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CARBON CAPTURE TECHNOLOGIES OVERVIEW, ASSESSMENT AND POTENTIAL DEVELOPMENT AND DEPLOYMENT IN THE ESCWA REGION

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General Introduction

Climate change, manifested in increasing global temperatures, melting of ice and rising sea levels, is mainly attributed to upsurge in atmospheric CO_2 and other greenhouse gases (GHGs) concentration [1], 67% of which is ascribed to anthropogenic activities. During the last 800,000 years, atmospheric CO_2 concentration fluctuated between about 180 ppm during the ice ages and 280 ppm during the interglacial warm periods. Today's rate of increase is more than 100 times faster than the increase that occurred when the last ice age ended [2]. Intergovernmental Panel on Climate Changes (IPCC) concluded that the reasons behind the increased concentration of CO_2 in the atmosphere are the human activities [3].

Options to reduce CO_2 emissions from the power generation sector

A deep reduction in CO_2emissions is required to stabilize the CO_2concentrationin the atmosphere and thus to mitigate climate change. IPCC concluded that there is a need to combine several options and technologies to reduce the CO_2 emissions to achieve the global emission stabilization and their projected relative contributions is given in Figure 1[1, 3, and 7]. Some of the proposed technologies are (1) Conservation and Energy Efficiency (2) Renewable Energy (3) Nuclear Energy (4) Coal to Gas Substitution (5) Carbon Capture, Transport, Utilization and Storage (CCUS). It is clear that all these technology options are needed to reduce theCO_2 emissions. However, the focus of this work is on the CCUS, which is expected to contribute up to 22% of the total projected reduction of atmospheric CO_2 emissions ($GtCO_2$/yr.)[7].CCUS atmosphericCO_2 emission reduction targets mainly emissions from the consumption of fossil fuels which contributes around 57% of the total GHGs emissions. In addition, 80% of the world's total energy demand is provided by fossil fuels and 38% of the total electricity generation is supplied by coal fired power plants [6]. World demand for coal advances by 2% a year on average, its share in global energy demand climbing from 26% in 2004 to 29% in 2030. Most of the increase in demand comes from the power-generation sector [4]. Oil demand grows far more slowly than demand for other fossil fuels, because of high final prices. Gas demand increases at the rate of 1.8% per annum and reaches 22% of world primary energy in 2030. All the analysis of the global primary energy demand between now and 2030 show that fossil fuel will be the main source of energy. This supports the need for the CCUS as a main option to reduce the CO_2 emissions, which could be applied to the fossil fuel power generation sector directly.

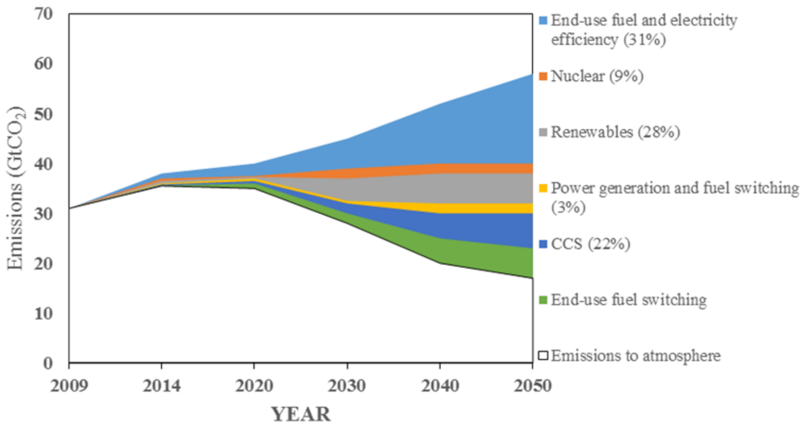

Figure 1: Options to reduce CO_2 emissions

Carbon Dioxide capture, transport, utilization and storage (CCUS)

Overview

CCUS is a promising method to reduce atmospheric CO_2 emissions considering the increasing worldwide energy demand, the continuous dependency on fossil fuel due to the lack of credible alternative and the possibility of retrofitting existing plants with capture, transport and storage of CO_2. The captured CO_2 can be used for enhanced oil recovery, in the chemical and food industries or can be stored underground instead of being emitted to the atmosphere. Due to the limitation in the scope of this work; the focus will be on the CO_2 capture technology overview and evaluation excluding CO_2 transportation, utilization and storage.

CO_2 capture

There are four basic systems for capturing CO_2 from both the power generation and industrial sectors, as shown in Figure 2, which are: capture from industrial process streams; post-combustion capture; oxy-fuel combustion capture; and pre-combustion capture. The comparison of the different technological routes (post,

pre and oxy-fuel combustion) for the CO_2 capture from fossil fuel power plants concluded that the net efficiency of the power plant, the overall cost of electricity and cost of CO_2 avoided for the different technologies are comparable [[9]-[12]]. However, the advantage of one technology route over the others could be related to the technology availability, the level of maturity of the technology, the possibility of capture process retrofitting to the existing power plants, the experience and repetition in commercial and large scale applications and the most important factor is the period needed for the technology implementation [5].In post-combustion process, CO_2 is captured from flue gases that contain 4 to 8 vol% CO_2 for natural gas-fired power plants and 12 to 15 vol% for coal-fired power plants. The CO_2 is captured using solvents in a cycle of absorption-desorption process, sometimes in combination with membrane separation. The basic amine-based solvents technology has been used on an industrial scale for many decades, but still recovery of CO_2 with a minimum energy penalty and at an acceptable cost remains to be a challenge [13].In Pre-combustion capture; the CO_2 is captured from a high-pressure gas mixture (up to 70 bars) that contains 15 to 40% CO_2, which makes physical separation technologies viable options for the CO_2 removal. The oxy-combustion process involves the combustion of the fossil fuel with pure oxygen using recycled flue gas to control the combustion temperature. This results in nearly pure CO_2 stream, which requires minimum dehydration and purification.

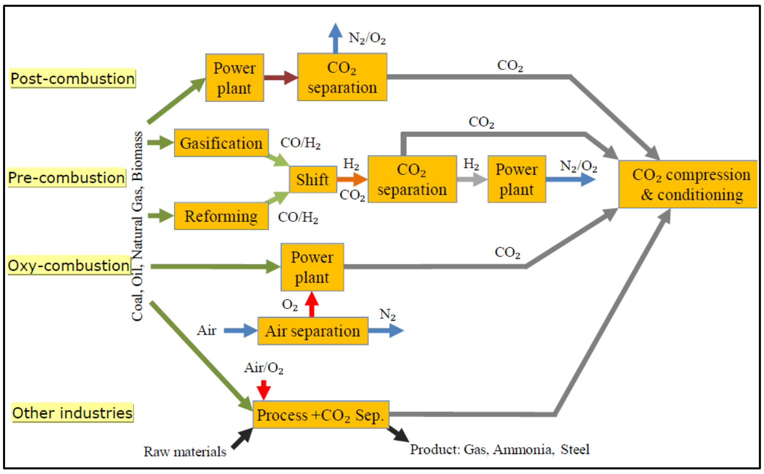

Figure 2: Pathways to CO_2 capture [8]

Table 1: CO_2 capture current and future technologies [3]

Capture method	Post-combustion decarbonisation (CO_2/N_2)		Pre-combustion decarbonisation (CO_2/H_2)		Oxyfuel conversion (O_2/N_2)	
Principles of Separation	Current	Future	Current	Future	Current	Future
Solvents/Absorption	Chemical solvents	Improved Porcess Design Improved Solvents Novel contacting equipment	Chemical solvents Physical solvents	Improved Process deisgn Improved solvents Novel contacting Equipment	NA	Bio-mimetic solvents
Membranes	Polymeric	Ceramic faciliated transport Carbon molecular sieve	Polymeric	Ceramic Palladium Reactors Contactors	Polymeric	Ion-transport facilitated transport
Solid Sorbents	Zeolites Activated Carbon	Carbonates Carbon based solvents	Zeolites Activated carbon Alumina	Dolomites Hydrotalcites Zirconates	Zeolites Activated carbon	Caronates Hydrotalcites Silicates
Cryogenic	Liquefaction	Hybrid Process Anti-sublimation	Liquefaction	Hybrid process	Distillation	Improved distillation
Biotechnology		Algae production		High pressure		Bio-mimetic

Currently, a wide range of technologies for separation and capture CO_2 from gas streams exist. They are based on different physical and chemical processes including absorption, adsorption, membranes and cryogenics. An overview of current CO_2 separation options and potential for each CO_2 capture route are given in Table 1.

Industrial process streams

Industrial CO_2 emissions are expected to increase by 134% between 2005 and 2050 reaching 23.2 Gt CO_2 in 2050[13], which are divided between the direct industrial emissions and indirect emissions in power generation. 72% of direct industrial CO_2 emissions corresponds to Iron and steel, non-metallic minerals and chemicals and petrochemical industries [13]. CCUS can play a pivotal role by reducing around 37% of the total industrial emissions. There are important opportunities for reducing CO_2 emissions through the use of CCUS in iron and cement manufacturing, ammonia production, and large CHP (combined heat and power) units and black liquor gasifiers in pulp production. The major potential for CCUS is in the Iron and steel and cement sectors; CO_2 is captured from blast furnaces, smelt reduction and direct reduced iron (DRI) production plants, in addition to the cement industry from the rotary kilns for clinker production. However, the CO_2 capture from cement kilns and blast furnaces is a relatively new technology that will require major

process adjustments. CCUS is the one of few options available substantially to reduce CO_2 emissions from steel and cement making.

Post-combustion capture

Post-combustion capture is a downstream process that is analogous to flue gas desulfurization. It involves the removal of CO_2 from flue gas produced after the combustion of the fuel. Post-combustion schematic with respect to power plant is given in Figure 3. The oxidant used for the conventional combustion is air and therefore the resulted flue gas has diluted concentration of CO_2. Therefore, large volume of the flue gases has to be treated with low CO_2 partial pressure. In principle, post combustion capture systems can be applied to flue gases produced from the combustion of any type of fuel. The impurities in the fuel are important for the design and costing of the complete plant[14].Flue gases coming from coal combustion will contain SO_x, NO_x, particulates, HCl, HF, mercury, other metals and organic and inorganic contaminants along with CO_2, N_2, O_2 and H_2O. These impurities have to be removed with existing technologies like Selective Catalytic Reactor, Electrostatic Precipitator and Flue Gas Desulphurization. Commercial experience is available at a sufficiently large scale for post-combustion processes, such as in the natural gas processing and ammonia industry. There are a number of existing separation technologies that could be used in post-combustion capture including: (i) Chemical absorption (ii) Physical absorption (iii) Membrane separation (iv) Adsorption (v) Cryogenic separation.

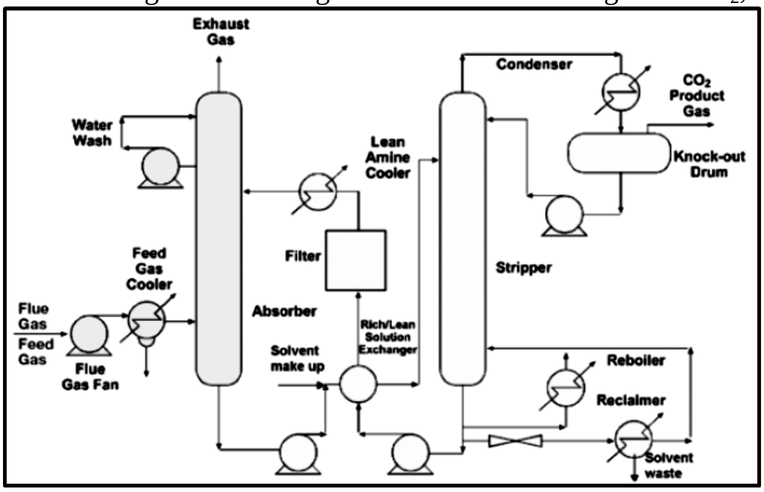

Figure 3: Process flow diagram for chemical absorption [3]

At present, the preferred and most mature option for post-combustion capture of CO_2 is chemical absorption system and post-combustion capture is considered the most suitable route for CO_2 capture from the power plants because of [5]: the possibility of add-on to existing power plants; capture technologies are considered available; and the solvent technologies are proven on a smaller scale; capture readiness makes the post-combustion capture relatively easy to incorporate into power plants; It has more operational flexibility in switching between capture-no capture operation mode; and learning by doing will lead to cost reductions similar to experience with SO_2 capture process development. The other technological options for post-combustion capture include adsorption using solid-based sorbent (chemical, physical), membrane technologies (gas selective, membrane gas absorption), and cryogenic distillation which are still underdevelopment and are not considered as mature and ready technology as the solvent-based absorption technology.

Oxy-fuel combustion capture

Replacing air with oxygen for combustion in the furnace is the basic concept of the oxy-fuel combustion technology. Combustion air is replaced with a mixture of near pure oxygen and the recycled CO_2 rich flue gas for combustion [16].Recirculation of flue gas is needed to control the combustion temperature and to maintain thermal balance in the existing boiler between the lower furnace region where evaporation takes place and the convective heat transfer surfaces where steam is superheated and reheated to the required combustion temperature level [15]. A schematic diagram of oxy-combustion capture process is given in Figure 4.

An Air Separation Unit (ASU) is necessary to supply a combustion gases with near pure oxygen. The boiler heat transfer surfaces and the burners have to be modified to compensate the change in the composition and the flow through the boiler. Air leakage into the boiler can increase the formation of NO_x, which may be as high as 8-16% in the case of retrofitting the technologies to the power plants; new boilers are needed to prevent this air leakage [17]. It is estimated that the air separation unit and the CO_2 compression and treatment plant would be responsible for the majority of the capital cost of the conversion, excluding installation and start-up costs for this system [18]. To improve the technology of oxy-fuel combustion as well as its application, the focus of various research activities directed towards combustion characterization, process and system analysis and economic analysis particularly the understanding of the differences between oxy-fuel combustion and air-fuel combustion arising from the change of combusting environment [19].The O_2 for oxy-fuel combustion is typically produced by a conventional cryogenic air separation unit. Cryogenic separation is expensive and energy intensive. In cryogenic air separation plant, air is compressed to high pressure (0.5 to 0.6 MPa) and purified to remove water, CO_2, N_2O and trace hydrocarbons. 3500 tO_2/day is the current available plant size and the power consumption for 95% O_2 delivery at low pressure is 200-240 kWh/tO_2. To reduce power and capital cost, several developments are being made in this technology [3]. An alternative method of separation is membrane technology at ambient or high temperature to separate O_2 from air [20].

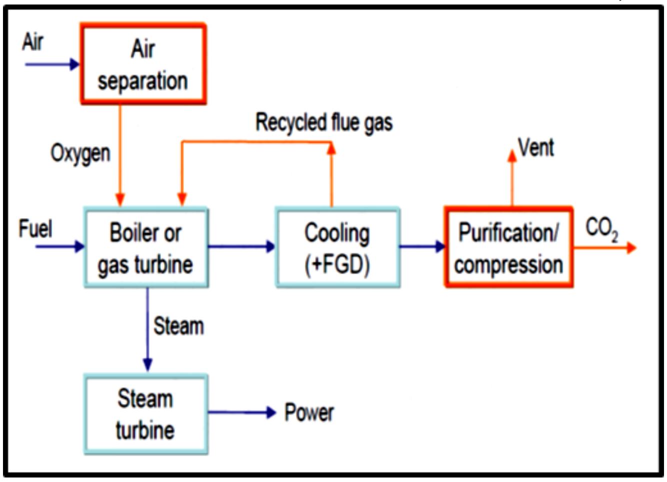

Figure 4: Schematic diagram of Oxy-combustion capture process [[3], [15]]

The power required to generate O_2 through cryogenic air separation prior to combustion and the power required to compress the captures CO_2 to pipeline pressures are the significant power consumption to impact the overall plant efficiency in the oxy-fuel combustion not like post-combustion capture where solvent regeneration is the most energy intensive part of the process.

Pre-combustion capture

A schematic diagram of pre-combustion capture principle applied to both natural gas and coal power plants is given in Figure 5. In this process a fuel is reacted (the gasification step) with air or oxygen to produce a fuel gas (syngas) containing CO and H_2, which is then reacted with steam in a catalytic reactor known as shift reactor to produce a mixture of CO_2 and H_2. The major process for gaseous and liquid fuels is called partial oxidation (addition of oxygen) and for solid fuel is called gasification. The CO_2 is then separated and H_2 is used as the fuel in a gas turbine combined cycle. Possibility of co-production of H_2, proven CO_2 separation and high CO_2 concentration with high overall pressure are the advantages of pre-combustion capture technologies. Low availability of coal-fired Integrated Gasification Combined Cycle (IGCC) plants, unfamiliar technology for power generators and the higher cost than pulverized coal combustion are the main disadvantages of pre-combustion capture technology [21].

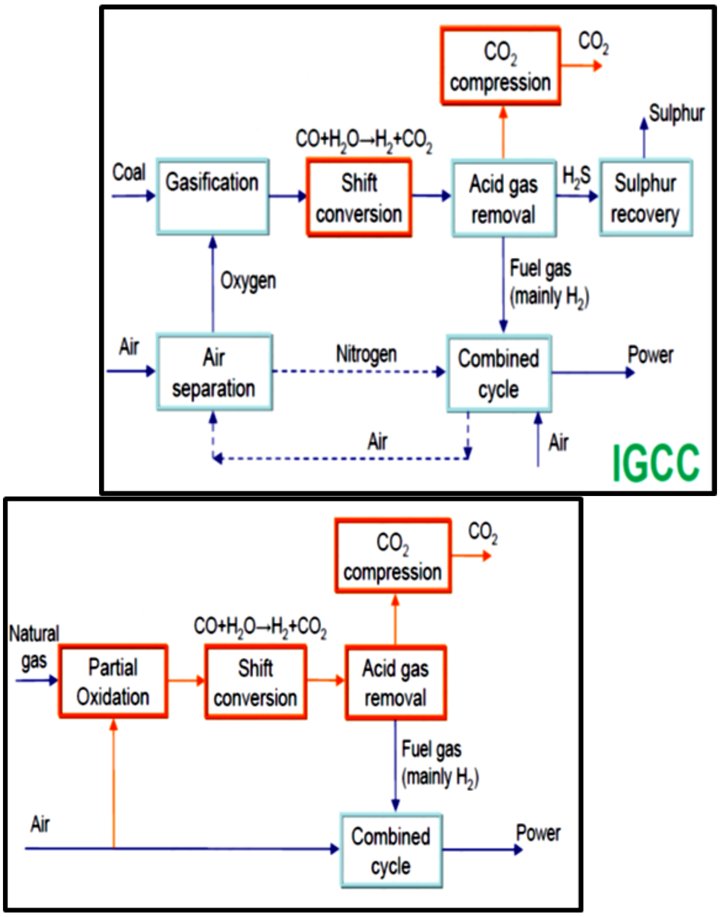

Figure 5: Principle of Pre-combustion technology and their application to natural gas and coal power plants [[8], [21], [22]]

The availability of the CO_2/H_2 stream at high pressure makes chemical solvents such as Monodiethanolamine (MDEA), physical solvent like selexol the best choices for the CO_2 removal [23]. In addition, other less mature separation technologies such as solid adsorbents and membrane technologies could be used, benefiting from the high CO_2 partial pressure. The relatively easy CO_2 separation technology in the pre-combustion capture does not require high energy demand. However, the high energy demand in the IGCC process is directed to the water gas shift reactor units for the supply of steam.

CO_2 capture technologies, status and outlook

The three CO_2 capture routes have different status and levels of demonstration. The oxy-fuel combustion technology is in the demonstration phase, means that the technology has been built and operated at the scale of a pilot plant, but further development is required before the technology is ready for the design and construction of a full-scale system. Post-combustion and Pre-combustion capture technologies are economically feasible under specific conditions phase, means that the technology is well understood and used in selected commercial applications, such as the natural gas processing. Other novel/newly developed capture technologies such as chemical looping, solid-based sorbents and biological-based capture technologies are immature and require further development before being commercialized (see Figure 6) [25]. Maturity of CCUS in natural gas or chemical processing is evaluated by the number of active industrial projects at the execution and operational stage. Less mature status of CCUS is observed when applied to the power sector, with most projects in the planning stage [24]. Main focus of development for CCUS technologies is to reduce the energy losses. U.S. Department of Energy (DOE)/ National Energy Technology Laboratory (NETL) is developing CCUS technologies that are more energy efficient to demonstrate that cost reduction could be achieved through energy savings; innovative development are taken for all technologies[26]. It is estimated that by 2025-2030, the CCUS innovative technologies under development today will be applied at large-scale. It is noted that both advanced fossil fuel conversion technologies and novel CO_2 capture technologies are required. This includes the innovations developed to reduce the cost and

energy losses in the power and industrial sections and their commercialization after the deployment of the CCUS technologies [[25], [27]].

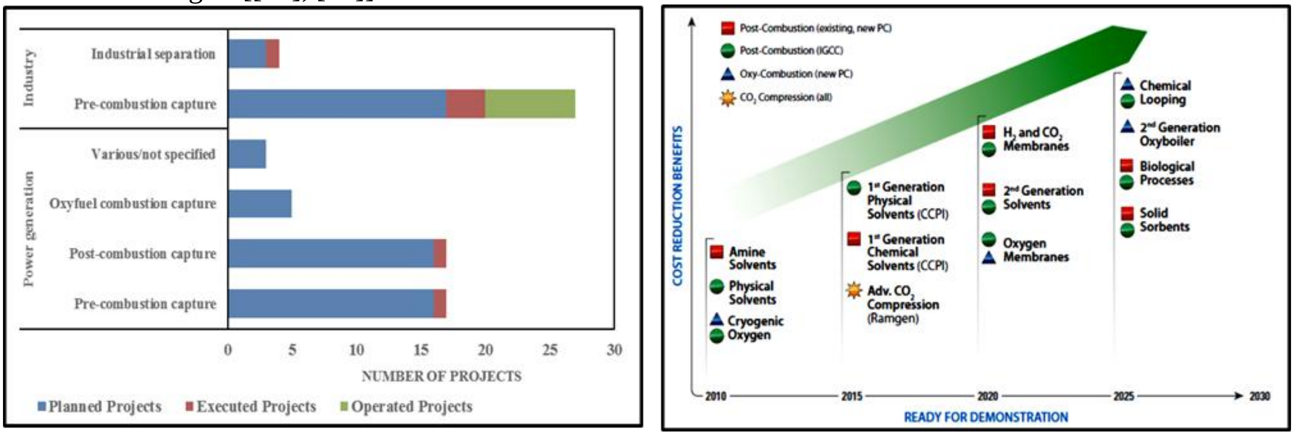

Figure 6: Status, Readiness and Maturity of CCUS technologies [[3], [25]]

Cost of CO_2 capture

CO_2 capture is considered the main contributor to the cost of the complete CCUS chain. Therefore, opportunities for cost reduction and improvements in performance are most sought in this area [29]. Technical factors related to plant design and operation (plant size, net efficiency, fuel properties and loading factor), economic and financial factors such as fuel cost, interest rates and plant life are the different assumptions for the estimation of CO_2 capture cost. It varies widely depending on the plant location, timeframe and finance [3].

With current CCUS technology, CCUS will increase the leveled cost of electricity for each fossil fuel power plant to which it is applied. 40-95% increase in the leveled cost of electricity (LCOE) will result when CCUS is applied to coal or gas power plants. The cost increase is lower for natural gas processing due to inherent CO_2 separation. Pre-combustion capture applied industrial hydrogen plants (ammonia, synfuels and steam methane reforming) have low additional cost for CCUS. The increase in cost for industrial applications is estimated to be 50% in the cement industries and 12% for steel [28].

The cost of capture depends on the emitting plant and the technology used. In addition, CO_2 capture involving separation, purifying and compression is an energy-intensive process. Low CO_2 concentration tends to make separation harder and increases the cost of separation and compression. Therefore, power plant, cement and process gas urea industries having lower concentration and lower pressure of CO_2 will have the higher CO_2 capture cost and natural gas processing having high pressure and high concentration of CO_2 will have lower cost for CO_2 capture [28]. In addition, continuous improvements in procurement and process engineering and reduced capital cost resulted from the second-generation capture technologies could decrease the leveled cost of CCUS plant. Learning curves of technologies show the potential for decreasing cost of CCUS [28].Moreover, there are many examples of technologies with potential to reduce the capture cost for specific applications; such as absorption technology which reduces capture cost considerably in IGCC and Refinery. High pressure membrane reduced capture cost in pulverized coal combustion process. Low pressure membrane did a good job for steel plants by reducing the capture cost. Natural gas and IGCC plant capture costs are reduced effectively by pressure swing adsorption process [30].

Environmental risk and aspects of capture systems

Stream of concentrated CO_2 for storage, flue gas or vent gas emitted to the atmosphere, liquid waste and solid waste are the product of a plant with CO_2 capture. The types and concentrations of impurities depend on the type of capture process, detailed plant design, waste handling methods and regulations [3]. Gas fired plants with CCUS has highest impurities level due to the emission of CH_4 and products with N_2/O_2 followed by Coal with oxy-fuel CCUS due to O_2 products. Due to the energy intensive nature of Carbon capture process, the power plant efficiency lowers and to compensate this efficiency loss, additional fuel input per unit of electrical power must be used [31]. Thereby, the main obstacle for carbon capture will be the high energy penalty associated with the corresponding emissions of impurities. Although the direct emission of CO_2 can be reduced by CCUS; upstream emissions from fuel and materials supply and downstream

emissions from waste disposal and waste water treatment cannot be avoided. Thus, a life cycle assessment becomes significant for a broad evaluation of environmental effects of CCUS technologies [31]. Global warming potential is higher for Lignite-fired power plant followed by Coal-fired post-combustion power plant, but they are reduced by applying post-combustion CCUS, even more reduced with oxy-fuel combustion CCUS in coal-fired power plants. Oxy-fuel combustion CCUS demands more energy than post-combustion for coal-fired power plants. Photochemical oxidation potential was estimated to be more for CCUS applied coal-fired post combustion power plant than other technologies. Acidification potential is higher for Lignite-fired post-combustion power plant with and without CCUS. Eutrophication potential is very high for Lignite-fired power plant with and without CCUS. Increment in potential environmental impact is lower for natural gas combustion cycle power plants than coal and lignite-fired followed by IGCC power plants [32].

There is a loss of solvents caused by irreversible interactions of flue gas or fuel gas components, oxidation, polymerization and evaporation, which has to be compensated by addition of excess solvents. Contaminated solvents have to be handles as hazardous waste. Up and downstream, processes will demand more material supply, waste management and energy [33]. The CO_2 capture system generates several new waste products such as ammonia gas (generated by degradation of amines) and reclaimer bottoms (a potentially hazardous solid waste generated during the recovery of spent sorbent for the process) [34]. The standard operating procedures and management practices of CCUS have to be followed properly to avoid more environmental impact and proper plant closure after operations will reduce the risk of polluted sites [3]. In addition, new waste handling regulations and technologies need to be deployed to cover these emerging technologies and waste streams.

Applicability of CCUS in ESCWA Regions

Energy, Energy efficiency & Renewable energy in ESCWA Region

56.8% of the world's estimated oil reserves and 19.94% of the world's proven natural gas reserves are in the ESCWA region [35].Figure 7shows that almost 90% of energy is supplied in ESCWA regions by Oil and natural Gas sources, whereas 52.8% energy supplied by oil and natural gas sources in the world in 2011[36]. Energy demand in ESCWA regions are mainly increasing due to the unavailability of water and the need residential/offices cooling. These resulted in an increase in the electricity requirement and production and as a result increase the CO_2 emissions as shown in Table 2 **Error! Reference source not found.**. CO_2 emissions from the ESCWA energy sector reached 1346 million tons in year 2010, which exceed the world average with an average annual growth rate of 5.8%. Renewable energy options such as hydro plants, solar energy, wind energy and biofuel projects are underway in ESCWA regions to meet the energy demand with clean environment **Error! Reference source not found.**. However, these renewable energy options are being slowly developed and are not expected to have a direct reduction in the CO_2 emissions in the short term, which supports the need for CCUS in ESCWA region.

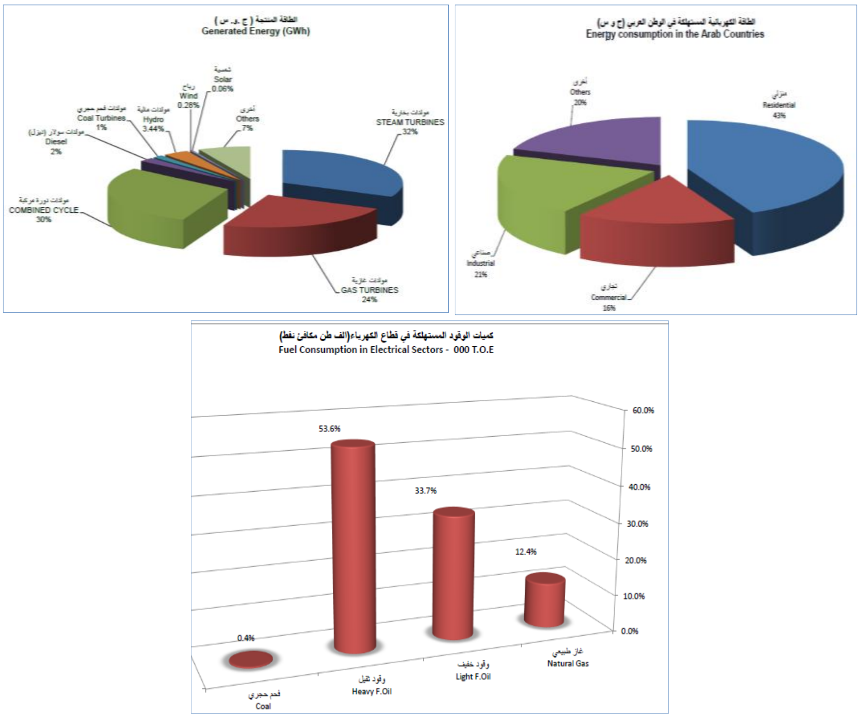

Figure 7: Energy supply by power generation technology, energy consumption by sector and the amount of fuel used for electricity generation in ESCWA region **Error! Reference source not found.**

Table 2: Electricity consumption (TWh) in ESCWA region **Error! Reference source not found.**

Electricity consumption (TWh) in ESCWA Region													
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
World	13514	14133	14272	14772	15329	16019	16716	17387	18194	18569	18462	19762	20407
Algeria	20.0	21.2	22.3	23.3	25.4	26.3	29.5	29.0	30.6	32.9	30.6	36.6	41.2
Bahrain	5.6	5.7	6.2	6.7	7.5	8.1	8.5	9.3	10.8	10.2	10.8	12.4	13.0
Egypt	63.6	67.2	72.2	77.1	83.5	88.3	95.3	102.5	110.8	116.2	123.4	130.4	138.4
Iraq	29.2	29.2	30.0	31.5	26.7	31.6	22.5	27.0	21.8	21.8	32.8	36.8	42.6
Jordan	6.3	6.6	6.9	7.5	7.8	8.7	9.1	10.1	11.2	12.1	12.5	13.4	14.2
Kuwait	28.1	28.8	30.5	32.4	35.4	36.7	38.8	42.2	42.8	45.2	46.6	50.1	50.4
Lebanon	9.6	9.8	10.0	10.7	11.1	11.1	11.3	11.0	11.5	12.2	13.1	15.1	15.3
Libya	11.5	11.9	12.3	15.3	16.6	17.7	19.9	22.3	22.7	26.7	26.9	28.4	24.0
Morocco	12.9	14.1	15.3	15.8	17.3	18.4	19.3	21.2	22.4	23.2	23.9	24.8	26.5
Oman	7.0	7.3	7.9	8.2	8.5	9.4	10.3	11.1	11.8	13.5	15.2	16.5	19.0
Qatar	8.0	8.5	9.3	10.2	11.2	12.3	13.4	15.9	18.1	20.1	22.6	26.4	30.1
Saudi Arabia	113.3	117.1	126.1	131.9	146.0	146.9	157.5	167.6	174.8	186.5	199.1	218.7	226.6
Sudan	2.1	2.2	1.9	2.2	2.4	2.5	3.0	3.5	3.8	4.3	5.1	6.0	6.7
Syria	16.2	17.5	19.2	21.1	22.5	24.9	27.5	29.3	30.6	32.2	32.1	39.0	37.7
Tunisia	9.0	9.5	10.1	10.5	9.9	10.4	11.0	11.3	11.9	12.4	13.4	14.2	13.8
UAE	36.2	38.6	40.1	43.8	46.2	49.0	56.3	61.9	70.5	73.5	77.2	83.2	83.8
Yemen	2.2	2.5	2.6	2.8	3.1	3.4	3.7	4.0	4.5	5.0	5.1	6.0	4.5
ESCWA total	360.7	376.3	400.5	427.8	455.7	479.4	507.3	550.1	580.0	615.2	659.9	721.4	746.5
share of the World	*2.7%*	*2.7%*	*2.8%*	*2.9%*	*3.0%*	*3.0%*	*3.0%*	*3.2%*	*3.2%*	*3.3%*	*3.6%*	*3.7%*	*3.7%*

Table 3: Total primary energy supply and total CO_2 emissions from fuel consumption in the Arab countries (1971-2010) **Error! Reference source not found.**

Region		1971	1980	1985	1990	1995	2000	2005	2008	2009	2010
Algeria	TPES	3.5	11.2	17.7	22.2	24.1	27.0	32.4	37.4	40.7	40.4
	TCO_2*	8.9	28.4	43.2	52.7	56.8	63.5	79.6	89.7	99.1	98.6
Egypt	TPES	7.8	15.2	25.7	32.3	35.3	40.7	62.7	71.9	71.4	73.3
	TCO_2	20.3	41.9	64.8	78.4	83.1	101.3	152.6	175.3	172.7	177.6
Libya	TPES	1.6	6.9	10.0	11.3	15.8	16.6	17.6	19.2	21.9	19.1
	TCO_2	3.7	18.6	22.5	27.4	35.1	39.7	42.5	47.0	49.8	51.6
Morocco	TPES	2.4	4.9	5.6	6.9	8.6	10.2	13.1	15.0	15.1	16.5
	TCO_2	6.8	14.0	16.5	19.6	26.0	29.4	40.1	43.5	42.7	46.0
Sudan	TPES	7.0	8.4	9.5	10.6	12.0	13.3	15.1	15.1	15.9	16.2
	TCO_2	3.3	3.7	4.2	5.5	4.6	5.5	9.2	12.4	13.5	13.7
Tunisia	TPES	1.7	3.3	4.2	4.9	5.8	7.3	8.3	9.4	9.0	9.6
	TCO_2	3.7	7.8	9.6	12.1	14.2	18.0	20.2	21.5	21.3	21.9
Bahrain	TPES	1.4	2.8	4.2	4.4	4.9	5.9	7.5	9.2	9.5	9.8
	TCO_2	3.0	7.4	10.4	11.7	11.6	14.1	18.1	22.3	22.8	23.6
Iraq	TPES	4.1	9.6	13.8	19.7	34.5	25.9	26.9	28.5	32.5	37.8
	TCO_2	10.4	27.0	36.8	53.4	97.5	70.3	74.9	73.4	91.9	104.5
Jordan	TPES	0.5	1.5	2.6	3.3	4.3	4.9	6.7	7.1	7.5	7.2
	TCO_2	1.3	4.3	7.4	9.2	12.2	14.4	18.0	18.5	19.3	18.6
Kuwait	TPES	6.1	10.5	14.0	9.1	14.9	18.8	26.4	27.9	30.2	33.4
	TCO_2	14.0	26.6	37.1	28.7	36.1	49.1	70.1	73.9	80.7	87.4
Lebanon	TPES	1.8	2.5	2.3	2.0	4.4	4.9	5.0	5.4	6.6	6.5
	TCO_2	4.5	6.6	6.5	5.5	12.8	14.1	14.5	15.8	19.1	18.6
Oman	TPES	0.2	1.1	2.1	4.2	6.1	8.1	10.8	15.9	14.9	20.0
	TCO_2	0.3	2.2	5.7	10.2	14.7	20.2	28.2	36.5	40.0	40.3
Qatar	TPES	0.9	3.3	5.4	6.2	7.9	10.4	16.9	21.5	23.5	30.2
	TCO_2	2.2	7.7	12.1	14.1	18.7	23.7	37.6	49.8	56.4	66.1
KSA	TPES	7.4	31.1	46.0	59.8	87.5	101.3	145.5	154.1	157.9	169.3
	TCO_2	12.7	99.1	122.6	159.1	207.8	252.8	333.8	387.1	411.4	446.0
Syria	TPES	2.4	4.5	7.8	10.5	12.1	15.8	20.8	23.1	21.2	21.7
	TCO_2	6.0	13.1	21.1	28.2	32.8	39.8	54.9	62.7	57.2	57.8
UAE	TPES	1.0	7.2	13.7	20.4	27.7	33.9	43.2	58.3	60.4	62.1
	TCO_2	2.4	19.1	35.6	51.9	69.6	85.6	108.4	145.6	149.4	154.0
Yemen	TPES	0.7	1.3	1.7	2.5	3.4	4.7	6.6	7.1	7.4	7.2
	TCO_2	1.2	3.4	4.8	6.4	9.3	13.2	18.8	21.1	21.6	21.7

* Total CO2 emissions from fuel combustion in the Arab countries, sectoral approach.
Source: IEA: CO2 Emissions from Fuel Combustion – Highlights, 2012.

How Regional Cooperation Helps to Enhance Energy Security in ESCWA Region

All ESCWA member countries pay great attention to setting up energy strategies which depend on the diversification of fuel sources, the application of energy efficiency improvement measures, and expand the use of renewable energy resources,. The main constraint for the deployment of Electrical and Renewable energy in ESCWA region is the subsidized electricity tariffs and oil-gas prices. Therefore, Regional Cooperation promotes awareness raising, capacity building, and Institutional framework, investment for electricity sector/gas and oil sectors, Technology transfer and promoting private and public partnership. Dolpin project (Qatar, UAE, Oman) and Arab Gas Pipeline (Egypt, Jordan, Syria and Lebanon) are examples of projects those help to distribute and enhance the energy security in the region [38].The expected increase in energy demands and future development scenarios clearly declare the need for CCUS in these regions to save the energy and CO_2 emissions to prevent global warming and climate changes. In addition, the collaboration models for energy supplies could be duplicated for the knowledge transfer, sharing and the establishment of CCUS joint projects in the ESCWA region.

Energy requirement for the ESCWA-Investment, Opportunities and Risks

The total primary energy that is produced in ESCWA region is 1596MTOE (of which 98.9% of O&G production including 1206 Mtoe of oil and 373 Mtoe of natural gas) which constitute 12% of the world production. The total consumption of primary energy in the ESCWA region is 781 MTOE, which is 48.9% of the total production for the countries in this region. The average consumption rate is increasing and it reached 78% in the period 1999-2011 with yearly average of 4.9% [41]. If this increasing demand continues without making any steps to increase energy efficiency, these regions will be forced to stop exporting oil and causing mainstay for their economy [39]. For this reason all the countries in this region should invest a great portion of their oil export revenues to build advanced systems of renewable energy plants, increasing the energy usage efficiency and CCUS technologies to prevent climate change and global warming potentials. The power generation efficiency varies from 25 to 41% depending on the technology used in each ESCWA country. Improving the efficiency to 40%, there is a possibility of saving 40 MTOE/yr and this will result in major reduction in CO_2 emissions [39].

Existing plants and their impact and CCUS applicability

Energy intensity and the carbon intensity indicators for the ESCWA countries are shown in Figure 8by considering GHG-emitting extractive industries, harsh climates and availability of large domestic energy sources. Total primary energy supply (TPES) and carbon emissions per capita are related to the level of per capita GDP (Gross Domestic product) as the use of energy increases with the improvement of economic conditions of the population. These figures show the intensities are well above the world average. Nonetheless, climate change is a variable which has to be seriously taken into consideration in the ESCWA region [40].

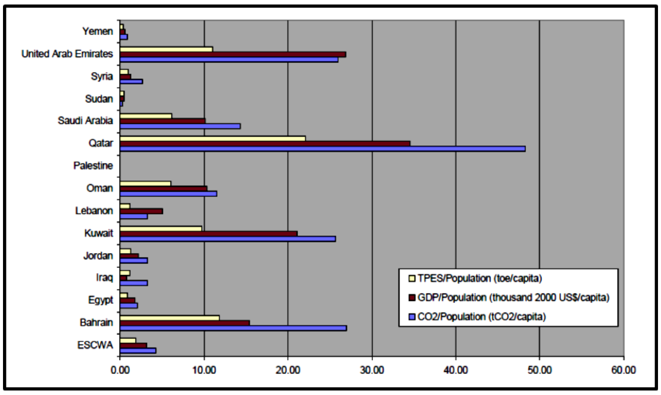

Figure 8: CO_2 emission intensity corresponding to the energy consumption [40]

Looking into the energy demands, sources, consumptions and CO_2 emissions per capita in the ESCWA region show the clear need for CCUS deployment in large scale. This deployment will be directed to the power generation sector from both natural gas and oil fired plant in addition to smaller industrial locations. However, there are many questions need to be answered; what technologies to deploy, what sector to start with and do we have a low hanging fruits, how to build the knowledge and human capacity to deploy this technology, how to establish cross-boarders projects to fulfill all the region needs, how to interact with the international communities to benefit from their knowledge, what is the rule of both the governments and the private sectors to support the starting phase of CCUS deployment in the region?

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