing, such as:

- Long-term liability issues associated with the risk of CO_2 leakage within and beyond the crediting period; specifically, who should assume this responsibility.
- CO_2 price risk: the price of CO_2 is likely to change over time, especially considering how the post-Kyoto climate change framework will evolve. In addition, if many large CCS projects are implemented and result in significant CO_2 reductions, they may suppress the price of CO_2.
- The uncertainty about the post-Kyoto climate change framework is substantial, even though the European Union has made a commitment to continue accepting emission offsets via CDM for the period 2013-2020. At COP17, there was a pledge to finalize a global climate treaty by 2015 which will take effect in 2020; however, the specifics of the treaty, and whether it will materialize at all, remain uncertain.

102. Some of the above issues and barriers could be addressed through public sector financing, but wide implementation of CCS will likely to have to rely on private financing. Public-Private Partnerships (PPPs) are another option. A number of countries are considering various methods to make financing easier by providing financial assistance and designing risk management mechanisms. Examples of such options include:

- Loan Guarantees by the Government to the private sector;
- Tax incentives including R&D expenditure treatment and accelerated depreciation;
- Allocation of emission credits for CCS activities;
- Assumption of liability, especially long-term liabilities after the completion of the project; these liabilities can be addressed through Government-funded insurance or a liability fund.

More details on these options can be found at "Report of the Interagency Task Force (of the US Government) on Carbon Capture and Storage", August 2010.

3.2.3 Lack of Post-Kyoto Climate Change Regulatory Framework

103. The uncertainty about requirements after the Kyoto period (2008-2012) represents substantial risk and makes it difficult to develop CCS projects. This is particularly relevant for developing countries which emit relatively small amounts of greenhouse gases, such as Jordan. As mentioned earlier, a key outcome of UNFCCC COP17 was a pledge by all countries to agree on a global climate treaty by 2015, to be put into effect by 2020. However, whether this will actually materialize and what specific requirements it will contain are uncertain. Furthermore, Canada withdrew from the Kyoto framework following COP17, increasing global uncertainty for the period up to 2015 and possibly later.

4. Assessment of Jordan's Capacity Related to CCS

104. As part of preparing this report, an assessment of Jordan's current capacity relating to CCS was carried out; the assessment covered CCS policy decision-making, planning, implementation and monitoring issues, as well as general stakeholder awareness including the general public. The conclusion is that **there is very limited awareness of CCS in Jordan, but the country's domestic capacity to design and manage CCS projects can be built.** At the beginning of this study, most Jordanian organizations were not aware of CCS as a technological option or how the technology could reduce the carbon footprint of energy plants and other facilities. However, the study team believes that there is an adequate technological base to build the expertise required for CCS.

105. Although the study team recognizes that Jordan is likely to follow lessons learned in other countries in terms of implementing CCS activities, the team emphasizes the need for building adequate domestic capacity to monitor CCS-related developments and to make informed decisions on behalf of the country.

The following section provides an overview of the typical capacity-building activities needed (in any country working with CCS) and as well as the specific needs within Jordan.

4.1 Typical Capacity-building Activities

106. In general, capacity-building in the CCS context is a multi-disciplined activity that addresses the needs of a wide spectrum of stakeholders, ranging from policy-makers to developers, suppliers and/or users of technology, financial institutions, insurance companies, local governments and the general public. All stakeholders need to be made aware of the key attributes of CCS that relate to their interests, as well as the role they may play in CCS implementation:

- Policy-makers need to understand the reasons why CCS is needed; the potential risks, costs and benefits; and how to structure appropriate laws and regulations within the context of a country's unique requirements. A monitoring, reporting and verification framework is one of the key elements of regulations to be enacted.
- The public should be aware of the key features of CCS, how these features may be implemented, and how such features could impact society in a positive or negative manner. Also, it is essential that the public understand why CCS is important and needed in terms of a country's energy needs and environmental responsibilities. While a Government needs to inform the public as part of any such activity, CCS is likely to be of particular concern for populations close to CCS facilities; these groups need to understand the potential (health and safety) risks and the mitigation measures taken.
- Stakeholders involved in CCS technology are likely to require more detailed training and/or education depending on their specific role. CCS suppliers are usually international companies which usually have experience in CCS technologies. If local engineering companies are involved, they may need appropriate training in certain

components which are unique to CCS technologies (especially CO_2 capture processes and sequestration). Users (owners/operators) of CCS facilities need to be trained as well; most of this training could be done as part of project implementation. In addition, an adequate level of technological know-how should exist in the country so that the various organizations involved in CCS can draw on it as necessary; in other words, an adequate number of engineers (chemical, mechanical, geological) should be available, preferably trained in CCS. Technical universities should be a primary focus for early capacity-building efforts in most countries.

- Project management is often provided by international engineering companies and suppliers, and thus is usually of secondary concern.
- Finally, commercial aspects such as financing, risk management and the structuring of commercial contracts all require specific expertise in the unique issues which surround CCS technologies.

107. For the reasons stated above, the study team believes that Jordan needs not to rush into an aggressive and/or broad capacity-building program that is focused on implementation. The country would be well-advised to instead focus current efforts on building adequate capacity to monitor CCS-related developments and make appropriate decisions as the circumstances require. The recommendation of the study team is that Jordan proceeds with an awareness-building program; more detailed capacity-building activities could be associated with CCS projects if and when such activity begins. Specific recommendations on awareness-building appear at the end of this section.

4.2 Capacity-assessment of Primary Stakeholders for CCS

108. The study team identified the primary CCS-related stakeholders in Jordan, as well as the capacity of these stakeholders to plan and implement CCS-related activities, policies and projects. The primary stakeholders are:

1. Government ministries and public agencies (in English alphabetical order):
    - Electricity Sector Regulatory Commission
    - Ministry of Energy and Mineral Resources (MEMR) – Energy and Environment Division
    - Ministry of Environment
    - Ministry of Industry and Trade
    - Ministry of Planning and International Cooperation
    - Ministry of Water and Irrigation
    - Natural Resources Authority
    - Water Authority of Jordan
2. Companies
    - National Petroleum Company and its concession partner BP

- National Electric Power Company
- Jordan Petroleum Refinery Company
- Electricity generation companies
- Cement companies (existing and prospective)

3. Academic institutions

- University Chemistry programs
- University Engineering programs
- University Geology programs
- University Environmental Management programs

109. **The assessment of institutional capacity suggests that adequate technical and vocational skill exists within Jordan, but specific training on CCS is likely to be needed.** The study team found that an adequate number of engineers is available in the key disciplines needed: electrical, mechanical, chemical, environmental engineers and geologists. Two leading universities participated in the preparation of this report, and discussions were initiated for further capacity building in CCS.

4.3 Recommendations for CCS-related Capacity-building in Jordan

110. Capacity-building for the stakeholders who would be affected by CCS requires prioritization according to stakeholder need. As such, the first recommended step is to raise awareness among the Jordanian organizations which will be directly involved in policy formulation and development of the first few CCS activities. This includes educational institutions, in order to raise the awareness of students and professors about CCS technologies and the professional opportunities they may represent.

The next step is to create the enabling environment for CCS, which would require obtaining the support of local governments and the public; acquiring the requisite technological and technical skills; identifying financial options for CCS projects; and developing the policy and regulatory framework necessary for CCS activities. The third step would be actual implementation of CCS activities.

4.3.1 Multi-track approach to capacity-building

111. This study recommends a multi-track approach to capacity building for Jordan, covering both institutional and human resources.

(i). Capacity to make informed policy decisions related to CCS

Key questions which Jordanian policy-makers may face include:

- The reasons why CCS should be considered and the potential benefits and costs, including environmental, social and economic. These questions are particularly significant for upcoming high-emission industrial activities in Jordan — such as new cement plants, oil shale activities — and for enhancing the country's natural gas exploration.

- The risks associated with CCS.
- The policy framework for safeguards and environmental and social impact that is required.
- How to achieve economy of scale for CCS activities, including regional cooperation with other MENA countries.

(ii). Capacity to study and assess evolving CCS technologies and potential applications

- Raise awareness of the public and the private sector to study and assess CCS.
- Encourage educational institutes, research institutes and/or governmental agencies to study and assess CCS, thus building local knowledge on CCS as it evolves over time.

(iii). Capacity to implement CCS activities

- Build ability in financing for CCS activities.
- Create strategy to widen the pool of local professionals involved in planning and implementation of CCS projects.
- Plan for effective outsourcing of CCS implementation.

(iv). Project-specific capacity building

Since Jordan's CO_2 emission footprint is relatively small, Jordan could consider micro-level or project-specific capacity building activities for selected CO_2 point sources. For example, the upcoming new cement plants or the planned oil shale power plants could be candidates for project-specific activities due to their relatively large CO_2 emissions compared to Jordan's baseline.

The following activities could be considered:

- Development of the legal and regulatory framework governing project development, operations, and social and environmental impact management;
- Training on CCS technologies and project implementation;
- Identification of financing options and structures;
- Public engagement and consultation.

4.3.2 Learning from the experience of Jordan's other advanced technology sectors

112. CCS-related capacity-building activities in Jordan could take advantage of the country's previous experiences in introducing advanced technologies in certain industries. Jordan has a long track record of acquiring and using technology that originated, developed and advanced elsewhere, including technologies in mining, gas exploration, cement production, power generation, and oil refining and commercial aviation, all of which were introduced more than forty years ago. These were followed by new technologies in the petrochemical

industry, and more recently the mobile telecommunications industry.

Jordan has been successful in acquiring, adapting and managing these new technologies. When they were introduced to Jordan, these technologies often required that foreign experts assist in the initial phases of acquisition, integration and early-phase management. Over time, all of these industries are now largely managed and operated by Jordanian specialists.

4.3.3 Potential capacity-building activities in the short- and medium- term, including recent past

113. Capacity building activities in the short- and medium-term:

1. World Bank CCS Conference in Washington DC, September, 2011.
   - Representatives from Jordan participated in a CCS training and workshop to exchange information about CCS and status of on-going CCS activities around the world.
   - The conference included one training day and one site-visit day to a CCS pilot facility in West Virginia.
2. A series of workshops took place in Jordan, December 2011:
   - Policy-focused workshop to inform the country's key stakeholders;
   - Technical workshop to inform specialists and practitioners; and
   - Academic workshops at Yarmouk University and the University of Jordan for students and faculty members.
3. An exploratory study on CCS
   - Fact-finding visits to CCS researchers, practitioners, technology providers, suppliers and site visits to CCS facilities
   - A regional conference to exchange information on CCS among countries of the Middle East and North Africa is also likely to take place in the coming year and will be an opportunity to exchange information from ongoing, similar CCS studies in Algeria, Egypt, Morocco and Tunisia, all of which are supported by the CCS Capacity Building Trust Fund.
4. A detailed geologic study for CCS storage and/or a feasibility assessment of prospective pilot CCS projects:
   - The CCS Capacity Building Trust Fund could provide financial support for MENA countries to carry out a detailed geologic study for CCS storage feasibility assessments of prospective pilot CCS projects as part of its ongoing capacity building assistance program.
   - For Jordan, there are two activities which the study team believes would be good next steps for strengthening the understanding of geologic options for storing CO_2 within the country: 1) a comprehensive geologic assessment of the Wadi Sirhan Basin in the

desert area of eastern Jordan; and 2) a rigorous reservoir characterization and CO_2 injectivity pilot in the deep Disi Sandstone in the Hamad Basin near Risha in the northeastern part of the country.

- In addition, as mentioned above, the planned oil shale power plants and cement plants could be candidates for CCS pilot feasibility assessment as they represent prospective new and substantial CO_2 point sources.

5. Concluding Remarks

The following observations and conclusions have emerged as key points from this study:

114. **The country's CO_2 emissions, while currently modest, are expected to increase.** While Jordan's current CO_2 emissions are modest, planned activities could introduce significant new volumes of CO_2. For example, Jordan plans to award a contract for the construction of a 500–600 MW oil shale-burning power plant in the near to medium term. Jordan has already awarded a 41-square-kilometer shale oil mining concession to Eesti Energia. This 44-year concession includes the eventual production of 36,000 barrels per day of shale oil. Early attention to the capture and storage of these new CO_2 emissions could help further motivate serious consideration of CCS in Jordan.

115. **Jordan has had limited prior exposure to CCS.** To a large degree, the topic of CO_2 capture and storage as a mitigation option for climate change is a new subject in Jordan. Further briefings and technical workshops on the topic of CCS would be useful for building a stronger base of domestic understanding and capacity.

116. **In spite of limited exposure, the Government's current policies broadly support CCS, at least at the international level.** Jordan supported the proposal to include CCS as a clean development mechanism instrument under the United Nations Framework Convention for Climate Change (UNFCCC). The country should benefit from future international agreements related to climate finance, including through the applications of CCS technology.

117. **There are no significant country-specific barriers against CCS in Jordan.** Because CCS technology is new to Jordan, the country has can extend or modify existing rules and regulations for the purpose of CCS activities or projects. The financing issues that exist in Jordan are not unique to the country, and Jordan can initially take a project-specific approach in addressing the general barriers against CCS.

118. **Jordan can take advantage of lessons learned.** Given the lack of prior exposure to CCS, it is quite understandable that Jordan does not have relevant regulatory or permitting procedures in place. A white paper and a briefing on the recently issued U.S. EPA Class VI CO_2 Storage Regulation Process would provide a valuable example of one such regulatory and permitting process that could be modified for use in Jordan. As far as other issues, Jordan could benefit from following the evolution of CCS technologies and make informed decisions as technology prices fall and additional lessons are learned in other countries.

119. **Over the short term, observation and knowledge exchange may be more appropriate than capital investment**. During the course of this study, it was identified that Jordan may benefit from following the evolution of carbon capture and storage technology from publicly available information. As similar CCS studies are being carried out in Egypt, Morocco and Tunisia, Jordan may benefit from a regional knowledge exchange event when those studies are concluded. However, given Jordan's other significant priorities, tight government fiscal situation and limited CO2 emissions, the study team believes that it is

not in Jordan's interest to pursue capital investment related to CCS in the short-term.

120. **Based on the study team's preliminary review, Jordan appears to have promising options for geologically storing CO_2.** This study has helped to identify several CO_2 storage options that present strong potential: the deep Disi (scoping level estimate: CO_2 storage capacity of 6 billion tons) and Dubeidib (1 billion tons of CO_2) saline formations in the Hamad Basin of northeast Jordan and the deep Disi saline formation (2.7 billion tons of CO_2) in the Wadi Sirhan basin of east-central Jordan. Costing estimates created under two scenario exercises are compelling:

    a. Scenario #1scoping level estimate puts CO_2 *transportation costs* from point sources in the Amman-Zarqa area to the Hamad Basin—a 250-km distance—at US$ 4.60–6.20 per ton of CO_2, and the estimate of CO_2 *storage costs* at US$ 4.70–6.50 per ton of CO_2

    b. Scenario #2 scoping level estimate puts CO_2 *transportation costs* from point sources in central Jordan (Qatrana) to the Wadi Sirhan Basin—a 150-km distance—at US$3.10–4.20 per ton of CO_2, and the estimate of CO_2 *storage costs* at US$4.90–6.70 per ton of CO_2.

    c. As for CO2 *capture costs*, the scoping level cost estimate was more than US$50 per ton of CO_2, depending on the type of CO_2 point sources in the Amman-Zarqa area and in central Jordan. In addition, water requirements for CO_2 capture activities are estimated at about 23.6 million m^3 per year. These cost estimates are based on presently available technology and are expected to decline in the future, as existing technologies are improved and new ones come to the marketplace.

    The next recommended steps are to obtain more detailed reservoir data on the characterization of the Disi saline reservoir in these two basins by drilling one or more deep reservoir characterization wells.

121. **Regional opportunities may exist for using captured CO_2 for enhanced oil recovery.** While Jordan's oil fields are small, large oil fields exist in Egypt, Iraq and Saudi Arabia that could offer viable options for productively using captured CO_2 for EOR. This study scoping level estimate puts CO_2 transportation cost from point sources in central Jordan to the oil fields in the Red Sea basin of Egypt—a 400-km distance—at US$8.30–11.10 per metric ton of CO_2, and that from the Amman area to oil field in western Iraq—a 800-km distance—at US$15.30–20.50 per metric ton of CO_2. Further, in-depth examination of this issue is warranted.

122. **High priority has been and will need to continue to be placed on protecting potable water resources.** Potable water is one of the most valuable natural resources of Jordan. Any discussion or implementation of CO_2 storage will need to directly address how the selection and design of CO_2 storage would assure the safety and protection of Jordan's potable groundwater and aquifer system.

123. **The potential for CCS-related capacity building in Jordan appears promising.** Jordan should benefit from more awareness about CCS as an evolving technology that could help address the country's GHG emissions. Jordan has adequate human professionals that can

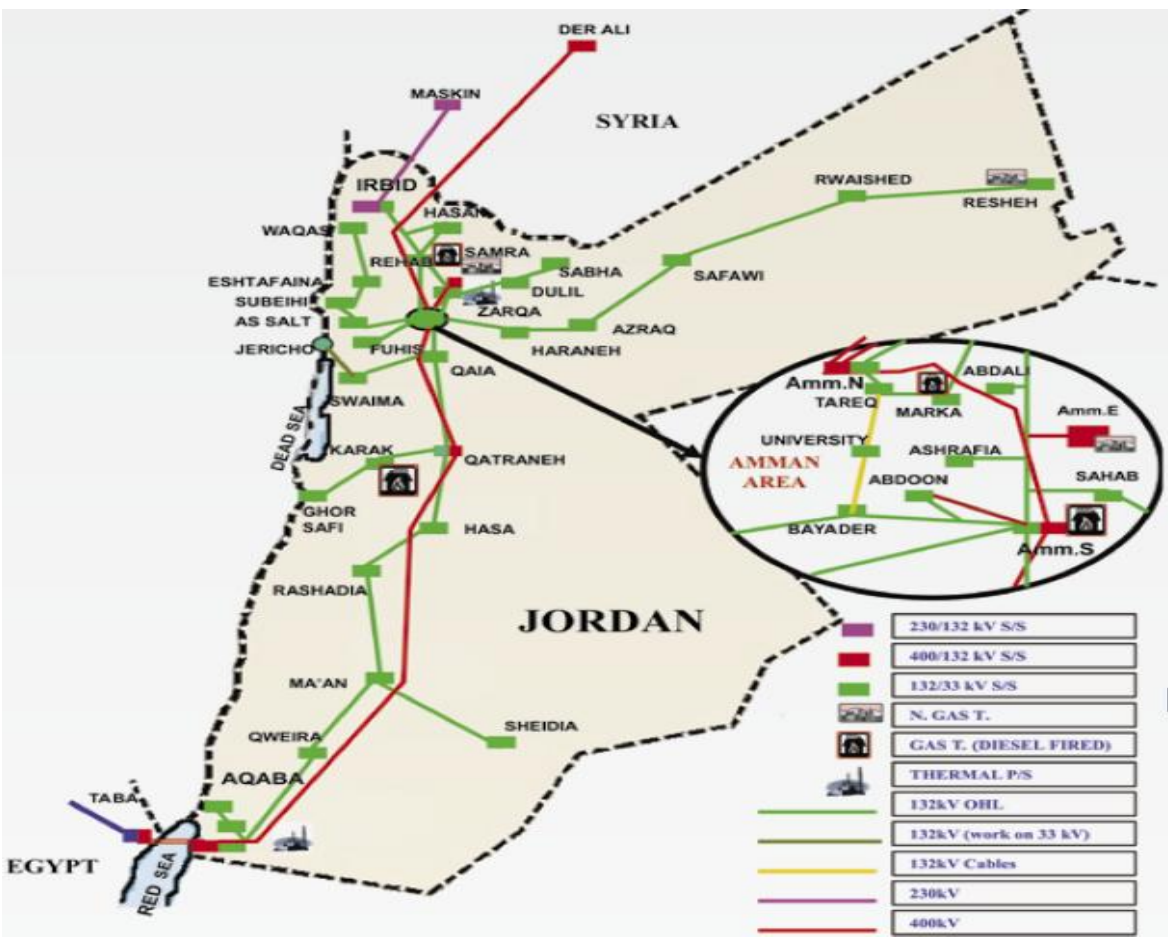
study and follow evolving CCS technologies, including geologists, engineers, chemists and others.

124. **The World Bank study team received full cooperation from the ministries and other governmental agencies within Jordan.** The staff of Jordan's ministries and agencies provided very valuable cooperation and indicated high receptivity to learning more about CCS. The World Bank CCS study team would like to acknowledge the high level of cooperation and receptivity shown by the staff of Jordan's ministries and agencies during our visits.

Annex 1: CO_2 Point Sources in the Amman-Zarqa and the Qatrana Areas

This Annex 1 explores a few CCS options for Jordan, based on previous analyses of the country's geology and available CO_2 sources. The geological investigation undertaken by the study team identified two options for potential sequestration: 1) The Risha area, close to the natural gas wheels which are presently in operation, and 2) the eastern desert area, to the east of the cities of Qatrana and Karak (see map below), where there are also substantial oil shale reserves. As a result, the following two scenarios are explored:

- ***Zarqa-Risha***: CO_2 generated by large energy sources in the Amman-Zarqa area to be transported to the gas fields of Risha.
- ***Qatrana-Wadi Sirhan Basin***: CO_2 generated by all the facilities in Qatrana area, including a 600 MW oil shale-fired power plant, to be transported to the eastern desert.



1. Zarqa-Risha

While there are numerous energy-consuming facilities in the Amman metropolitan area, the study team selected the largest CO_2 sources which are expected to be operating for many years to come, including rehabilitation (at least 20-30 years). The facilities selected are listed in the following table:

Sources of CO2	MW 2013	GWh/y 2013	Mt CO2/y 2013
Power plants			
- Amman East (CCGT)	370	2,269	0.84
- Rehab (CCGT)	300	1,840	0.68
- Samra/SEPGCO (CCGT)	1,020	6,255	2.31
Refinery	90,400	bbl/d	0.68
Cement Plants in Amman Area			
- Fuheis (JCFC)	3	Mt/y	1.20
- Muwaqar (NCo)	1	Mt/y	0.40

The three power plants that appear in the table are combined cycles utilizing natural gas or oil. Samra presently has an installed capacity of 970 MWs, but this is expected to increase to 1,020 MW by 2013 (this is one of the reasons why 2013 was chosen as the base year for this assessment).

The oil refinery (located in Zarqa) currently has a capacity of 90,400 barrels/day. There are plans to expand its capacity to 150,000 barrels/day, but it is not clear when this may materialize. For the purposes of this analysis, it is assumed that the output of the refinery will stay at its present level even though some modifications may be made to improve the quality of the fuels produced (1% sulfur HFO rather than 3-4% Sulfur HFO). CO_2 emission estimates were taken from Jordan's 2nd National Communication to UNFCCC.

Jordan has a vibrant cement production industry; two facilities were selected for this scenario, which are in the Amman metropolitan area:

- JCFC's Fuheis cement production facility which has been in operation since the 1950s; and
- The facility at Muwaqar, recently built by Northern Cement Co.

The Muwaqar facility produces 1 million tons of cement per year; the Fuseis facility's output was estimated at 3 million tons per year. There are many more cement-producing facilities in operation and in the planning stages, but most of them are in the Qatrana area and the border area near Iraq.

Other existing facilities are far from Amman and were not included in this analysis, including:

- Potash facility in Safi;
- Fertilizer production facilities;

- Sheidiyah Phosphate in Aqaba;
- Al-Hasa Phosphate; and
- Indo-Jordan Chemicals.

2. Qatrana-Wadi Sirhan Basin

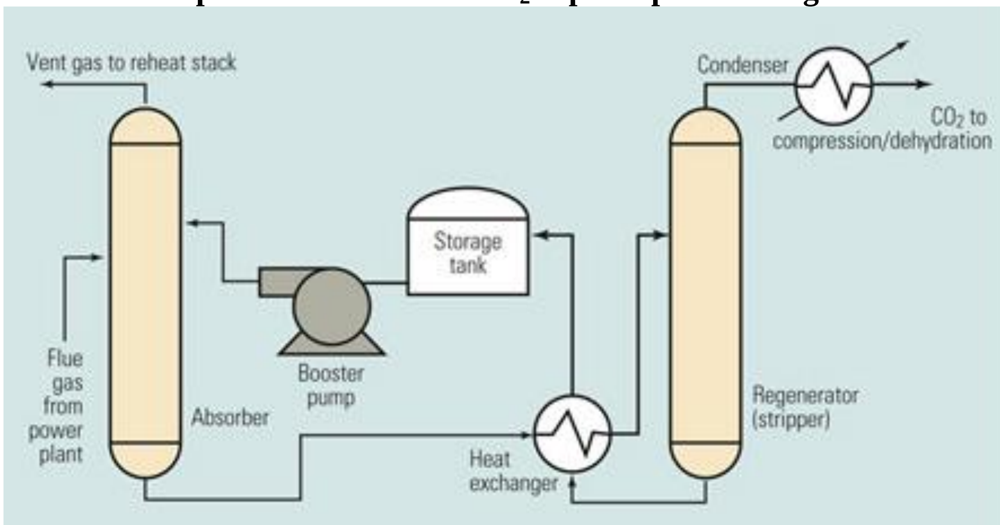
The following facilities have been identified in the Qatrana area:

- A 2 metric ton per year cement production facility at Karak owned and operated by Arabian Cement Co. of Saudi Arabia;
- A 1.2 metric ton per year cement production facility at Qatrana owned and operated by Modern Cement and Mining Co. of Jordan;
- Oil shale-fired power plant close to Qatrana. Geological studies and exploration have concluded that 60% of the Jordanian territory may be underlain by oil shale. The total resources are estimated to exceed 50 billion tons with the best locations (e.g., Sultani, Attarat Umm Ghudran and El Lajjun) near Qatrana. Therefore, it is assumed that oil shale will be used in a 600 MW circulating fluidized bed power plant (similar to Estonia), and that the power plant will release 1,100 g of CO_2/kWh. While oil shale production will result in additional CO_2 emissions, these emissions cannot be captured.

Note on CO_2 capture

Most of the facilities identified in Jordan would require post-combustion CO_2 capture. There are a few cases which may require minor gas cleaning; for example, if a refinery uses oxy-fuel in catalytic cracking, or a hydrogen SMR plant may produce nearly pure CO_2 requiring only minor treatment (e.g., de-watering). However, for the purposes of this study and considering that the majority of the flue gas comes from power plants and cement production facilities, it is assumed that post-combustion CO_2 capture would be required. The most suitable CO_2 capture technology is amine-based (see following figure).

Simplified amine-based CO_2 capture process diagram



Source H. Herzog, "An Introduction to CO_2 Separation and Capture Technologies" (MIT Energy Laboratory, 1999)

As shown in the diagram above, the flue gas passes through a packed tower-type absorber where a chemical solvent selectively absorbs the CO_2. The solvent is typically monoethanolamine (MEA); it is regenerated (in the regenerator) and then recycled back to the absorber.

Heating in the regenerator (stripper) separates the streams of CO_2 and solvent. Then, the CO_2 is condensed and dehydrated and compressed before being stored for commercial use or sequestration.

The MEA process produces relatively pure CO_2; the technology involved is mature and commercially available today. The main disadvantages of this process are the high capital costs and the substantial energy penalty required.

While there are a number of variations of the MEA technology (e.g., Mitsubishi's KM-CDR; Fluor's EFG+; and Alstom's Chilled Ammonia Process), in this report we refer to a generic variance of the technology. The key parameters and assumptions for a typical MEA process associated with a nominal 500 MW CCGT power plant are the following[6]:

[6] Source: IEA, "Cost and Performance of Carbon Dioxide Capture from Power Generation", 2011

Summary of CO_2 Capture Parameters for a 500 MW CCGT

	Without CCS	With CCS	Notes
Net Output (MW)	528	461	
Net Efficiency (%LHV)	56.6	48.4	
CO_2 emissions (g/kWh)	370	55	85% capture
Capital costs ($/kW)	960	1,715	82% increase
LCOE ($/MWh)	77	102	33% increase
Cost of CO_2 ($/ton)	-	80	

LCOE: Levelized cost of electricity
Data are normalized and expressed in 2010 US dollars

The application of CO_2 capture technologies for industrial settings such as cement production and refineries has not yet been demonstrated. Even though the same technologies could be used as are currently utilized in power plants (e.g. MEA capture processes), there is not yet adequate information on exactly how other applications might work, especially on capital and O&M costs. For the purposes of this study the following assumptions are made:

- Capital costs for CO_2 capture in refineries represents 70% of the cost of CCGTs (based on gas flow rate). The rationale for this high figure is that some of the flue gas stream in a refinery has a higher CO_2 concentration than that in power plants.[7]
- Capital costs for CO_2 capture in cement plants is 80% of the cost of CCGTs (based on gas flow rate).
- O&M costs for CO_2 capture is proportional to the capital costs.

Whether each facility in this study would have its own CO_2 capture plant or whether all the flue gas streams would be brought together to a central CO_2 capture plant requires a detailed (site-specific) analysis. Economies of scale support the idea of one central CO_2 capture facility; however, the compressors and gas pipelines from each source to the central facility would be more expensive as they would handle the total amount of flue gas which contains a majority of other substances (CO_2 is a very small percentage). For the purposes of this study, it is assumed that each CO_2 source would have its own CO_2 capture facility and the various streams would be brought to one location (e.g., Scenario #1: Samra power plant; Scenarios #2: Qatrana) for further transport to the sequestration sites.

The results of the preliminary analysis regarding CO_2 capture the two scenarios described above are shown in the following table.

[7] IEA, "Technology Roadmap Carbon Capture and Storage in Industrial Applications", 2011

CO_2 Capture from various sources in Jordan

Sources of CO2	MW 2013	GWh/y 2013	Mt CO2/y 2013	Capital ($ million)	O&M ($M/yr)	Cost ($/ton CO2)	Water Requirements (million M3)
Power plants							
- Amman East (CCGT)	370	2,269	0.84	279	28	74	1.89
- Rehab (CCGT)	300	1,840	0.68	226	23	74	1.53
- Samra/SEPGCO (CCGT)	1,020	6,255	2.31	769	77	74	5.21
Refinery	90,400	bbl/d	0.68	157	16	52	1.52
Cement Plants in Amman Area							
- Fuheis (JCFC)	3	Mt/y	1.20	319	32	59	2.70
- Muwaqar (NCo)	1	Mt/y	0.40	106	11	59	0.90
Cement Plants in Qatraneh Area							
- Karak (Arabian Cement)	2	Mt/y	0.80	213	21	59	1.80
- Qatrana (MCM)	1.2	Mt/y	0.48	128	13	59	1.08
Oil shale power plant	600	3,679	4.05	988	90	52	8.36
TOTAL			**11.44**	**3,185**	**308**	**61**	**24.99**

Water requirements for CO_2 Capture

Water requirements for CO_2 capture derive mainly from the additional cooling water that is required during the capture and compression processes.

CO_2 capture in CCGT plants is expected to increase the cooling water requirements by 0.22 gallon/kWh[8]. It is assumed that the water requirements for CO_2 capture in the refinery and the cement plants are similar to the CCGT plants (in terms of water per processed CO_2 flow rate).

Water requirements associated with the oil shale power plant will be 0.6 gal/kWh[9]. Oil shale production (retorting etc.) is projected to require 18.9 million m^3 of water for a 100,000 bbl/day facility[10]. However, the latter is not included in this analysis, as it is assumed that only oil shale for the power plants will be produced; i.e., there will be no additional production of oil.

As the previous table shows, approximately 25 million m^3 of water per year will needed for all CO_2 capture activities.

[8] The University of Texas at Austin, "Water Demand Projections for Power Generation in Texas", August 31, 2008 (http://www.twdb.state.tx.us/wrpi/data/socio/est/final_pwr.pdf)

[9] Ciferno, J. P., et al. (2010). "Determining Carbon Capture and Sequestration's Water Demands." *Power Magazine* March 2010.

[10] US TDA, "Technical Assistance on Oil Shale Resources Development in Jordan", February 2008

Annex 2: Documents Collected and References

Jordan-specific

- Presentation titled *"An International Oil Shale Council for Egypt, Jordan, Morocco, Turkey, and Syria"*, prepared by T. Sladek of Ockham Energy Services, February 2010.
- Paper titled *"Future Policies and Strategies for Oil Shale Development in Jordan"* by the Jordan Journal of Mechanical and Industrial Engineering, March 2008.
- Final Report on *Technical Assistance on Oil Shale Resources Development in Jordan*, prepared by Behre Dolbear & Company (USA), Inc., February 2008.
- Paper titled *"Jordan Oil Shale, Availability, Distribution, and Investment Opportunity"* by the Natural Resources Authority of Jordan, November 2006.
- Initial Communication Document to UNFCCC, January 1997.
- Jordan's Second Communication to UNFCCC, 2009.
- Updated Master Strategy of Energy Sector in Jordan for the period (2007-2020), December 2007.
- "Technical and Economic Evaluation of Geothermal Data for Energy Application in Jordan" November 2006.
- Annual reports of National Resources Agency for 2008 and 2009.
- Presentations, December 5th, 2010:
  - "Geology of Jordan/An Overview" by A. Masri, NRA
  - "Paleozoic of Jordan" by A. Masri, NRA
  - "Regional Petroleum Geochemistry of Jordan" by H. Ramini, NRA

CCS-specific

- IEA, "Carbon Capture and Storage Model Regulatory Framework", November 2010. (http://www.iea.org/ccs/legal/model_framework.pdf)
- IEA, "Carbon Capture and Storage/Legal and Regulatory Review", October 2010.
- IEA, "Cost and Performance of Carbon Dioxide Capture from Power Generation", 2011.
- IEA, "Progress of CCS must be speeded up", Carbon Capture Journal, September-October, 2010, pages 2-3.
- European Commission, "GSE briefing paper on CO2 storage", September 2009.
- European Commission, Directive 2009/31/EC of 23 April 2009 "*On the geological storage of carbon dioxide"*.

- "GSE briefing paper on CO2 storage", September 2009.
- "Report of the Interagency Task Force (of the US Government) on Carbon Capture and Storage", August 2010.
- U.S. Carbon Sequestration Council, "CCS: Legal and Regulatory Framework – 10 Year Progress Report", November 2010. [This report reviews CCS regulatory developments in 15 countries]
- "Cost and Performance Baselines for Fossil Energy Plants" US DOE, November, 2010. (http://www.netl.doe.gov/energy-analyses/baseline_studies.html)
- MIT, "The future of coal", 2007. (http://web.mit.edu/coal/)
- Herzog, H. "An Introduction to CO2 Separation and Capture Technologies", MIT, 1999. (http://www.me.unm.edu/~mammoli/ME561_stuff/introduction_to_capture.pdf)
- "Legal design of carbon capture and storage/Developments in the Netherlands from an International and EU Perspective", ISBN 978-90-5095-801-1 (2009, published by Intersentia).
- Bellona, "Insuring energy independence/A CCS roadmap for Poland", 2011.

Annex 3: Report on Options for CO_2 Transportation and Storage for Jordan

[Full report is provided separately.]

Annex 4: Laws, Regulations and International Conventions of Jordan which May Relate to CCS

1- The Ministry of Water and Irrigation/The Water Authority / By-Law No. (85) of 2002/**Underground Water** Control By-Law (originally issued in 1977).
2- Regulation No. (37) of 2005/**Environmental Impact Assessment** Regulations.
3- Regulation No. (26) of 2005/Protecting the Environment from Pollution in **Emergency Situations** Regulations.
4- Regulation No. (21) of 2001/Protection of Environment in the **Aqaba Special Economic Zone** for the year 2001.
5- Temporary **Public Health** Law No. 54 for the year 2002.
6- JISM (286:2001-4th edition) Technical Regulation / **Drinking water.**
7- JVA Law 30 of 2001/ **Jordan Valley** Development Law.
8- Law No. 8 for the Year 1996/The Jordanian **Labor** Law.
9- Regulations No. (29) of 2005/ **Natural Reserves** and National Parks Regulations.
10- Law No. (12) For the Year 1968/ Amendments for Regulating Natural Resources Affairs
11- Regulation No. (28) of 2005 / Regulations for the **Protection of the Air.**
12- Regulation No. (131) For the Year 1966**/Mining regulations.**
13- Regulation of **Hazardous Waste** Management and handling.
14- Regulation No. (25) of 2005 / **Soil Protection** Regulations.
15- **Industrial Wastewater** JS: 202/1991 standards.
16- Law No. 18 of 1988/ **The Water** Authority Law.
17- The **Aqaba Special Economic Zone** Law No. (32) for the Year 2000 and its amendments.
18- **Civil Defense** Law No. (18) For 1999 and its Amendments.
19- Guidelines for **drinking water** resources protection.
20- General **Electricity** Law.
21- Regulation No. (24) of 2005 / Management, Transportation and Handling of Harmful and **Hazardous Substances** Regulations.
22- Regulation No. (27) of 2005 / Management of **Solid Waste** Regulations.
23- The Regulation of Protection and Safety from **Industrial Tools** and Machines and Work Sites.

24- Regulations of 2005 / Regulations for the **Protection of Water.**

25- Management of **Natural Resources** law No. 12,1968.

26- **Traffic** law.

27- **Expropriation** law No. 12 of 1987.

28- The **environment protection** law No. 52 of 2006

29- The **development zones** law No.2 of 2008.

30- The **antiquities** law and its amendments of 2004.

31- **Transportation** law.

32- **Agriculture** law of 2002.

33- **Trade, Industry and Occupational** law No. 16 of 1953.

34- **Forestry and Soil** protection law No. 23 of 1972.

35- **Land-use planning** regulation No. 6 of 2007.

36- Regulations for the **licensing and permitting of excavation** and infrastructure network projects.

37- Regulations for controlling the use of substances that **deplete the ozone layer** of 2003.

38- **Noise** regulations of 1997.

39- Regulation for the establishment of **occupational health** and safety committees No. 7 of 1998.

40- Regulations for protection of **birds and wildlife** No. 113 of 1973.

41- Instructions and procedures for the establishment of **sites for quarrying** and mining permits of 2006.

42- **Ambient air** quality standards.

43- Requirements for discharge of **industrial effluents.**

44- Standards for maximum allowable limits of **air pollutants** emitted from **stationary sources.**

45- Standards of **heat level** exposure in work environments.

46- Emissions standards for **electricity generation.**

47- International **plant protection** convention 24/4/1970.

48- Convention concerning the protection of the world **cultural and natural heritage** 17/12/1975

49- Convention on wetlands of international importance especially as waterfowl **habitat** and its amendment (RAMSAR) 1/10/1986.

50- Convention on international trade in endangered species of wild **fauna and flora** and its amendment 13/4/1987.

51- The Hague protocol and convention for the protection in the event of **armed conflict** 1954.

52- Convention for the protection of the **Ozone layer** 31/8/1989 and its amendment of Montreal on 28/9/1995

53- Basel convention on the control of trans-boundary movements of **hazardous wastes** and their disposal 5/5/1992.

54- Convention on **biological diversity** 10/2/1994.

55- International convention to combat **desertification** in countries experiencing serious drought and/or desertification 26/12/1996.

56- Constitution of the **Food and Agriculture Organization** of the United Nations 23/1/1951.

Annex 5: Global CCS Regulations Update

Significant progress has been made with regard to adoption of regulations related to CCS, especially in Australia, Europe and North America. A number of developing countries, including Malaysia, South Africa and Vietnam, are in the process of evaluating options.

Australia

Australia's regulators continue to lead the way in developing law and regulations for CCS activities. Onshore storage is legislated by the state governments, while federal legislation, consistent with the London Protocol, covers offshore storage. However, the state governments have worked together to develop nationally-consistent Australian Regulatory Guiding Principles.

During 2011, the Federal Government introduced amendments to legislation governing offshore CCS activities and the development of further secondary legislation. The *Offshore Petroleum and Greenhouse Gas Storage Legislation Amendment (Miscellaneous Measures) Act*, entered into force in late 2010 and made a number of amendments to the *Offshore Petroleum and Greenhouse Gas Storage Act 2006 (OPGGS Act)*, most notably by expanding the powers of the National Offshore Petroleum Safety Authority to cover some aspects of greenhouse gas facilities.

A number of regulations have also been developed under the auspices of the OPGGS Act, including: the *Offshore Petroleum and Greenhouse Gas Storage (Management of Greenhouse Gas Injection and Storage) Regulation 2011*, the *Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulation 2011*, and the *Offshore Petroleum and Greenhouse Gas Storage (Regulatory Levies) Amendment Regulation 2011*. These regulations address a range of issues related to the rights and obligations of titleholders under the OPGGS Act, including management and administrative responsibilities related to CCS operations.

Further amendments to the OPGGS Act are anticipated under Bills introduced into Parliament. These proposals introduce, amongst other items, new regulatory bodies, cost recovery levies and other consequential amendments to support government policy.

In 2011, a number of state jurisdictions have also commenced work on regulatory frameworks for CCS. Western Australia is drafting a Greenhouse Gas Storage Bill, which will amend the *Petroleum and Geothermal Energy Resources Act 1967* and adopt a similar approach to the federal OPGGS Act. Also, the Government of New South Wales introduced its *Greenhouse Gas Storage Bill* to Parliament in November 2010, but it failed to pass as a result of a delay to the legislative process caused by the subsequent state elections. The proposed legislation provided a full permitting and licensing regime for the permanent storage of CO2, including provisions for the post-closure transfer of liabilities to the Crown.

Canada

Canada's provincial governments continue to lead national efforts in the development of law and regulation for CCS. The Governments of Alberta and Saskatchewan have both introduced legislation to regulate CCS at the provincial level.

Alberta's *Carbon Capture and Storage Statutes Amendment Act 2010* entered into force in December 2010 and makes several amendments to provincial statutes to provide clarification around the regulation of CCS activities in Alberta. The Act does not present a full regulatory framework, but it addresses a number of key issues, including a determination that pore space in the province is owned by the government. The Act includes provisions for the transfer of long-term liabilities to the government upon the provision of data demonstrating the containment of the injected CO2 as well as establishing a post-closure stewardship fund. The adoption of the *Carbon Sequestration Tenure Regulation* in April 2011, established a further process for those seeking pore space tenure rights for carrying out CO2 geological storage. The Regulation sets out further guidance around the terms, areas and boundaries and MMV (Monitoring, Measurement and Verification) requirements associated with evaluation permits and carbon sequestration leases.

Also, Alberta is undertaking a Regulatory Framework Assessment to examine the regulatory regime in Alberta, in particular the environmental, safety and assurance processes and requirements, and determine whether they meet the requirements of the commercial deployment of the technology. The process is a considerable achievement and draws upon both domestic and international expertise. The final report and recommendations are to be provided to the Ministry of Energy in 2012.

The Government of Saskatchewan has begun work to address CCS activities within its provincial regulatory regime. The provincial government has sought to include CCS within its existing regulatory portfolio and as such, has adapted a number of existing laws to accommodate the technology. Amendments to the *Pipelines Act, Crown Minerals Act* and *Oil and Gas Conservation Act* are expected to adequately facilitate the transportation and storage phases of the process. Saskatchewan's participation in Alberta's Regulatory Framework Assessment may also lead to the development of further legislation or the adoption of a more holistic and integrated approach to regulation.

European Union

Europe has made the most progress regarding legal and regulatory developments for CCS. After issuing a CCS (*CO2 Storage)* Directive in 2009 and a set of CCS Guidelines in 2010, EU Member States are required to transpose the CCS Directive into their domestic laws by June 25, 2011. As of this deadline, twelve countries had communicated to the Commission their actions towards implementation of legislation: Austria, Belgium, Denmark, France, Ireland, Latvia, Lithuania, Luxembourg, Romania, Spain and the United Kingdom.

The progress made varies significantly from country to country. For example, Germany is still facing difficulties in getting consensus to support CCS regulation. On the other side of the spectrum, Romania has already transposed the CCS Directive into national law (*Governmental Emergency Ordinance No.64 of 29 June 2011*) and is expected to pass further secondary legislation to ensure the full implementation of its requirements. Similar progress has been made in Spain. Finland determined that CCS is not feasible in its territory.

United Kingdom

UK indentifies CCS as a key technology that can bridge the gap between renewables and the required baseload output. Legislation introduced by the UK requires all new coal plants greater than 300MW to prove their capture readiness. The financial mechanism announced by the UK government to support CCS, which will take the form of a levy on electricity bills, is estimated to have the potential to raise around £10 billion. The majority of the UK's CO_2 storage sites are offshore in depleted oil and gas fields; storage could be regulated alongside petroleum licensing.

United States

In late 2010, the EPA finalized its reporting rule governing aspects of the CCS process, as well as its final rule for CO2 geologic sequestration wells as part of its Underground Injection Control Program, as established under the *Safe Drinking Water Act*. The former, the *Mandatory Reporting of Greenhouse Gases from Carbon Dioxide Injection and Geological Sequestration*, Subparts RR and UU, sets out monitoring, reporting and verification objectives for all facilities conducting geological sequestration and the injection of CO2, while the latter creates a new Class VI well specifically for long-term, incremental storage of CO2.

On 4 August 2011, the EPA released a proposed rule to modify their pre-existing hazardous waste legislation. The proposed amendments will remove injected CO2 streams from the scope of the hazardous waste regulations, provided they are to be injected into wells designated under the *Safe Drinking Water Act*. The rule document states that the EPA is proposing this course of action because “it believes that the management of these CO2 streams under the proposed conditions does not present a substantial risk to human health and the environment”.

The EPA has also published draft guidance documents to assist operators and owners of the new Class VI well. Guidance documents for financial responsibility have already been finalized, while draft documents addressing site characterization, corrective action, well construction and the content of well plans were opened for public consultation.

A number of states have introduced or enacted legislation to regulate discrete aspects of the storage process or to provide financial incentives or security to operators. For example, in the State of Mississippi a new Bill (2723) sets out a regulatory framework for CCS, which also allows existing EOR (Enhanced Oil Recovery) operations to continue without conflicting with the EPA’s underground injection control program. Under the Bill, regulatory authority for the storage of CO2 is divested in the environmental and oil and gas authorities and provisions are introduced governing the title to CO2, the approval of storage reservoirs and the establishment of a fund to manage the long-term liabilities associated with storage sites.

In the State of Illinois, the legislature passed the *Clean Coal FutureGen for Illinois Act of 2011*, which seeks to establish a comprehensive liability regime for the FutureGen 2.0 project. Under the Act the FutureGen Alliance is required to hold a private insurance policy for the duration of the operational phase, as well as establish a trust fund to supplement their insurance. Of particular note is the Act's transfer to the State of Illinois, of all liabilities surrounding the stored CO2 at the end of the operational phase of the project.

A number of regional sequestration projects are being implemented under the auspices of the US Department of Energy (DOE) which enhance co-operation on CCS on a local level.

References

1. International Risk Governance Council, "Policy Brief: Regulation of Carbon Capture and Storage" (http://www.irgc.org/IMG/pdf/Policy_Brief_CCS.pdf);
2. Baker & McKenzie, "Legal and regulatory developments related to carbon capture and storage", December 13, 2011 (http://www.globalccsinstitute.com/publications/legal-and-regulatory-developments-related-carbon-capture-and-storage-between-november-2);
3. IEA, "Carbon Capture and Storage/Legal and Regulatory Review", May 2011 (http://www.iea.org/Papers/2011/ccs_legal.pdf);
4. IEA, " Global CCS legal and regulatory developments", May 2011 (http://www.cnr-cme.ro/evenimente/2011/12_mai_CCS/Justine_Garrett_IEA.pdf);
5. NZEC, "International CCS Policies and Regulations" (http://www.nzec.info/en/assets/Reports/International-Policies-Regulations-English.pdf);
6. Armeni C., "An update on the state of CCS regulation from Europe", Feb 13, 2012 (http://www.globalccsinstitute.com/community/blogs/authors/chiara-armeni/2012/02/13/update-state-ccs-regulation-europe).

Annex 6: List of Counterparts in Jordan

Institutions	Names
Ministry of Energy and Mineral Resources	Eng. Ziad Sabra Eng. Mohammad Dabbas Eng. Lina
Ministry of Environment	Eng. Mohammed Alam Eng. Hussein Badarein
Ministry of Planning and International Cooperation	Mr. Mohammad Assaf Eng. Mojahed Kraishan Mr. Awwad Salameh
Ministry of Water and Irrigation	Eng. Mohammad Almomani
National Energy Research Center	Eng. Walid Shahin Eng. Salah Azzam Eng. Muhieddin Tawalbeh
Natural Resources Authority	Dr. Maher Hijazin Eng. Darwish Jaser Eng. Ahmad Masri Dr. Mousa Alzyoud Mr. Hazem Ramini Eng. Ghussaina Hilu
Royal Geographic Center	Dr. Awni Al-Khassawni Eng. Ahmad Eng. Osama Eng. Ibrahim Awad
Water Authority of Jordan	Dr. Khair Hadidi Eng. Mamoon Ismail
National Petroleum Company	Eng. Qutaiba Abu Qorah Dr. Abdel Rahman Qteishat Mr. Nabeel Rabadi Dr. Firas Malahmeh (external counsel)
University of Jordan	Dr. Ahmed Al-Salaymeh Dr. Ahmad Sakhrieh Dr. Ibrahim Odeh Dr. Abbas Al-Omari Dr. Lina Abu Ghunmi
Yarmouk University	Dr. Muheeb Awawdeh Dr. Sameh Gharaibeh

Annex 7: Jordan – The National Committee on Climate Change

GEF

وزارة البيئة
المملكة الأردنية الهاشمية

The National Committee on Climate Change
Final Mandate/ToR

With support from: *Developing Policy Relevant Capacities for the Implementation of the Global Environmental Conventions in Jordan* "*CP-2*" Project, UNDP-Jordan

I. Current Committee's Members:

1. Ministry of Environment
2. Ministry of Energy and Mineral Resources
3. Ministry of Planning and International Cooperation
4. Ministry of Agriculture
5. Ministry of Industry and Commerce
6. Ministry of Transport
7. Ministry of Water and Irrigation
8. Ministry of Health (was dropped by mistake in the decree letter received from the Prime Minister's office dated 13/6/2011)
9. Ministry of Tourism
10. Ministry of Social of Development
11. Jordan Meteorological Department
12. General Security Directorate/ Drivers & Vehicles License Department
13. Royal Scientific Society
14. Jordanian National Forum for Women
15. Greater Amman Municipality (was dropped by mistake in the decree letter received from the Prime Minister's office dated 13/6/2011)
16. Aqaba Special Economic Zone Authority (ASEZA)
17. National Center for Agricultural Research and Extension (NCARE)
18. The Jordanian National Commission for Women (JNCW), hosted by the Jordanian Hashemite Fund for Human Development (JOHUD), to represent both JOHUD and JNCW, which in turn represents all women organizations in Jordan (such as the General Federation of Jordanian Women [GFJW] and Jordanian National Forum for Women [JNFW]).
19. Two national universities selected based on criteria set by committee (for 2011/2012 Hashemite University and Jordan University for Science and Technology, JUST, were selected)
20. Two national environmental NGOs selected based on criteria set by committee (for 2011/2012, Royal Society for Conservation of Nature and Jordan Environment Society were selected)