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Towards a Technology Roadmap for Carbon Capture and Management for Qatar

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Abstract**—**A rapid growing interest in the application of CO_2 capture and storage technology worldwide is being observed. This growing interest has brought about a growing global consensus that CCM is one of a number of measures to be taken to address CO_2 emissions and that without CCM; it will be extremely difficult, if not impossible to reduce CO_2 emissions to the levels needed to mitigate climate change effects. The Gas Processing Center (GPC) Carbon Capture and Management (CCM) Technology Roadmap (TRM) is being developed to identify promising directions for research in carbon dioxide (CO_2) capture and management (CCM). The Technology Roadmap is being developed to take into account the significant CCM developments that have occurred worldwide and identify key knowledge gaps and areas where research should be undertaken specifically for Qatar.

Keywords**—** Carbon Capture, Management, Roadmap, Qatar.

I. INTRODUCTION

DESPITE the current economic slowdown observed worldwide, global energy demand continues to increase in the coming years. The global energy security is directly linked to the electricity generation capabilities which in turn heavily depend on fossil fuel which will remain a central part of the world energy consumption. The World Energy Outlook in 2008 estimated that 80% of global energy needs in 2030 will continue to be met by fossil fuels which results in the emission of large quantities of CO_2 causing a clear impact on climate change. Hence, a pressing need to take action to reduce carbon emissions is acknowledged world-wide as a lot of countries are preparing roadmaps to advance innovative energy technology with the support of the International Energy Agency (IEA). The goal of these roadmaps is to accelerate the overall R&D process in order to deliver an earlier uptake of the specific technology into the marketplace. Countries including Qatar are committed to urgently develop, deploy and foster clean energy technologies, recognise and encourage a wide range of policy instruments such as clear regulatory frameworks, economic and fiscal incentives, and public awareness to foster the investments in new CO_2 abatement technologies.

The importance of CCM arises from the concerns over the climate change at international, regional and national levels. According to the IEA statistics of 2009 [1] shown in Figure 1.1, the world CO_2 emissions were estimated at about 31 Giga tones, they mainly come from the power generation sector of which 67% comes from the burning of fossil fuels.

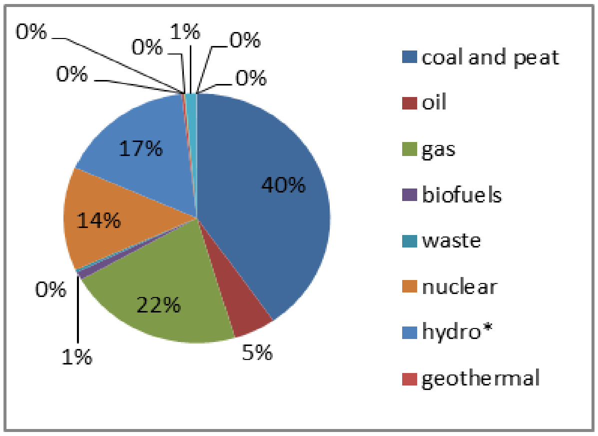

Fig.1 Energy Demand- Electricity Worldwide Production in 2009

The expectations of 2030 as shown in Figure 1.2 predict a total electricity production of 31 million GWh. The scenario expects that fossil fuels will have a higher share of 71% and increased electricity production by 35%.

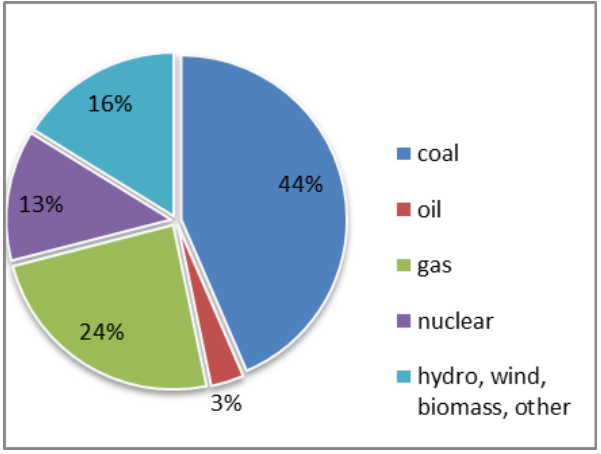

Fig.2 Expected Electricity Worldwide Production in 2030

The International Energy Agency (IEA) Blue map scenario, which assessed strategies for reducing GHG emissions by 50% by 2050, concluded that CCM will need to contribute one-fifth of the necessary emissions reductions to achieve stabilization of Green House Gases (GHG) concentrations in the most cost-effective manner (Figure 1.3). The Blue Map results revealed that if CCM technologies are not available, the overall cost to achieve a 50% reduction in CO_2 emissions by 2050 will increase by 70% [2]. CCM is therefore an essential part of the portfolio of technologies that is needed to achieve substantial global emissions reductions.

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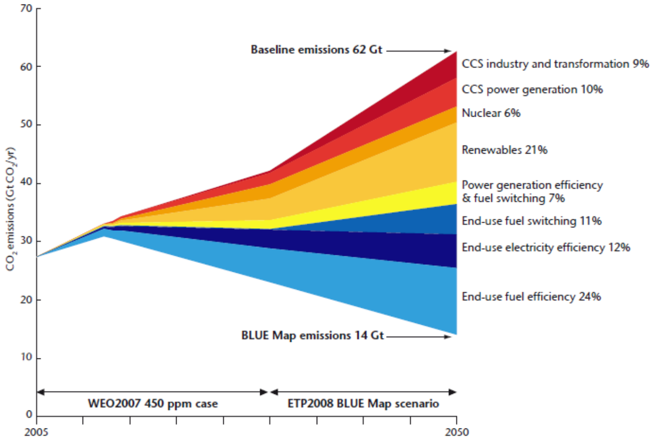

Fig. 3 IEA Blue map scenario

These facts have pushed the G8 leaders in Japan's Hokkaido Toyako Summit about CCM (Aug 2008) to declare for the first time the launching of 20 large-scale CCM demonstration projects globally by 2010, with a view to beginning broad deployment of CCM by 2020". However, the number of 20 projects has not been reached as only few projects have been launched since then. This international commitment was further fostered in the later Communiqué of Third Carbon Sequestration Leadership Forum (CSLF) ministerial meeting in London, U.K., on October 11-14, 2009 where they reiterated that "the 20 industrial-scale demonstration projects by 2010 endorsed by the G8 are vital, and that more such projects could be required by 2020 both in developed and developing countries". They also stated that "Co-operation and knowledge sharing on CCM needs to be increased between developed and developing countries". The fourth Communiqué of the Carbon Sequestration Leadership Forum (CSLF) ministers meeting on September 2011 Beijing, China, stated that "We are fully committed to the CSLF strategy to build and operate multiple successful commercial-scale CCUS project demonstrations by 2020".

Qatar, the world's leader of liquefied natural gas, who's economic growth, builds on the development of a global energy industry. Diversification into petrochemicals and metallurgy as well as cogeneration facilities providing desalinated water make Qatar's economy heavily dependent on energy consumption. According to the 2008 IAE statistics [2], Qatar produced about 68.48 Million tons of CO_2 in 2008. Fuel combusted during energy production accounts for 67% of Qatar's carbon dioxide emissions (Figure 1.4). Of these emissions, 37% stems from energy expended in basic oil and gas production, about 12% is attributable to gas flaring, and another 18% results from petrochemicals and cogeneration of water and power for industrial users. Households and commercial users account for the remaining 33% of total emissions.

Qatar's carbon dioxide emissions are comparatively low, about 0.2% of the world's total. But as a major energy-producing country with a small population, Qatar is unfairly penalized when carbon dioxide emissions are measured on a per capita basis. By this yardstick Qatar emerges as the world's highest emitter of CO_2 (Table 1.1). However, Qatar would be ranked much lower if only emissions stemming from consumption were measured.

Like its neighbors, Qatar is highly vulnerable to the various shifts that may result from climate change. It is among the 10 countries that would be most affected by a rise in sea level, which could damage coastlines and marine life.

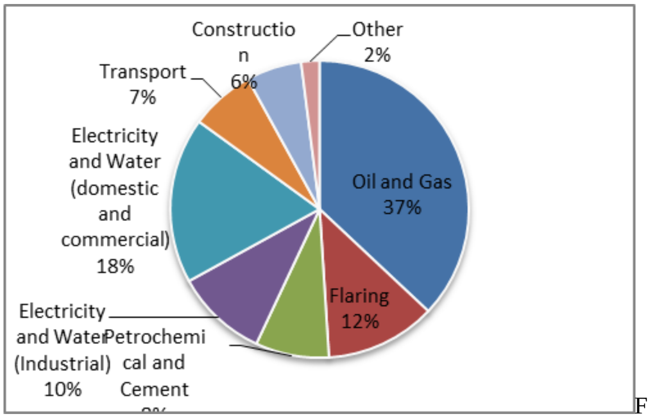

Fig.

Fig. 4 Qatar CO_2 Emissions Sources

TABLE I
CO_2 EMISSIONS PER CAPITA IN QATAR IN 2009

Country	Rank	Tones/year/capita
Qatar	1	40.12
United Arab Emirates	2	31.97
Trinidad and Tobago	3	30.00
Kuwait	4	28.88
Bahrain	5	28.86

If average temperatures rise, demand for water could increase, along with salinity in the groundwater. Climate change scenarios envision more weather extremes, which could mean heavy local flooding and sandstorms.

Qatar is committed to working with other countries to address global climate change and to eliminating in-efficiencies that raise carbon dioxide emissions. In 2007 Qatar introduced its first United Nations Framework Convention on Climate Change Clean Development Mechanism. In recent years, it has taken major steps to reduce carbon emissions -especially from gas flaring- which accounts for about 12% of total emissions. The steps include legislation to limit emissions, investment in cleaner technologies and improvements in industrial processes, the Al-Shaheen Oil Field Gas Recovery and Utilization Project, which reduced flaring by about 80%. Facilities completed at the Al-Karkara field in 2011 have been designed to achieve zero gas flaring by injecting excess sour gas back into the reservoir. Qatar commitment to the cause was fostered in the National Development Strategy (NDS) 2011-2016 [3], by developing a national policy to manage air pollution, greenhouse gas emissions and the broader challenges of climate change. Furthermore, Qatar has reiterated its commitment to CO_2 reduction by hosting the United Nation Framework on Climate Change (UNFCC) COP 18 conference which took place in Dec 2012 in Doha.

II. APPROACHES FOR CO_2 CAPTURE

The Gas Processing Centre is setting plans on investigating a broad portfolio of research pathways in three general technology approaches for CO_2 capture, namely: pre-, post-, and oxy-combustion, with less emphasize on the later.

A. Pre-Combustion Capture

Pre-combustion capture is generally implemented in IGCC power plants or in Natural gas purification as the case of Qatar. The CO_2 is removed from the syngas prior to its combustion for power production or in the gas sweetening unit in case of Natural Gas treatment. The gas mixture is at elevated pressure (20 -70 atm) and the CO_2 concentration is significantly high (15–60 %). Because of high pressure, Physical solvents are generally preferred in this process.

B. Post-Combustion Capture

It refers to removal of CO_2 from the flue gas produced from fossil fuel combustion and/or biomass in air. It is primarily applicable to conventional coal-fired, oil-fired or gas-fired power plants, but it could also be applicable to natural gas combined cycle (NGCC) flue gas capture. The preferred CO2 removal technique is generally chemical solvent scrubbing.

The main concerns [4] with chemical solvents such as MEA for capturing CO_2 from combustion flue gases include:

- corrosion of equipment in the presence of O_2 and other impurities [5]
- high solvent degradation due to reaction with oxygenated impurities [6-8]
- high energy requirements
- potential emissions of solvent to the environment [9], and
- very large equipment required due to the huge volumes of flue gas.

Amine impregnated solid sorbents are seen as the “next generation” of amine based sorbents for post combustion CO_2 capture. They offer the potential to improve the overall efficiency because they avoid the thermal penalty associated with the use of aqueous-based amine systems. Ionic liquids (ILs) have also been considered for post-combustion capture. The major advantage of ionic liquids is that they are physical solvents with the potential to minimize the energy requirements associated with CO_2 release and regeneration; and they remain stable at temperatures up to about 300 °C, which means the need for flue gas cooling prior to CO_2 capture may be avoided. Task specific ionic liquids (TSILs), e.g., those with ions incorporating amine functional groups, are touted as a major advancement in terms of CO_2 capture capacity [10]. The use of biological systems such as algae to remove CO_2 from flue gas is also an active area of research, which has received a lot of commercial interest. A range of methods have been considered including open ponds or tanks, and closed bioreactor systems. High-temperature solid sorbents has recently attracted a lot of research attention. Significant research efforts are focused on improving the long-term capacity of CaO-based sorbents [11]. Particularly a promising candidate known as post-combustion carbonate looping that offers four key advantages [12]:

- potential to minimize energy requirements for CO_2 capture;
- unique prospects for synergies with heavy-emitting industry;
- use of mature large-scale equipment, which reduces scale-up risk; and
- relatively cheap sorbent derived from natural limestone.

C. Oxy-Combustion Capture

Oxy-combustion is an alternative to post-combustion CO_2 capture for coal-fired power plants which is not the case of Qatar where all power plants are using Natural gas and oil as fuel, therefore less attention will be given to this area.

D. Membrane separation

Membrane separation technology involves the selective permeation of gases through tailored materials driven by a pressure gradient achieved by either compressing the feed stream, or creating a vacuum down-stream. Different types of membrane material are available including polymeric, metallic and ceramic membranes depending on the application. Membrane separation technologies offer significant potential for the future. The major challenges to overcome include: cost of membrane materials, life-time of membrane and reliability issues due to exposure to particulates, SO_x, NO_x and trace metals.

III. THE R&D PROCESS – PROGRESS OVER TIME

GPC’s CO_2 capture R&D timeline is consistent with the GPC’s plan to overcome the barriers to the widespread, cost-effective deployment of CCM within eight years. The GPC envisions having a CO_2 capture technology portfolio ready for full-scale demonstration by 2020 to meet Qatar’s goals for reducing GHG emissions. GPC’s CO_2 capture R&D effort is engaged in a variety of advanced CO_2 capture technologies, including liquid solvents, solid sorbents and membranes. It is expected that at least one of these advanced technologies should be ready for full-scale demonstration by the year 2020 after successfully completing a sequential progression of laboratory-, bench-, and pilot-scale testing.

The goal of GPC’s CO_2 capture technology R&D effort is to develop fossil fuel conversion systems that achieve 90% CO_2 capture at a less than 30% increase in COE. Reaching these goals require an integrated R&D effort linking fundamental advances in CCM to practical advances in technologies amenable to extended commercial use. By 2013, the R&D effort seeks to have small pilot-scale unit that be used for operation performance and solvent development as well as for new researches training.

The GPC CO_2 capture R&D effort includes the following future targets that are planned to be completed by 2015:

Develop a portfolio of bench-scale pre-combustion technologies.

Complete small pilot-scale testing of the CO_2 capture technologies that were successful at bench scale and identify opportunities for integration of the technologies with the power plant.

Initiate second generation advanced CO_2 capture technologies that have the capability to reduce costs to near zero, reduce energy penalties, and improve performance over first generation CO_2 capture technologies that are currently being tested at small pilot-scale.

By 2020, complete large pilot-scale field testing of advanced post- and pre-combustion CO_2 capture technologies.

Beyond 2020, starting demonstrating large-scale testing facility

IV. CO_2 TRANSPORTATION

CO_2 transportation is an important element in the CCM chain. After being captured and compressed, CO_2 needs to be transported to a suitable geological site for storage via pipeline. GPC has to put efforts on investigating the possibilities of building a national and regional CO_2 pipeline network and identifying the challenges and benefits associated with it, the research efforts will be based on developing models to map pipeline scenarios to identify cost estimates and the environmental impact associated to present an illustrative blueprint to stakeholders for future decades. GPC will engage in conducting regional case studies to determine theoretical pipeline routes that could develop to efficiently transport CO_2 from stationary sources to the nearby viable geologic storage sites. The implications of economics, resources, environmental impact and timing of pipeline development will be evaluated to determine overall pipeline costs. These studies will provide insight into possible future pipeline development scenarios based on current economic and policy trends. They will provide groundwork for better estimates of the impacts and costs associated with a nation-regional-wide pipeline network that can be utilized by interested parties.

V.CO_2 STORAGE

Once captured, compressed, and transported to a suitable site, CO_2 is stored in a suitable geologic storage site previously identified. Safe, underground geologic storage of CO_2 must be conducted through planning, analysis, sound operating practices, and careful monitoring of the CO_2, both during and after the period when CO_2 is injected. Ensuring that CO_2 storage is safe and effective will require site-specific quantitative risk assessment, which combines performance assessment of a storage site, coupled with an assessment of potential environmental, health, or economic consequences. Critical challenges associated with CO2 storage and the research and technology implementation pathways addressing those challenges are summarized in Figure 5.

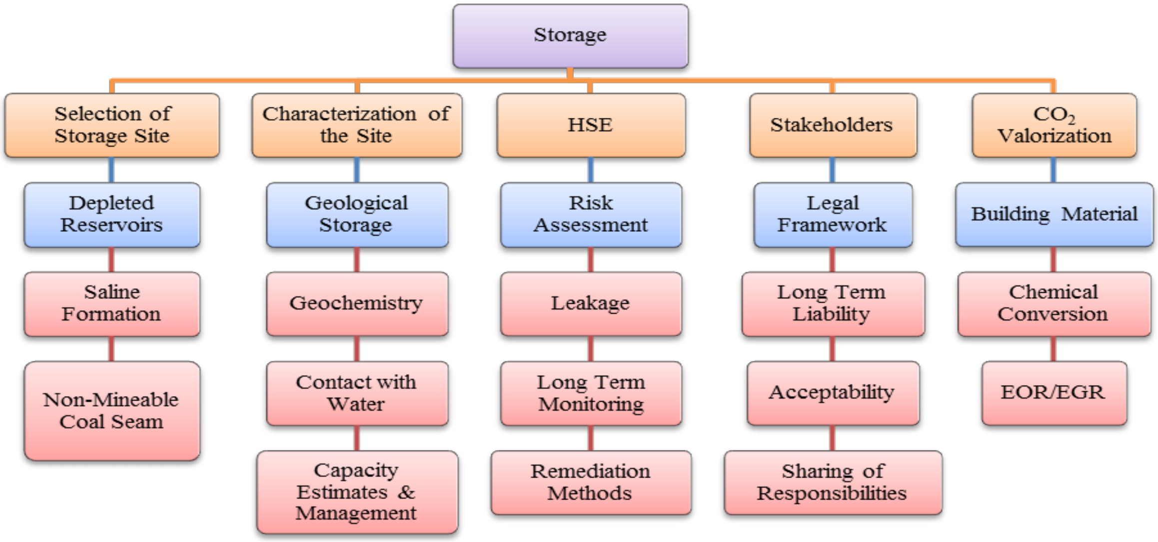

Fig.5 CO_2 Storage Research and Technology Pathways and Critical Challenges

The goal of GPC research in this area is to develop technologies to safely, permanently, and cost-effectively store CO_2 in geologic formations and monitor its movement and behavior. This involves developing an improved understanding of CO_2 flow and trapping mechanisms within the geologic formations that can support the development of improved and novel technologies for site construction, reservoir engineering, and well construction. Experience gained from field tests will facilitate the development of CCM best practices for site development, operations, and closure to ensure that CO_2 storage is secure and environmentally acceptable and does not impair the geologic integrity of underground formations.

VI. EDUCATION AND OUTREACH

Developing public support for CCM is an essential component in the GPC-CO_2 roadmap. In order to improve acceptance of CCM, increased education and awareness are needed by the general public, regulatory agencies, policymakers, and industry officials to foster the future commercial deployment of advanced CCM technology. The GPC utilizes innovative outreach approaches to communicate to a wide range of audiences. Particular importance is focused on increasing the public's awareness and addressing quickly and accurately concerns raised by the public, leading to the successful implementation of CCM projects in the regions. These outreach approaches include, but are not limited to public meetings; websites; fact sheets; video; education programs available at local libraries and schools where a yearly competition called Gasna on the gas industry in Qatar and its environmental impact is organized for schools ranging from grade one to grade twelve.

VII. TECHNOLOGY ROADMAP

The GPC, consistent with its vision, has catalyzed the adoption and deployment of CCM technologies among its consortium members. Since its establishment in 2007, the GPC is setting an ambitious research program to promote the development of improved cost-effective technologies through knowledge creation, information exchange, collaboration and partnership. The GPC intends to enhance its on-going and future activities to close the key CCM technology gaps highlighted in this Roadmap through close collaboration with governmental agencies, consortium members, industrial partners, key funding bodies, and support from strategic partners such as the International Test Center (ITC) for carbon capture and storage and all sectors of the international research community.

VIII. SUMMARY

This Roadmap is an attempt to identify the current status of CCM technologies around the world in general and in Qatar in particular, the increasing activity in research and development, the major technology needs and gaps, and the key milestones for a wide development of improved cost-effective technologies for CO_2 capture, transport, and long-term storage. Implementation of national demonstration projects is seen as an ultimate goal. Critical component in projects have to be built with R&D effort in order to close the technological gaps in a cost effective way. CCM is believed to play a critical role in tackling greenhouse effect and global climate change. It is believed that CCM must be demonstrated as soon as possible with wide deployment projects before the target date of CCM commercialization by 2020. To achieve this, the establishment of the technical foundations for affordable capture, transport, and safe long-term geologic storage of CO_2 is compulsory. The GPC will continue to engage deeply in the deployment of CCM technologies by actively working with strategic partners, governments, industry, and all sectors of the international research community on the strategic priorities outlined in this Roadmap in order to efficiently utilize scarce world resources and effort and to ensure that key technology gaps are addressed and closed.

TABLE II
CCM KEY MILESTONES AND TECHNOLOGY ROADMAP FOR GPC

Element	**Need**	**20013-2016**	**2016-2020**	**2020- 2030**
Capture	Reduce CO_2 capture cost and efficiency penalties	• Scale-up of selected existing technologies • Tailor guidelines and best practices to Qatar needs • Research and develop low-energy liquid solvents, adsorbents and membranes for mainly the two categories of capture technology • Achieve good understanding of environmental impacts of capture technologies, in particular amines • Perform system studies of alternative solutions • Harmonize cost estimation methods	• Demonstrate at pilot-scale existing capture systems • Continue R&D on, and partly validation of, concepts, including: • Solvents, adsorbents , membranes in post- and pre-combustion • Chemical looping, reforming, shift catalysts • R&D and validation of new and emerging technologies	• R&D and validation of new and emerging technologies • Scale-up and integration of technologies validated to commercial scale
Transport	• Create the ability to optimize transport infrastructure to accept CO_2 from different sources • Reduce the risks and costs	• Establish models to optimize transport networks of CO_2 between sources and potential sinks • Build pipeline models linking single CO_2 sources with single storage locations.	• Contribute in the establishment of technical standards for trans-boundary CO_2 transport • Establish regional networks models as examples of multiple source CO_2 transportation	• Establish large infrastructure for CO_2 transport that link multiple CO_2 sources with multiple storage locations
Storage	• Demonstrate sufficiency of CO_2 storage capacity • Validate monitoring for safety and long-term security • Improve understanding of and verify environmental impact	• Develop national and regional atlases of CO_2 storage site and capacity • Determine most suitable / applicable technologies for estimating infectivity, containment and storage capacity for Qatar • Establish methodologies and models for predicting the fate and effects of injected CO_2 and for risk, including well-bore integrity assessment • Establish industry best practices guidelines for reservoir selection, CO_2 injection, storage and monitoring	• Refine the national and regional atlas of CO_2 storage capacity • Improve best practices for updating industry standards suitable for Qatar • Validate remediation measures	• Successfully complete field tests for validation of injection and MMV

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