1st WPC Spanish Youth Petroleum Award

Papeles de Cuadernos de Energía

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Entrega de premios del
1st WPC Spanish Youth Petroleum Award

1ST WPC SPANISH YOUTH PETROLEUM AWARD

Presentación Presidente del Comité Español del WPC

Como Presidente del Comité Español del *World Petroleum Council* (WPC), es un placer presentarles esta Separata de Cuadernos de Energía que incluye los papers finalistas del ***1st WPC Spanish Youth Petroleum Award***, así como los abstracts de todos los trabajos presentados al certamen.

Las actividades del Comité Español del WPC, integrado en Enerclub, se estructuran en torno a tres líneas de acción. En primer lugar, el aumento de la visibilidad de la industria española del petróleo y el gas, promoviendo su participación en las actividades del WPC. Como segunda línea, la promoción de importantes eventos energéticos en nuestro país, contando con ponentes de relevancia en el sector.

La tercera y última línea de acción del Comité español del WPC está centrada en impulsar su Comité de Jóvenes. Las cualidades que la gente joven ofrece, como pensamiento creativo, sensibilidad a nuevos asuntos y potencial innovador, son vitales para el futuro. El talento joven es probablemente el activo más grande que tiene cualquier industria. Es crucial atraerlo y retenerlo para garantizar un sector de petróleo y gas competitivo hoy y para las generaciones futuras.

Este Comité constituye un punto de encuentro para los jóvenes líderes del petróleo y el gas en España, además de promover el diálogo intergeneracional entre juniors y seniors de la industria, desarrollar un programa atractivo de actividades de interés y dar acceso a una red internacional de jóvenes.

Muchas han sido las actividades desarrolladas por y para el Comité Español de Jóvenes desde su constitución en febrero de 2015, en las que sus más de 300 miembros han tenido la oportunidad de participar. Entre todas ellas, el principal hito planteado para este ciclo ha sido la creación del *1st WPC Spanish Youth Petroleum Award.*

Esta iniciativa del Comité Español que presido está orientada a identificar y mostrar el talento de los jóvenes del sector energético español, dotándoles de una mayor exposición tanto a nivel nacional como internacional.

Para ello, se realizó una convocatoria invitando a los jóvenes a desarrollar trabajos relacionados con las temáticas del próximo 22º Congreso Mundial del Petróleo, que tendrá lugar en Estambul en julio de 2017.

Como reconocimiento a los mejores trabajos, desde el Comité Español otorgaríamos a los tres finalistas la oportunidad de participar en un programa de *mentoring* para mejorar sus trabajos de cara a su posible participación en el *Call for Papers* del citado Congreso Mundial del Petróleo. Además, el autor del paper ganador del 1st YPA podría asistir en otoño de 2016 al Foro de Jóvenes en Río de Janeiro (Brasil), gracias al patrocinio de CORES.

Para la evaluación de los papeles se constituyó un jurado compuesto por Antonio Gomis, Juan Pons, Milton Costa y María Teresa Costa como presidenta, todos ellos reconocidos expertos del sector Oil & Gas. El jurado evaluó individualmente cada paper, distribuido sin nombre de autor, en base a su carácter innovador, contribución a la industria, solidez científico–técnica e interés internacional del tema. Los ganadores se dieron a conocer el pasado 8 de junio en un acto celebrado en el auditorio de Cepsa.

Tras la entrega de los premios, desde el Comité Español del WPC y el Club Español de la Energía consideramos que sería interesante para la industria conocer el contenido de los 12 papers que se presentaron, publicándose todos ellos en las páginas web de ambas organizaciones.

Pero, además, quisimos ir más allá y darles aún una mayor difusión, incluyendo los trabajos en la Separata de Cuadernos de Energía que el lector tiene ahora en sus manos. En concreto, esta Separata recoge los papers completos de los tres finalistas, así como los abstracts del resto de trabajos presentados que, estamos seguros, serán todos ellos de gran interés para el sector.

El 1st WPC Spanish Youth Petroleum Award se ha presentado a otros Comités Nacionales como proyecto de referencia, constituyendo una de las iniciativas de las que el Comité Español se siente más orgulloso. Por ello, desde el Comité quisiéramos aprovechar estos breves párrafos introductorios para agradecer a todas las personas que han estado involucradas en el éxito de la misma, incluyendo a los miembros del Jurado por el trabajo realizado y, por supuesto, a todos aquellos jóvenes que decidieron participar en esta primera edición, que sin duda tendrá continuidad en el futuro.

El YPA cuenta con vocación de permanencia, por lo que, tras el éxito acontecido, se replicará de cara a próximos Congresos Mundiales del Petróleo, promoviendo así la presencia internacional de los jóvenes españoles del sector.

Pedro Miras Salamanca
Presidente del Comité Español del World Petroleum Council

El Comité Español del Consejo Mundial del Petróleo

Qué es el Consejo Mundial del Petróleo:
El Consejo Mundial del Petróleo (World Petroleum Council), es una institución internacional sin ánimo de lucro fundada en 1933. Desde entonces ha constituido el principal foro de opinión de la industria del petróleo y del gas mundial. El Consejo, compuesto por más de 60 Comités Nacionales, ayuda a crear y facilitar el diálogo entre sus principales actores y buscar soluciones sostenibles a los asuntos energéticos clave. Una de las actividades fundamentales del Consejo es la celebración del Congreso Mundial del Petróleo que reúne a las máximas personalidades del sector cada tres años.

Qué es el Comité Español del Consejo Mundial del Petróleo:
El Comité Español del Consejo Mundial del Petróleo, a través del Club Español de la Energía, es el instrumento que hace posible la participación del sector energético español en las actividades del WPC y que promueve sus actividades en el ámbito nacional.

Qué es el Comité Español de Jóvenes del Consejo Mundial del Petróleo:
El Comité Español de Jóvenes del Consejo Mundial del Petróleo busca ser el punto de encuentro entre juniors y seniors de la industria y el instrumento para la proyección tanto a nivel nacional como internacional de los jóvenes líderes del petróleo y el gas en España.

WORLD PETROLEUM COUNCIL
COMITÉ ESPAÑOL

PAPER GANADOR

Assessment of the integration of CO_2 capture in the refining sector

Andrea Ariadna Checa García

Key Words:
CO_2 capture, Refining, Post-combustion, Pre-combustion, Oxy-fuel

Abstract:
The industrial sector represents one-fifth of total global CO_2 emissions. Refining is the fourth largest contributor to CO_2 industrial emissions. The implementation of carbon capture and storage technologies (CCS) in the industrial sector is considered a key action by the International Energy Agency (IEA) to reduce CO_2 emissions. However, the majority of the development for CO_2 capture and storage is driven by the electric-utility sector. The aim of this paper is to assess the potential deployment of CO_2 capture within the refining sector as first step of the CCS chain.

The assessment starts with the description of the four main approaches for CO_2 capture, namely: post-combustion, pre-combustion, oxy-fuel combustion and chemical looping combustion.

Next, four principal CO_2 emissions routes are identified in the processes of a refinery: process heaters, hydrogen production, utilities and fluidised catalytic crackers (FCC). Suitable CO_2 capture technologies for each of these routes are analysed. Also, a brief overview of some CCS projects in the refining sector is presented.

The conclusions extracted point that there is an interest from the refining sector in CO_2 capture, as indicated by initiated demonstration projects. CO_2 capture is a technically feasible option for reducing CO_2 emissions from the refining sector through a range of post combustion, pre-combustion and oxy-fuel technologies. Yet, there are a number of challenges that are hindering widespread deployment of CO_2 capture that need to be overcome. Potential for early deployment of CO_2 capture in refineries exists for some high purity CO_2 streams, which are a by-product of certain hydrogen production processes. The latter, along with development of CCS in the power generation sector, could be the initial stage for a further progress of CO_2 capture in the refining sector.

Introduction

The industrial sector, mainly cement, iron and steel, chemicals and refining, represent one-fifth (7.1 $GtCO_2$) [1] of total global CO_2 emissions. Emissions from these sectors are expected to grow by around 35% up to 2050 [2] under current policies. Reducing CO_2 emissions from these sectors is crucial for the global action to prevent climate change.

In order to prevent climate change, the Intergovernmental Panel on Climate Change (IPCC) estimates that global CO_2 emissions need to decrease by between 50% and 85% of their 2000 levels by 2050[3]. Carbon Capture and Storage (CCS) systems have emerged in recent years as feasible methods to mitigate CO_2 emissions. However, the majority of the development for CO_2 capture and storage is driven by the electric-utility sector, in which the emphasis is on large centralized units for electric power generation. Still, power generation sector accounted for 25% [4] of global greenhouse gas emissions in 2010, only 4% [4] more than industrial sector.

The International Energy Agency (IEA) considers the implementation of CCS in industrial sector as a key action to achieve the CO_2 reduction goal by 2050. Specifically, IEA estimates that CCS in industrial applications could represent around half of the emission reductions achieved through CCS by 2050[1].

CCS encompasses a family of technologies and techniques that enable the capture of CO_2 from fuel combustion or industrial processes, the transport of CO_2 via ships or pipelines, and its storage underground, in depleted oil and gas fields and deep saline formations.

This paper intends to assess the deployment feasibility of CO_2 capture technologies in the refining sector, as one of the major industrial contributors to CO_2 emissions. Concretely, refining sector is responsible for 0.7 $GtCO_2$ out of the 7.1 $GtCO_2$ [1] from the industrial sector, being the fourth largest contributor, after iron and steel, cement and chemicals. This paper is structured as follows:

- Firstly, the main CO_2 capture technologies are presented. The aim of these technologies is to produce a stream of CO_2 highly concentrated from the flue gases originated in fuel combustion or industrial processes. Thus, this stream is next compressed and transported to its storage site. Both the functioning principles and the technical restrictions of each technology are described here.

- The third chapter assess the potential implementation of CO_2 capture technologies in a refinery. Four major emission routes in refineries potentially compatible with CO_2 capture are identified and analysed. Besides, a brief overview of current CCS projects in the refining sector is presented.

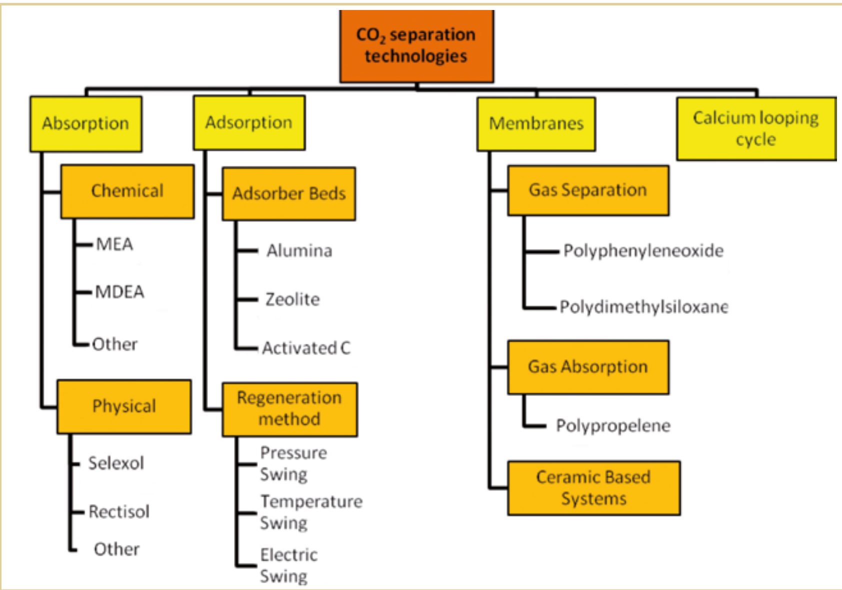
- Finally, chapter 4 contains the conclusions extracted from the analysis.

CO_2 capture options

In general, to economically sequester CO_2 derived from industrial plants, it is first necessary to produce a relatively pure, high pressure stream of CO_2. The process of producing this CO_2 stream is referred to as separation and capture, which encompasses all operations that take place at the plant site, including compression. For ease of transport, CO_2 is generally compressed to the order of 100 atm.

A variety of technologies for separating CO_2 from a mixture of gases are commercially accessible and widely used nowadays. Figure 1 illustrates

Figure 1. Technical options for CO_2 separation. Adapted from [5].



[1] IEA, Global Actions to Advance Carbon Capture and Storage. 2013.
[2] IEA, Industrial applications for CCS. 2013.
[3] IPCC, Fourth Assessment Report: Climate Change 2007. 2007.
[4] IPCC, Climate Change 2014. 2014.
[5] Edward S. Rubin, Hari Mantripragada, Aaron Marks, Peter Versteeg, and J. Kitchin, The outlook for improved carbon capture technology, in Progress in Energy and Combustion Science2011.

some of the technical approaches available. The selection of the technology is dependent on the requirements of product purity and on the conditions of the gas stream being treated (such as its temperature, pressure or CO_2 concentration).

There are four main approaches to capture CO_2 from fossil-fuel-fired energy systems or industrial processes: pre-combustion, post-combustion, oxy-fuel combustion and chemical looping combustion. These technologies are suitable for large stationary carbon emission point sources, such as refineries. However, capture is only the first step of the CCS chain. Once captured, the CO_2 requires to be compressed, for its subsequent transportation to the storage site.

Post-combustion

Post-combustion capture is the removal of CO_2 from flue gases downstream of the emission sources. At first glance, these capture methods can be applied to flue gases from the combustion of any fossil fuel, but actually their content in impurities affect the installation in terms of design and cost. Hence, it becomes necessary to place upstream of the capture system, units for the removal of other pollutants, such as SOx or particles [6, 7].

In broad terms, CO_2 can be captured in post-combustion using:

- Chemical absorption
- Physical absorption
- Adsorption
- Membranes
- Calcium looping cycle

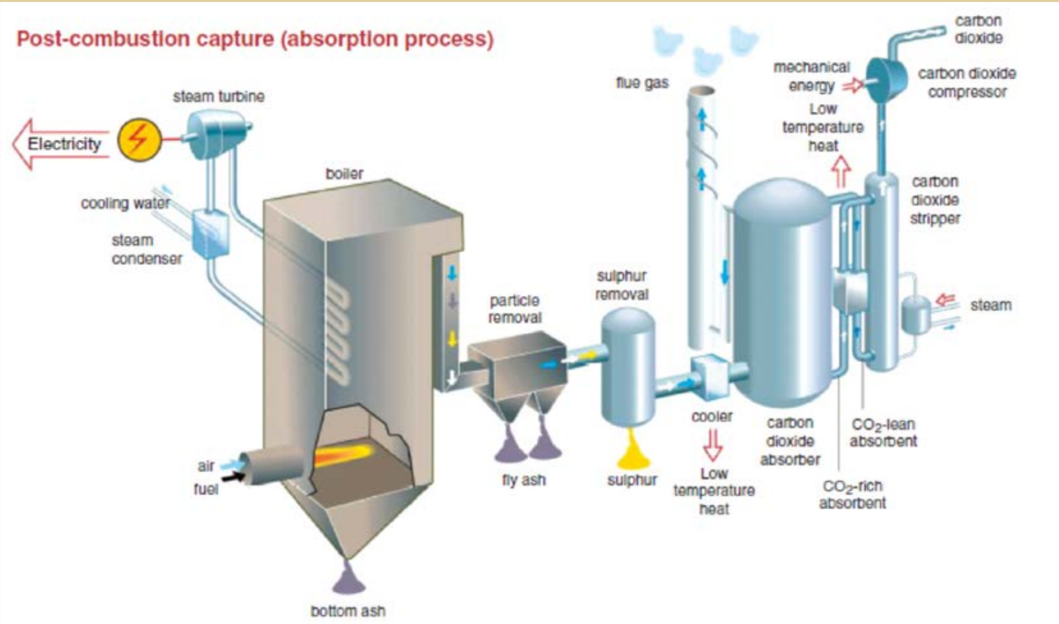
Chemical absorption

The most mature post-combustion capture techniques comprise liquid absorption using chemical solvents. Liquid absorption involves a mass transfer process with a chemical reaction process. Figure 2 shows a scheme of a post-combustion plant based on chemical absorption.

Low CO_2 partial pressures in flue gases are the main reason for the selection of CO_2 capture based on chemical absorption. During the capture process, the exhaust gas is cooled and channelled to an absorber, where it flows counter current of a chemical solvent. Here, most of the CO_2 is absorbed within the solvent, which is then sent to a stripper where CO_2 is recovered by the application heat, regenerating the solvent. The recovered CO_2 is next dehydrated and compressed for transport.

The most commercially mature post-combustion technology is Fluor's Econamine FG Plus. It uses a 30 wt% monoethanol amine (MEA) solution that can achieve CO_2 recovery efficiencies ranging from 85% to 95%. Although MEA is the best-known solvent, its high energy requirements and degradation rates are major drawbacks. Another process, developed by BASF, uses activated methyldiethanolamine (MDEA) for H_2S and CO_2 removal [6, 8].

Figure 2. Post-combustion capture schematic [6]



[6] Odorica-García, G., M. Nikoo, M. Carbo, and I. Bolea, Technology Options and Integration Concepts for Implementing CO_2 Capture in Oil-Sands Operations. Journal of Canadian Petroleum Technology, 2012.

[7] Prieto Fernández, I., Captura y almacenamiento de CO_2 procedente de instalaciones de combustión para la genereación de energía eléctrica. 2008, http://ocw.uniovi.es/: Grupo de investigación de Ingeniería Térmica (GIT). 45.

[8] Luis Romeo, Luis Díez, Pilar Lisbona, Ana González, Isabel Guedea, Carlos Lupiáñez, Ana Martínez, Yolanda Lara, and I. Bolea, Captura y almacenamiento de CO_2. 2010. 221.

Physical absorption

Physical absorption methods are explained below for pre-combustion technologies. These methods can be applied for post-combustion separation of CO_2; however, the exhaust gases conditions (low pressure) are not the most adequate.

Adsorption

The CO_2 adsorption process comprises the capture, fixation and accumulation of the CO_2 gaseous molecule on the surface of another one, typically a solid. This phenomenon depends on the adsorbent mass, pressure, temperature and the nature of both the gas and the solid surface. The key for the consolidation of this process remains on developing an adsorbent with high adsorption capacity for CO_2 and high selectivity for different concentrations of CO_2 in the gas stream. The adsorption process also involves a sorbent regeneration process. The most common regeneration methods are those based on temperature and pressure changes. The main three regeneration methods are:

- PSA (Pressure Swing Adsorption): under high pressure, gases tend to be attracted to solid surfaces, or "adsorbed". The higher the pressure, the more gas is adsorbed; when the pressure is reduced, the gas is released, or desorbed.

- TSA (Temperature Swing Adsorption): with this method, sorbent is regenerated when temperature is increased.

- ESA (Electric Swing Adsorption): regeneration occurs when a low voltage currents is applied to the sorbent.

Membranes

Membranes are permeable materials that can be used to selectively separate CO_2 from other components of a gas stream. They effectively act as a filter, allowing only CO_2 to pass through the material. The driving force for this separation process is a pressure differential across the membrane, which can be created either by compressing the gas on the feed side of the material or by creating a vacuum on the downstream side.

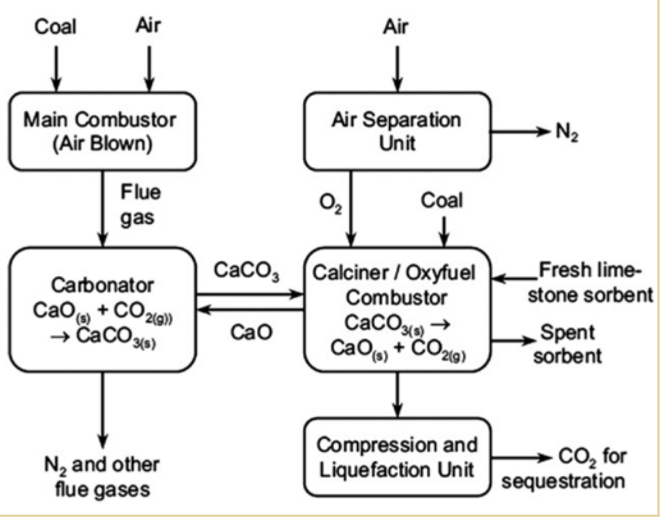
Despite it is a relatively simple technology, the volume of the gas stream to be treated in post-combustion systems is very large, and CO_2 is usually very dilute, so the separation efficiency falls. Another inconvenience is derived from the high degradation rate of membranes, caused by the flue gas conditions (e.g. temperature, impurities) [5, 8, 9].

Calcium looping cycle

Some new post-combustion capture processes employ solid sorbents rather than liquid solvents to capture CO_2 from the flue gas.

An advanced concept called calcium looping cycle or carbonate looping cycle is currently believed to be a breakthrough in the cost of avoided CO_2. Studies indicate that calcium looping has the potential to be more efficient and lower in cost than amine-based capture methods. In this process the desulfurized flue gas passes through a carbonator bed where calcium oxide (CaO) reacts with CO_2 in the flue gas to form calcium carbonate ($CaCO_3$). The carbonate is then heated in a separate reactor called the calciner where the reverse reaction takes place, releasing the CO_2. Energy for this reaction is supplied by combusting a fuel such as coal with high-purity oxygen. The CaO formed in the calciner is then sent back to the carbonator to complete the loop. A schematic of this process is shown in Figure 3 [5, 8].

Figure 3. Calcium looping cycle schematic [5]



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[9] Bolea, I., SIMULACIÓN DEL FUNCIONAMIENTO DE UNA TORRE DE ABSORCIÓN QUÍMICA E INTEGRACIÓN EN UNA CENTRAL TÉRMICA PARA LA CAPTURA DE CO2 DE LOS GASES DE COMBUSTIÓN, 2006, Universidad de Zaragoza.

Pre-combustion

In pre-combustion capture, CO_2 is separated from a gaseous fuel mixture under reducing conditions before its combustion. The fuel entering the combustion chamber has been previously decarbonized; thereby the flue gas produced is emitted to the environment free of CO_2.

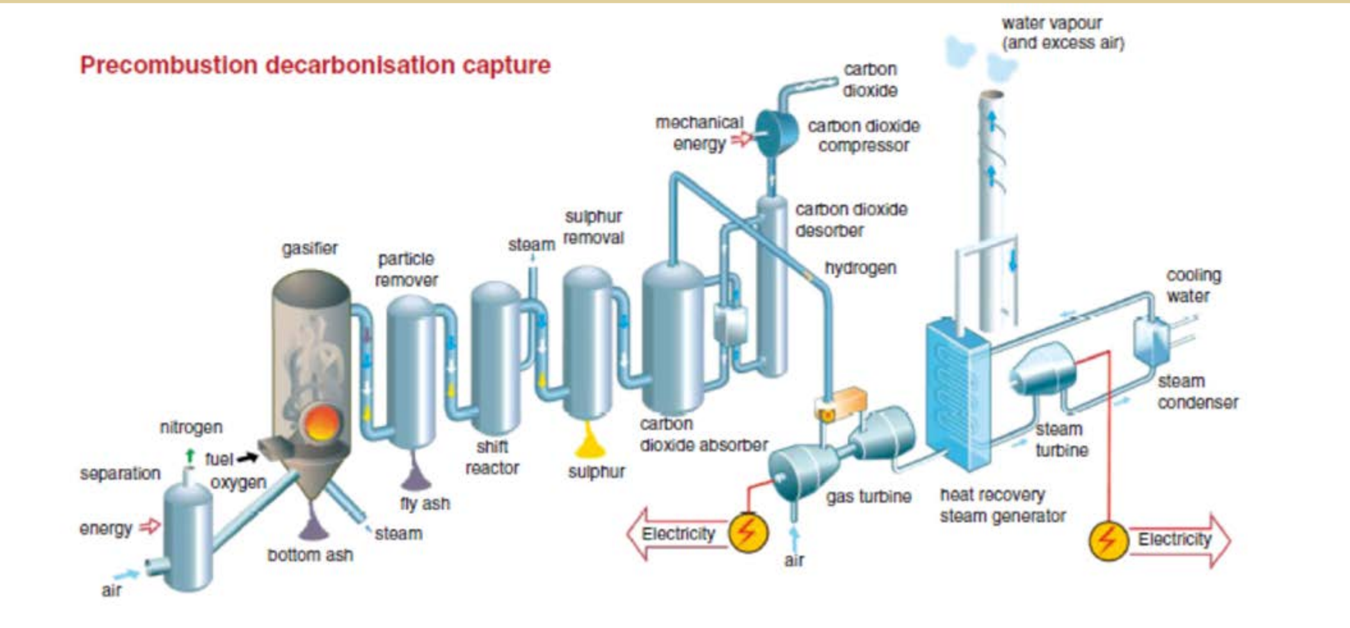
CO_2 separation techniques for pre-combustion are those described above for post-combustion, but applied to the gas stream derived from the decarbonization process. The most commercially available technologies rely on liquid solvents for CO_2 absorption, usually by scrubbing the gas stream with physical solvents. A simplified diagram is depicted in Figure 4.

Pre-combustion capture starts with the conversion of the carbonaceous fuel (e.g. natural gas, biomass, or oil) to a gaseous mixture consisting primarily of H_2 and CO, named syngas. This fuel-conversion step, called gasification for solid fuels and reforming for gaseous fuels, is endothermic and requires supplementary heating, typically supplied by the partial oxidation of the fuel. In CO_2 capture application, high-purity O_2 obtained from an air separation unit (ASU) is often used as oxidant, yielding the high temperatures required to produce syngas. The CO in the syngas is converted to H_2 and CO_2 through the water/gas shift (WGS) reaction. The WGS reaction is facilitated by commercially available catalysts. CO_2 can now be separated from the gaseous mixture.

Syngas production from gasification and partial oxidation is generally carried out at high pressure, resulting in high CO_2 partial pressures. For this reason, physical solvents are the preferred means to capture CO_2 in pre-combustion applications. The CO_2-rich solvent is regenerated by pressure reduction, releasing the CO_2, and the regenerated solvent is reused for CO_2 absorption. The recovered CO_2 is dried and compressed for its transport and storage, while the hydrogen-rich stream can be used as fuel. The most extended processes employ Rectisol and Selexol as solvents.

Physical absorption is subject to Henry's law, which results in a linear dependency between the CO_2 partial pressure and the solvent capture effectiveness. As a result, although the fuel-conversion process is laborious and costly, CO_2 separation is straightforward, avoiding the need of a chemical reaction for CO_2 capture [5, 6, 8].

Figure 4. Pre-combustion capture schematic [6]



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[8] Luis Romeo, Luis Díez, Pilar Lisbona, Ana González, Isabel Guedea, Carlos Lupiáñez, Ana Martínez, Yolanda Lara, and I. Bolea, Captura y almacenamiento de CO_2. 2010. 221.

Oxy-fuel combustion

Oxy-fuel combustion systems are being developed as an alternative to post-combustion technologies. In oxy-fuel combustion, pure oxygen is used as oxidant instead of air. This eliminates the huge amounts of N_2 in the flue gas stream.

After the particulate matter (fly ash) is removed, the flue gas consists of CO_2, smaller amounts of pollutants such as SO_2 and NOx, and water vapour. The latter, can be removed by condensation, and the remaining impurities using the adequate conventional technology, thus obtaining a nearly-pure CO_2 stream that can be sent directly to storage, as shows Figure 5.

Using oxygen instead of air reduces the oxidant mass, reaching higher temperatures than in conventional combustion. Hence, a certain portion of flue gas is recycled to the combustion process to moderate the flame temperatures. Temperature can be also reduced by water injection.

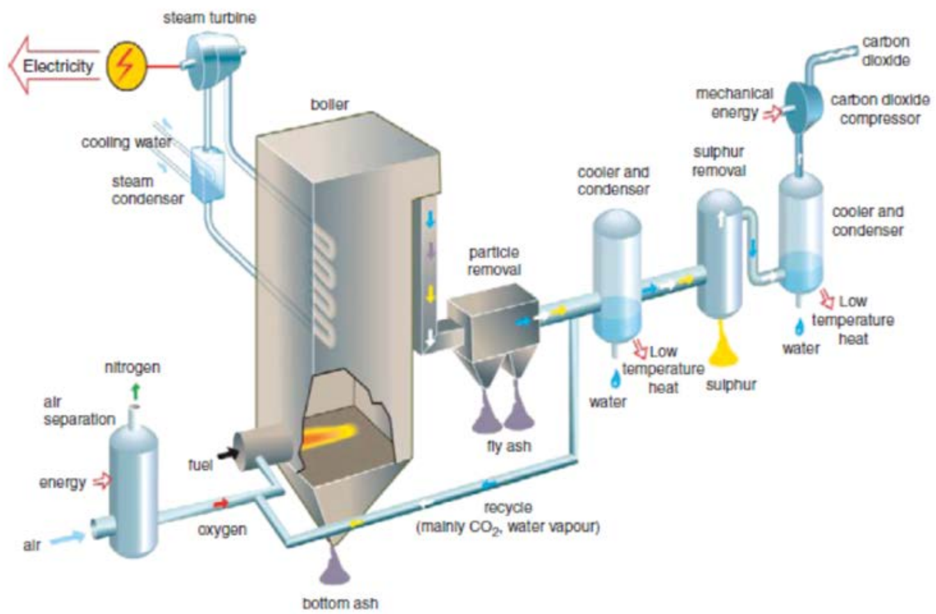
The principal benefit of oxy-fuel combustion is that it avoids the need for a costly post-combustion CO_2 capture system. However, it requires an air separation unit (ASU) to generate the relatively pure oxygen (95%-99%) needed for combustion. In addition, this technology requires three times more O_2 than pre-combustion methods, elevating costs related to the ASU [5, 6].

Chemical looping combustion

This technique involves splitting the combustion of a hydrocarbon in two independent oxidation and reduction reactions. For this purpose, a suitable metal oxide acts as carrier of O_2 between two reactors. The carrier transfers O_2 from the combustion air to the fuel, thus, direct contact between the fuel and the combustion air is avoided. Figure 6 shows a simplified diagram of the chemical looping combustion.

In this process, the air passes through a reactor containing a powdered metal at 800 – 1,200ºC. The metal is oxidized; next

Figure 5. Oxy-fuel combustion capture schematic [6]



[5] Edward S. Rubin, Hari Mantripragada, Aaron Marks, Peter Versteeg, and J. Kitchin, The outlook for improved carbon capture technology, in Progress in Energy and Combustion Science2011.

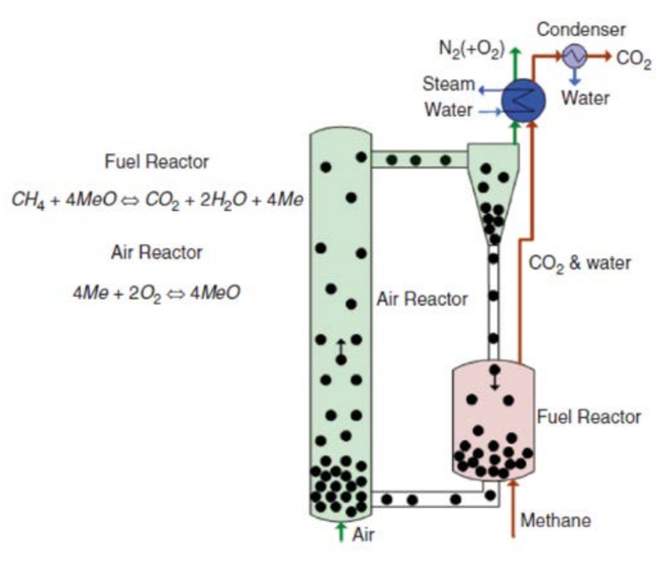
[6] Odorica-García, G., M. Nikoo, M. Carbo, and I. Bolea, Technology Options and Integration Concepts for Implementing CO_2 Capture in Oil-Sands Operations. Journal of Canadian Petroleum Technology, 2012.

enters into another reactor where it is reduced by the fuel, releasing the O_2 required for the combustion. The cyclone in Figure 6 is used to separate the metal oxide from the excess air.

An ASU is not needed for this kind of CO_2 capture. The advantage of avoiding direct contact between air and fuel is that the products of combustion, CO_2 and water, are separated from N_2 and any excess O_2. After water is condensed, a nearly-pure CO_2 stream is obtained which does not require any additional treatment except compression. If impurities such as NOx or SOx were present, conventional technology could be applied.

Chemical looping combustion has a great potential to significantly reduce CO_2 capture costs. However, it is still in the initial phase of its development, with challenges to overcome regarding the materials used and the selection of O_2 carriers [5-7, 10].

Figure 6. Chemical looping combustion capture schematic [6]



CO_2 capture in Refining Sector

The application of CCS to refineries is challenging due to the fact that CO_2 is emitted from many sources, which may be dispersed and could be relatively small compared to other industrial sectors. Most applications of CCS in industry require a capture step to concentrate the relatively dilute streams of CO_2 to a level that will enable economic transportation and storage. Combustion-derived emissions produce the majority of CO_2 at refineries, generally at low pressure and concentrations (4% to 15%, similar to power plants). There are also some refining processes that produce flue gas streams with higher CO_2 concentration, allowing lower capture costs.

Deploying CO_2 capture in Refining Sector

There are four major emission routes at refineries which are potentially compatible with CO_2 capture technologies. These routes are associated to the following production processes in refineries: process heaters, hydrogen production, utilities and fluidised catalytic crackers (FCC).

Suitable CO_2 capture technologies for each of these processes are analyzed below. Many of these technologies are already available but are not yet mature for CCS, or are only at demonstration stage.

CO_2 capture from process heaters

Refineries employ numerous fired heaters and boilers of different sizes and capacity throughout the facility. These could have capacities ranging between 2 MW and 250MW, and a typical refinery could have between 20 and 30 different interconnected processes around the site. This heating equipment usually uses different types of fuel that are available on-site, thus producing flue gas with a wide-ranging CO_2 composition. Together, these dispersed emission sources can in some cases be the largest producers of CO_2 in the refinery, being able to reach up to 60% of the total emissions.

Post-combustion capture and oxy-fuel combustion currently offer possibilities for reducing emissions from process heaters in

[5] Edward S. Rubin, Hari Mantripragada, Aaron Marks, Peter Versteeg, and J. Kitchin, The outlook for improved carbon capture technology, in Progress in Energy and Combustion Science2011.
[6] Odorica-García, G., M. Nikoo, M. Carbo, and I. Bolea, Technology Options and Integration Concepts for Implementing CO_2 Capture in Oil-Sands Operations. Journal of Canadian Petroleum Technology, 2012.
[7] Prieto Fernández, I., Captura y almacenamiento de CO_2 procedente de instalaciones de combustión para la genereación de energía eléctrica. 2008, http://ocw.uniovi.es/: Grupo de investigación de Ingeniería Térmica (GIT). 45.
[10] Capítulo 6.1- "Tecnologías de captura y almacenamiento de CO2" del informe "El futuro del carbón en la política energética española", 2008, Fundación para estudios sobre la energía.

refineries. Technologies that could potentially be implemented in the future in new facilities include chemical looping combustion, and pre-combustion capture in the production of hydrogen fuel for use in boilers and heaters.

The retrofit of heaters with post-combustion capture technologies is limited due to the wide distribution of heating units within the refinery complex. Some experts have proposed to resolve this by ducting the gases from dispersed heaters to a central location where CO_2 could be separated and compressed. Others, have questioned the feasibility of such an approach and proposed instead to capture only the CO_2 from the largest on-site stacks.

Oxy-fuel offers another potential mechanism for capturing the CO_2 from heaters and boilers. For this scenario it is proposed that all heaters and boilers on site are modified for firing with pure oxygen, produced at a central location, and that flue gases from the combustion plants will be initially treated at each CO_2 generation point (where water will be removed and CO_2 will be compressed to 30bar). Final compression of CO_2 will take place at one central location. One of the challenges will be the large distances for piping oxygen and CO_2 across the site between oxygen facilities and CO_2 compression stations [11-13].

CO_2 capture from hydrogen production

Between 5% and 20% of refinery CO_2 emissions are linked to the production of hydrogen (H_2). Hydrogen is a by-product of the catalytic reformer and fluid catalytic cracker (FCC) processes, but as demand of H_2 has increased (due to changes in fuel specification to reduce sulphur content), demand now exceeds supply from these processes in most refineries. To meet the increased demand, hydrogen is produced either through the steam methane reforming (SMR) of natural gas or through the gasification of heavy residues and fuel oil. The hydrogen produced in both of these processes needs to be separated from other constituents in the flue gases.

Hydrogen is most commonly produced through SMR. Traditionally, hydrogen produced in SMR plants was purified using chemical absorbents such as amines MDEA, resulting in high purity CO_2. However, in the past three decades has emerged a trend towards separation using PSA. In the current refining market, PSA offers two advantages over amine chemical absorption: 1) PSA produces very high purity hydrogen, and 2) the overall energy efficiency of the hydrogen production process is increased compared with chemical absorption. The change to PSA has been driven by the market need of high purity hydrogen. But PSA results in much lower concentration CO_2 in streams which contain 20-30% impurities. The impurities include H2, CO and methane (CH_4) making the gas suitable for reuse as fuel in the SMR furnace, but reducing the feasibility of CO_2 capture and increasing the cost.

Gasification plants for hydrogen production are generally larger than SMR and operate at high pressures of 50-70 bar. These conditions are suitable for the use of physical absorption solvents over chemical absorption solvents because they have higher loadings, require less energy input and produce dry CO_2 under these conditions. With gasification, all the CO_2 emissions associated with conversion end up in the flue gas stream and therefore, the rate of capture is higher than with SMR [13, 14].

CO_2 capture from utilities

Refineries require a large amount of steam and electricity to meet the energy demand of the different processes, and can account for 20% to 50% of the total refinery emissions. Steam is provided on-site, and in order to increase efficiency, it may be undertaken in conjunction with electricity production via combined heat and power (CHP). As these processes closely mirror those used in the power sector, this implies that opportunities for applying CO_2 capture in the utility installations of the refineries will follow the development of CO_2 capture technology in the power sector. Post-combustion and oxy-fuel combustion are the most promising technology for CHP. In the case of Integrated Gasification Combined Cycle (IGCC) pre-combustion would be the most suitable technology for CO_2 capture [11, 12].

CO_2 capture from fluidized catalytic cracking

In those refineries that operate fluidised catalytic cracking (FCC) units, such units can account for 20% to 50% of the total CO_2

[11] Veritas, D.N., Global Technology Roadmap for CCS in industry. 2010.
[12] Plants, E.T.P.f.Z.E.F.F.P., CO2 Capture and Storage (CCS) in energy-intensive industries. 2013.
[13] UNIDO, Carbon Capture and Storage in Industrial Applications. 2010.
[14] IEA and UNIDO, Technology Roadmap. Carbon Captrure and Storage in Industrial Applications. 2011.

emissions from the refinery. Unlike most of the other emissions from a refinery, the emissions from FCCs are process-related rather than combustion-related. During processing, carbon is deposited on the surface of a catalyst powder. The catalyst is regenerated by the oxidation of coke with air.

Depending on the process, the concentration of CO_2 in the flue gas typically ranges from 10% to 20%. Two technology options exist for the capture of CO_2 from the FCC: post-combustion capture, the most mature, and oxy-fuel combustion of the regeneration process, still in development. The potential of both has been compared, and despite the relatively high capital cost of oxy-fuel, the potential of lower operating costs makes it attractive option too [13-15].

Status of CCS in Refining Sector

Some CCS projects in the refining sector are already underway, and others are planned. Some of them are presented below:

- In Norway, Statoil, Gassnova (which represents the Norwegian Government in matters relating to CCS), Norske Shell and Sasol have established an agreement to develop, test and verify solutions for carbon capture, in Statoil's refinery in Mongstad. They have built a centre for carbon capture technologies at Mongstad, known as the "CO_2 Technology Centre Mongstad" (TCM). TCM aims to test CO_2 capture from flue gas streams in the refinery cracker and in the cogeneration power plant of the refinery. They are also planning to develop a full-scale capture plant at Mongstad [16].
- In Brazil, Petrobras is operating a demonstration project for CO_2 capture by oxy-firing FCC in a refinery.
- In Canada, the Alberta government financially supports the North West Upgrading bitumen refinery project, which will capture CO_2 from a gasification process used to produce hydrogen [14].
- In Rotterdam, CO_2 from Shell's Pernis refinery is captured, transported and used in nearby greenhouses. Plans to transport more CO_2 from the refinery and store it in the depleted Barendrecht gas field were cancelled because of public resistance to storage [17].
- In France, Total has been testing since 2010 oxy-fuel combustion capture at the countries' largest production site of liquid hydrocarbons, in Lacq [18].

Conclusions

This paper has analysed the potential integration of CO_2 capture technologies in the refining sector. There are four main approaches for CO_2 capture: post-combustion, pre-combustion, oxy-fuel combustion and chemical looping. To explore their potential within the refining industry the main emission sources of a refinery have been identified: process heaters, hydrogen production, utilities and FCC. The contribution to the total refinery emissions of each source is shown in Table 1.

Table 1. CO_2 emissions at a typical refinery complex

CO_2 emitter	% of total refinery emissions
Process heaters	30%-60%
Hydrogen production	5%-20%
Utilities	20%-50%
FCC	20%-50%

[13] UNIDO, Carbon Capture and Storage in Industrial Applications. 2010.
[14] IEA and UNIDO, Technology Roadmap. Carbon Captrure and Storage in Industrial Applications. 2011.
[15] De Mello, L., R. Pimienta, G. Moure, O. Pravia, L. Gearhart, P. Milios, and T. Melien, A technical and economical evaluation of CO2 capture from FCC units. 2008.
[16] www.statoil.com.
[17] http://www.rotterdamclimateinitiative.nl/.
[18] www.total.com.

Process heaters represent the largest CO_2 sources. The technical feasibility for CO_2 capture from process heaters is highly dependent on plant configuration, and the availability and accessibility of combined stacks. Retrofitting process heaters in a refinery with post-combustion capture technologies is limited by the wide distribution of heating units. The possibility of ducting multiple flue gas streams to a single CO_2 capture unit has been proposed, but the feasibility of these solutions is contested. Oxy-fuel combustion is emerging as an alternative to post-combustion. On the one hand, the energy penalty for CO_2 capture is reduced by avoiding the solvent regeneration need. On the other hand, inconveniences related to piping need to be overcome.

Hydrogen production accounts from 5% to 20% of CO_2 emissions from a refinery. It produces concentrated streams of CO_2 often at a high pressure. Thus, it offers a low-cost option for CO_2 capture deployment. However, not all hydrogen production routes are equally suitable for CO_2 capture. Two pre-combustion separation processes dominate: chemical absorption and PSA. Chemical absorption could lead to a very pure stream of CO_2, which could be directly compressed. By contrast, PSA produces lower CO_2 concentrations and is more focused on re-firing the gas stream. Although PSA produces hydrogen of higher quality and at a lower cost, this may not be the most adequate option for a carbon constrained world.

Regarding utilities, capture technologies for the power generation sector will probably reach development before other sectors, so refinery utilities may be a good opportunity for the deployment of their learnings. CHP also makes CO_2 capture technologies more applicable because emissions are centralized.

Finally, for FCC the potential to reduce the energy penalty of CO_2 capture derived from post-combustion may support oxy-fuel combustion in the long term.

There is an interest from the refining sector in CO_2 capture, as indicated by initiated demonstration projects. CO_2 capture is a technically feasible option for reducing CO_2 emissions from the refining sector through a range of post combustion, pre-combustion and oxy-fuel technologies. Yet, there are a number of challenges that are hindering widespread deployment of CO_2 capture that need to be overcome. Potential for early deployment of CO_2 capture in refineries exists for some high purity CO_2 streams, which are a by-product of certain hydrogen production processes. The latter, along with development of CCS in the power generation sector, could be the initial stage for a further progress of CO_2 capture in the refining sector. ■

2º FINALISTA

Offshore CO_2 enhanced oil recovery with CCS programs

Marcos Barrero Menéndez

Key Words:
Offshore, CO_2, Enhanced Oil Recovery, Carbon Capture and Storage

Abstract:
CO_2 can be an effective EOR agent and is the dominant anthropogenic greenhouse gas driving global warming. Capturing CO_2 for EOR projects can maximize hydrocarbon recovery and help provide a possible bridge to a lower carbon emissions future, by adding value through EOR production and field life extension, and providing long term storage post-EOR operations.

Offshore use of CO_2 for enhanced oil recovery is in its infancy, but, with the adoption of carbon capture and storage to decarbonize fossil-fuelled power generation, there is a time-critical opportunity to add value to the CCS chain by adopting and maturing offshore CO_2-EOR.

In shallow water oil fields in a mature stage, with their strong natural water driver, high (40% to 60%) recovery of original oil in-place can be already achieved, leaving a much smaller target for CO_2-EOR. Furthermore, when there is low content of CO_2 in the associated gas, unless CCS programs are carried out in order to supply sufficient CO_2, other advanced EOR technologies such as low-salinity water injection or deep reservoir flow diversion, with higher reservoir sweep and oil displacement efficiencies at this moment may be preferred to economically target these reduced volumes of residual oil and push recovery factors up to 70%.

In deep-water oil fields, which entail higher cost wells and more complex facilities, higher oil recoveries than currently offered are also required to become economically viable using CO_2-EOR. However, in contrast with shallow water oil fields, the primary/secondary oil recovery efficiencies in deep water fields are considerably lower, providing a larger residual oil target using CO_2-EOR.

CCS programs with offshore storage to abate emissions from power generation or associated gas may now become a reality; especially after the COP21 and Major Oil companies asking for a carbon policy (as the one in Norway) to be applied worldwide.

Introduction

The twenty-first session of the Conference of the Parties (COP) and the eleventh session of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) took place from 30 November to 11 December 2015, in Paris, France. The final text can be found in ref. [6]. According to the organizing committee at the outset of the talks, the expected key result was an agreement to set a goal of limiting global warming to less than 2 degrees Celsius (°C) compared to pre-industrial levels.

The year ended with what may become the most important element of all, Article 6 of the Paris Agreement. While this doesn't mention carbon pricing at all, it nevertheless provides fertile ground for its development through international trade of allowances and various other carbon related instruments. It also seeks to create a new global mechanism to underpin emissions reductions and promote sustainable development. Nonetheless, the ambitious goal of the Paris Agreement will need much wider and faster uptake of carbon pricing policy than is apparent from the charts below.

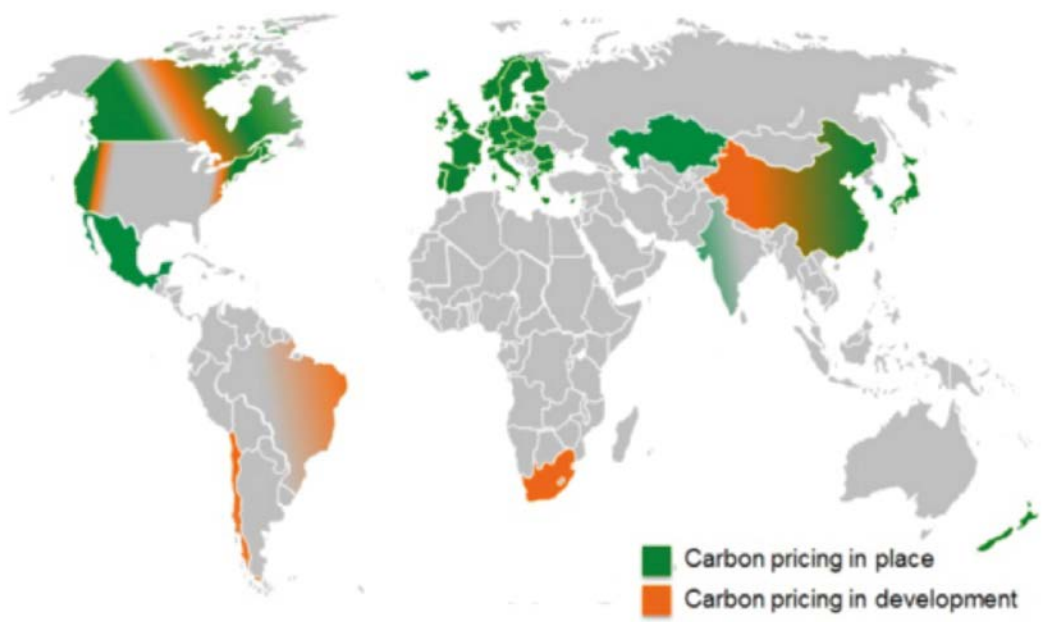
Carbon capture and storage (CCS), through a suite of technologies, separates and captures CO_2 from power and industrial sources, then transports the CO_2 to a suitable site for injection into deep underground formations for permanent storage. CCS makes possible the strong reduction of net CO_2 emissions from fossil-fuelled power plants and industrial processes, providing a protection strategy for power plants that would otherwise be decommissioned, mothballed or suffer reduced operations in a carbon-constrained world. CCS may then become a potential source of CO_2 for enhanced oil recovery. This process is presented throughout the following paper.

The CCS opportunity

Background

The International Energy Agency (IEA) in its 450 Scenario[1] (see ref. [2]), states that CCS is increasingly adopted from around the mid-2020s, with deployment accelerating in the 2030s and capturing around 5.1 Gt of CO_2 emissions per year by 2040 (nearly triple India's energy sector emissions today). Over the period 2015 to 2040, about 52 Gt of CO_2 emissions are captured. This involves a massive increase in CCS deployment over the 13 large-scale projects in operation today, which capture a total of about 27 Mt CO_2 per year (though only 5.6 Mt CO_2 at present is being stored

Figure 1. Countries with carbon policies in place or in development as of January 2016 (ref. [1])



[1] The IEA's 450 Scenario in ref. [2] depicts a pathway to the 2 °C climate goal that can be achieved by fostering technologies that are close to becoming available at commercial scale.
Reference [1]. The World Bank group – Carbon Pricing Watch report – 2015
Reference [2]. IEA – World Energy Outlook 2015
Reference [6]. Adoption of the Paris Agreement - https://unfccc.int/resource/docs/2015/cop21/eng/l09.pdf

with full monitoring and verification). To date, CCS investments are being made in sectors in which costs are relatively manageable (e.g. natural gas processing or refining) and where the captured CO_2 has a valuable application, such as for enhanced oil recovery. Widespread deployment will require moving well beyond these boundaries.

With the given carbon pricing or other policy measures to incentivise low-carbon operations, equipping coal or gas-fired power plants with CCS can be a commercially sound investment, allowing them to operate for more hours. The retrofit of existing plants with CCS can provide plants with a new lease on life as low-carbon generators, which could be particularly important in countries like China that already have a large fleet of coal- and gas-fired power plants and where coal prices are anticipated to remain relatively low.

Countries and companies with revenue streams from the extraction and processing of fossil fuels thus have a clear interest in supporting the development and deployment of CCS.

Both public and private sector actors can foster wider adoption of CCS technology. The priority is demonstration with large, focused and direct financial support. No trade-off between subsidizing CCS or other low carbon technologies should be made before the end of the demonstration phase that will define the real economic potential of CCS. UNFCCC countries have acknowledged that following the precautionary principle, uncertainty is not a reason for inaction. If by 2020, demonstration projects do not prove as promising as expected, governments will be able to readjust their incentive programs.

Carbon Capture processes

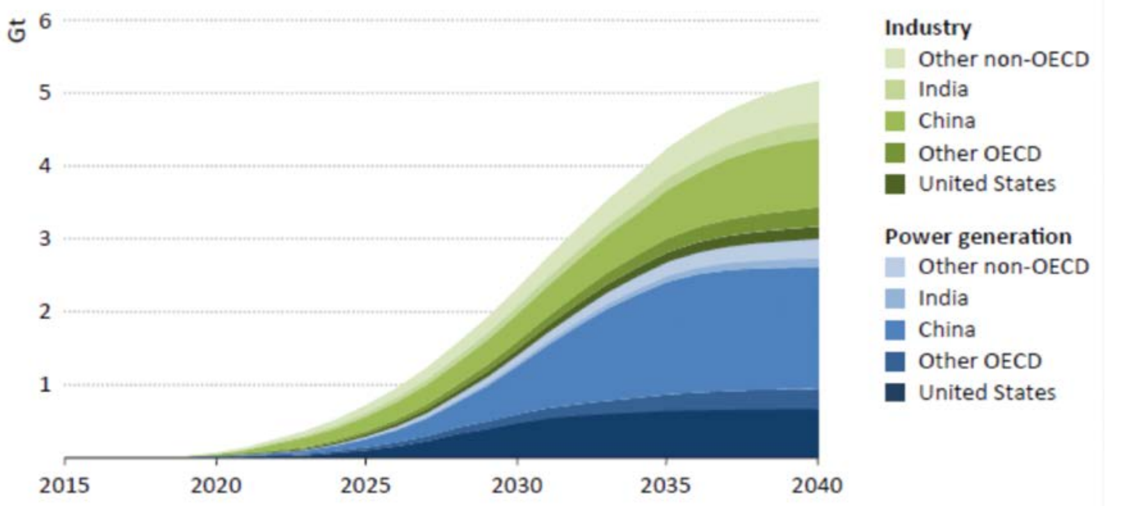
Four main capture processes exist: three for power or industrial plants (pre-, post- and oxy-combustion), and one for natural gas processing.

Post-combustion

Thermal power plants burn fuel with air to produce heat and emit flue gases that generally consist of a hot gas at standard pressure with 80% N_2, 10% CO_2, some oxygen, vapor and other pollutants (NOx, etc.). The CO_2 is then separated from the flue gases with various methods. The main hurdle is to separate CO_2 from N_2, which stays inert along the whole reaction. Most CO_2/N_2 separation systems today are using amine-based solvents. Additional drying, purification and compression are required before transportation (Figure 4).

Post-combustion systems are the most mature capture technology, and are expected to be retrofitted to modern and efficient thermal power

Figure 2. CO_2 captured in IEA's 450 Scenario by sector and region (ref. [2])



Note: Industry includes the following sectors: steel, cement (energy- and process-related), chemicals and paper production; oil refining; coal-to-liquids, gas-to-liquids and natural gas processing.

Reference [2]. IEA – World Energy Outlook 2015

Figure 3. Capture options for power or industrial plants (~90%)

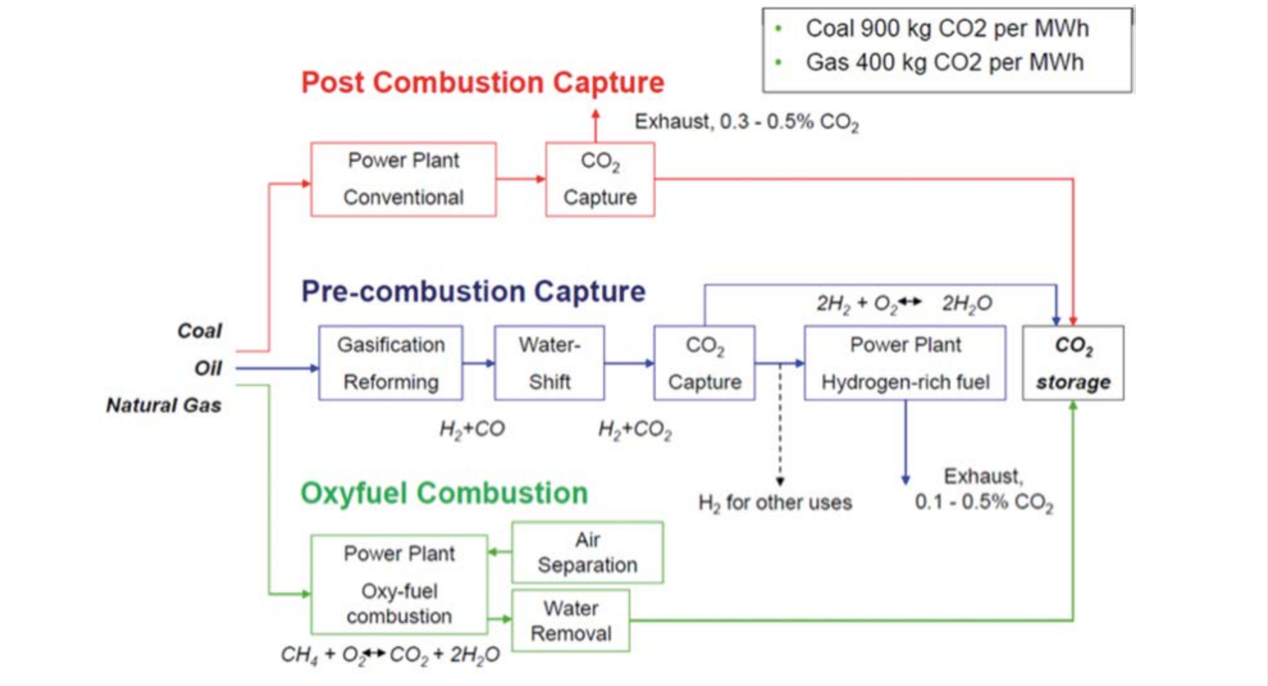
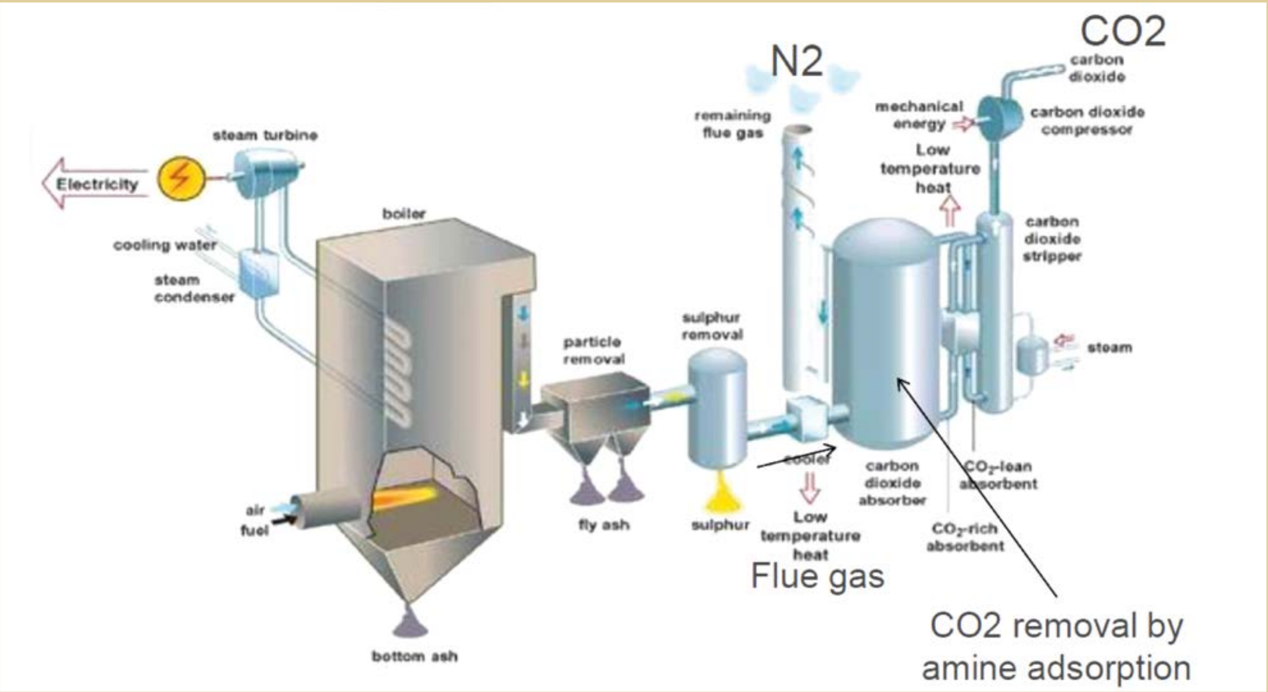


Figure 4. Schematic of Post Combustion Capture Plant (ref. [4])



Reference [4]. http://www.europeanenergyforum.eu/archives/european-energy-forum/environmental-matters/co2-capture-and-storage-2013-part-of-the-solution-to-the-climate-change-problem plant: supercritical pulverized coal (SPC) and natural gas combined-cycle (NGCC). But it can virtually be retrofitted to almost any existing plant with large and steady source of CO_2, by adding the capture process to the exhaust gas circuit. Post-combustion is the only system that does not require an additional oxygen production plant. However, the process is still highly inefficient, given the low partial pressure of CO_2 in the flue gas. Energy requirement with existing amine-based solvent developed for non-CCS purpose are about 4.5GJ/tCO_2 capture, decreasing plant efficiency by 25%. Therefore, new and more efficient solvent are being demonstrated at pilot scale, but no commercial scale power plant with solvents-based post combustion have been built yet.

Oxy-combustion

Thermal power plant burners are modified to burn fuel with nearly pure oxygen instead of air - which contains only 21% of O_2. As a result, CO_2 concentration in flue gas varies between 80% and 98%, mixed with vapor, resulting in a stream almost ready to transport. Additional drying, purification and compression are also needed before transportation. Extremely high temperature is reached when fuel and pure oxygen are combusted, so flue gas needs to be partially recycled to cool down the burner, modified to resist higher temperature (see Figure 5).

However, the main hurdle is the very large stream of pure oxygen needed for the oxy-combustion: Various O_2/N_2 separation systems exist but the main technology used today – cryogenic air separation units (ASUs), based on distillation at low temperature – is energy intensive. Another important issue is the insufficient purity of CO_2 in flue gases, which happened to be a matter of prime importance in early demonstration projects. Overall, the efficiency of the system is theoretically better than in post-combustion, but oxy-combustion is the less mature process for power generation. Oxy-firing process is being studied for steelmaking within the Ultra-Low CO_2 Steel Making (ULCOS) consortium of western European steel producers. In power generation, it has been proven at pilot scale (Total Lacq and Vattenfall Schwarze Pumpe) but remains to be demonstrated at large scale. One major challenge is to create such a massive flow of pure oxygen at reasonable costs.

Pre-combustion

The pre-combustion process regroups all industrial processes that transform hydrocarbon sources (coal, oil, gas or biomass) to generate synthesis gas (syngas) (hydrogen, carbon monoxide and dioxide) as an intermediate step.

Syngas is a strategic building block that can be used to produce a wide range of products (Figure 6). It can be transformed into liquid hydrocarbon, or hydrogen: another high energy content fuel that can be burnt to produce electricity or heat, used to enrich industrial products into higher valued ones ('upgrading' of fossil fuel in refineries, producing ammonia for the fertilizing industry, etc.), or more marginally used to produce electricity directly in fuel cells. The syngas process has been in use for more than 50 years and is considered mature.

The advantage of this capture system is that the separation of CO_2 from H_2 is easier than from flue gas: concentration (17-38%) and partial pressure of CO_2 is much higher (typically 8bar) than in flue gases (0.1bar), allowing various gas separation methods that cannot be currently applied to post-combustion, and that are more efficient. Pressure swing adsorption (PSA) is the system of choice

Figure 5. Oxy-combustion process

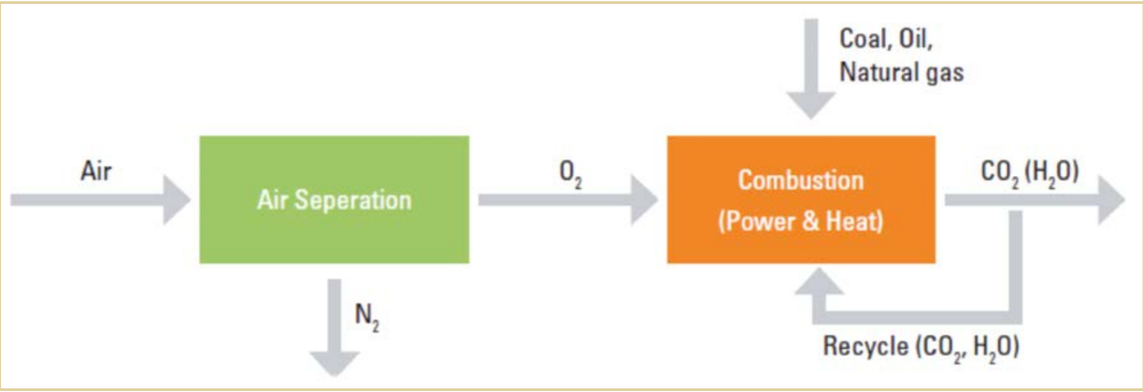
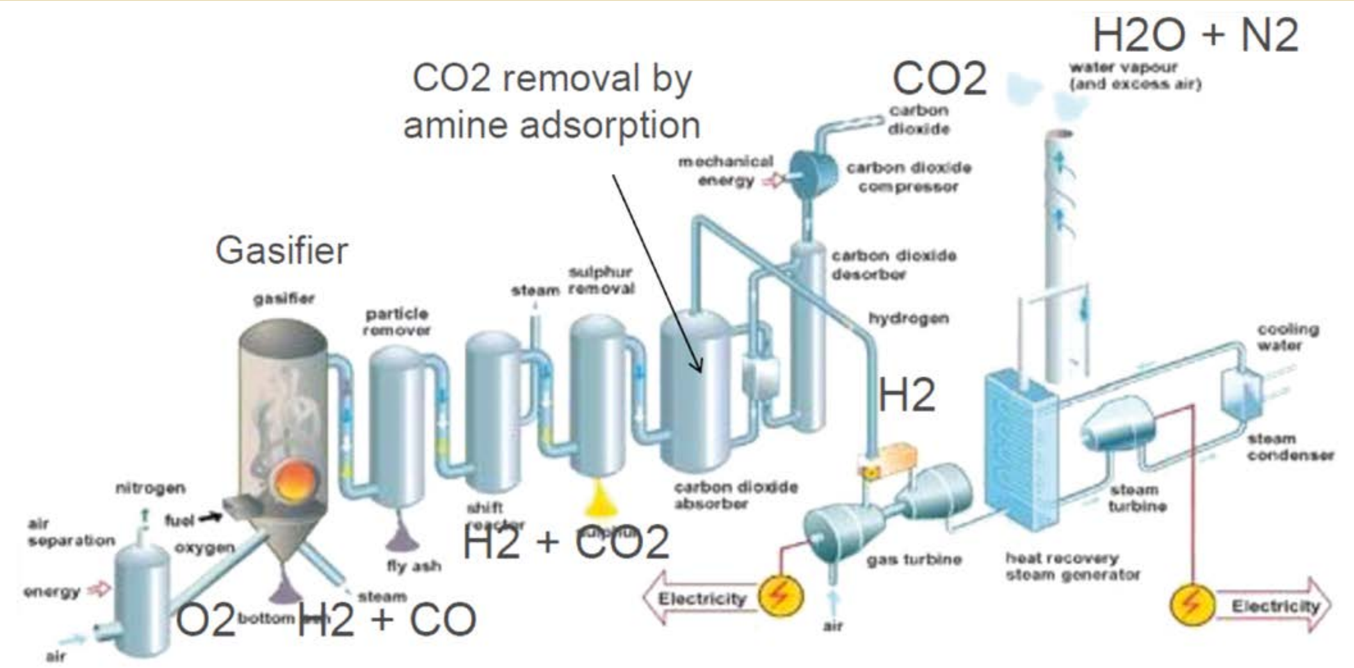


Figure 6. Schematic of Pre-combustion Capture Plant (ref. [4])



today, but CO_2/N_2 membranes, efficient only at high pressure, could potentially reduce drastically costs of separation.

CO_2 is removed from syngas (previously shifted with vapor), and the remaining H_2 is burned in hydrogen turbine to produce electricity without CO_2 in the flue gases.

Integrated gasification combined-cycle (IGCC) remains much more expensive than conventional plant because of their complexity. They need, for instance, an air separation unit, although three times smaller than for oxy-combustion power plants. IGCC facilities are generally 'CCS ready', providing additional drying, purification and compression.

Ultimately, the syngas process with CCS could be applied to many sectors:

- Power Generation (IGCC from coal, IRCC from natural gas, BIGCC from biomass)
- Second generation biofuels (BtL or Biomass to Liquid)
- Synthetic liquid fuels from natural gas (GtL, Gas to Liquids) or coal (CtL, Coal to Liquids), the latter having an extremely high carbon footprint without CCS
- Synthetic natural gas (SNG)
- Chemical production (Ammonia NH_3)
- In Refineries, 5-20% of CO_2 emissions come from production of hydrogen, and demand is increasing with new regulations for higher quality fuels from lower quality crude.
- Furthermore, hydrogen fuel offers the flexibility to design pre-combustion power plant with mixed output, selling both electricity (during the day) and hydrogen byproducts like ammonia (at night).

Natural gas sweetening

About half of the raw natural gas produced worldwide contains more than 4% CO_2 by volume, which is above specifications for its transport (2% for pipelines). Natural gas processing facilities includes a 'gas sweetening' step which separate and remove CO_2. It is the lowest cost opportunity to create a large flow of CO_2 ready to be stored: CO_2 flow rate can be very high, separation is inherent to the process of natural gas production, and operates at already high pressure, reducing further cost of compression. The first large-scale integrated CCS projects were gas processing facilities, and CO_2/CH_4 separation system is already commercialized and mature.

Reference [4]. http://www.europeanenergyforum.eu/archives/european-energy-forum/environmental-matters/co2-capture-and-storage-2013-part-of-the-solution-to-the-climate-change-problem

Enhanced Oil Recovery

Background

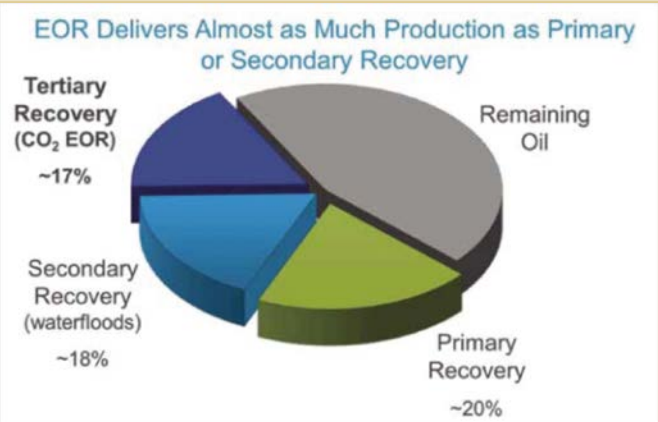
Oil production is separated into three phases: primary, secondary and tertiary, the latter also being known as Enhanced Oil Recovery (EOR). Primary oil recovery is limited to hydrocarbons that naturally rise to the surface, or those that use artificial lift devices. Secondary recovery employs water and gas injection, displacing the oil and driving it to the surface. According to the Institute for 21st Century Energy (U.S. Chamber of Commerce) in ref. [8], utilizing these two methods of production can leave up to 50% of the oil in the reservoir.

The way to further increase oil production is through the tertiary recovery method or EOR. Although more expensive to employ on a field, EOR can increase production up to a maximum of 70% recovery. The following figure shows an example of the different recovery percentages reaching a maximum of 55%.

Used in fields that exhibit heavy oil, poor permeability and irregular fault lines, EOR can entail changing the actual properties of the hydrocarbons, which further distinguishes this phase of recovery from the secondary recovery method. While water flooding and gas injection during the secondary recovery method are used to push the oil through the reservoir, EOR applies steam or gas to change the makeup of the reservoir.

Whether it is used after both primary and secondary recovery have been exhausted or at the initial stage of production, EOR enhances oil displacement in the reservoir.

Figure 7. Example of approximate recovery factors shown for onshore U.S. (ref. [8])



EOR techniques

There are three main types of EOR, including thermal recovery, chemical flooding and gas injection. Since it increases the cost of development alongside the hydrocarbons brought to the surface, producers do not use EOR on all reservoirs. The economics of the development equation must make sense. Therefore, each field must be well evaluated to determine which type of EOR will work best on the reservoir. This is done through reservoir characterization, screening, scoping, and reservoir modeling and simulation.

Thermal Recovery

Thermal recovery introduces heat to the reservoir to reduce the viscosity of the oil. Many times, steam is applied to the reservoir, thinning the oil and enhancing its ability to flow. First applied in Venezuela in the 1960s, thermal recovery now accounts for more than 50% of applied EOR in the US, as stated in ref. [8].

Chemical Injection

Chemical injection EOR helps to free trapped oil within the reservoir. This method introduces long-chained molecules called polymers into the reservoir to increase the efficiency of water-flooding or to boost the effectiveness of surfactants, which are cleansers that help lower surface tension that inhibits the flow of oil through the reservoir. Less than 1% of all EOR methods presently utilized in the US consist of chemical injections.

Gas Injection

Gas injection used as a tertiary method of recovery involves injecting natural gas, nitrogen or carbon dioxide into the reservoir. The gases can either expand and push gases through the reservoir, or mix with or dissolve within the oil, decreasing viscosity and increasing flow. Nearly half of the EOR employed in the US is a form of gas injection according to ref. [8].

Carbon dioxide EOR (CO_2-EOR) is the method that is gaining the most popularity. While initial CO_2-EOR developments used naturally occurring carbon dioxide deposits, technologies have been developed to inject CO_2 created as byproducts from industrial purposes.

First employed in the US in the early 1970s in Texas, CO_2-EOR is being successfully used in the oil fields of the Permian Basin of West Texas, the Gulf Coast, the Rockies, and basically all over the world as depicted in Figure 10. Moreover, it is expected to become even more widely spread in the near future.

Other EOR applications

Other EOR applications gaining acceptance are low-salinity water flooding, which is expected to increase recovery by nearly 20%, and well stimulation, which is a relatively low-cost solution because it can be employed to single wells (rather than the whole reservoir).

Figure 8. Thermal Recovery

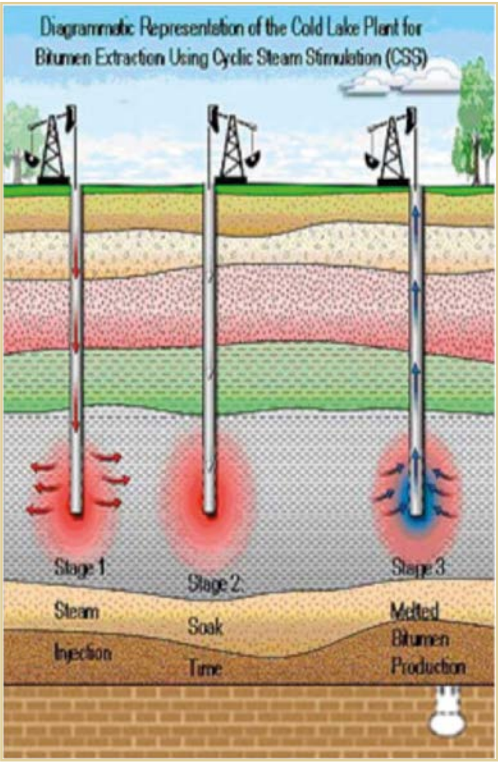


Figure 9. The schematic of the CO_2 miscible process showing the transition zone between the injection and production well

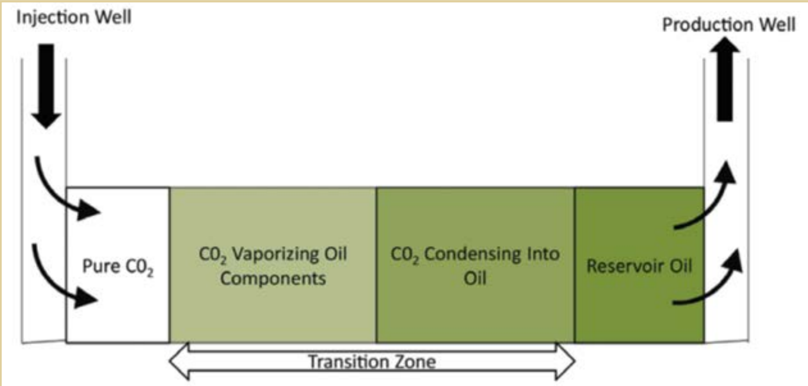


Figure 10. Active CO_2-EOR project counts (1986-2010) (ref. [15])

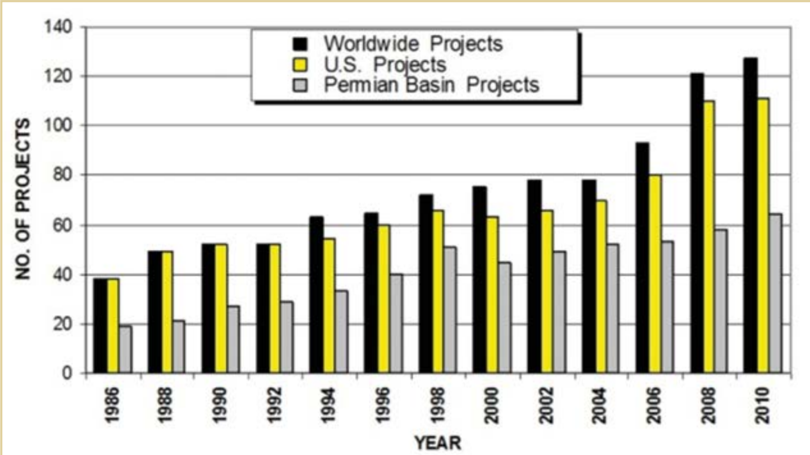
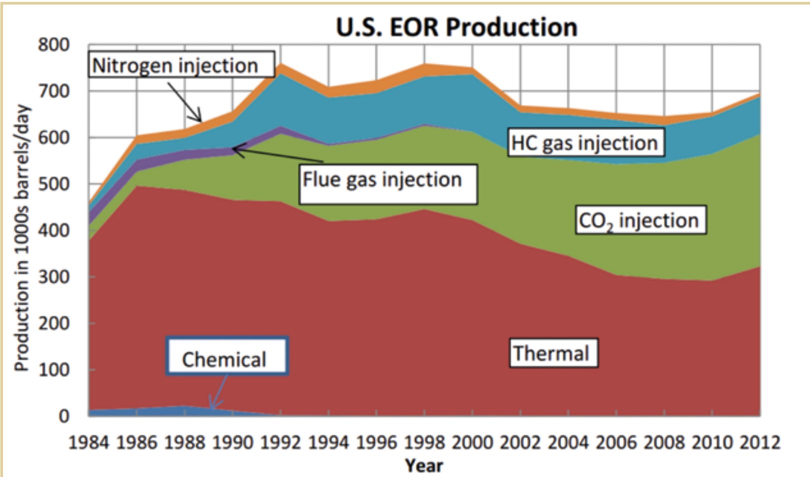


Figure 11. U. S. EOR Production by type (1984-2012) (ref. [16])



Reference [15]. Hargrove, B. et al. – A status report on North American CO2-EOR production and CO2 supply – 2010
Reference [16]. USGS – Fundamentals of Carbon Dioxide-Enhanced Oil Recovery – 2015

Offshore CO_2-EOR Current Applications

General

Although EOR applications are predominantly employed today onshore, technologies are being developed to expand the reach of EOR to offshore applications. Challenges that presently exist for offshore EOR include economics of the development; the weight, space and power limitations of retrofitting existing offshore facilities; and fewer wells that are more widely spaced contributing to displacement, sweep and lag time.

Currently, the application of EOR is being considered for a number of offshore developments. With successful subsea processing (for mature fields) and secondary recovery methods employed in offshore environments through water and gas injection, the technologies to apply EOR methods is quickly nearing.

As such, the success of using CO_2-EOR in onshore oil fields inspires operators to consider using CO_2-EOR in offshore oil fields. The international pursuit of offshore EOR is somewhat active, as illustrated by the following five active or planned international offshore CO_2-EOR projects:

1. Offshore Brazil, Pre-Salt Layer (ref. [9])
2. North Sea, Draugen/Heidrun Oil Fields (ref. [17])
3. Offshore Abu Dhabi, Persian Gulf Oil Fields (ref. [12])
4. Offshore Vietnam, Rang Dong Oil Field (only offshore EOR application using anthropogenic CO_2) (ref. [18])
5. Offshore Malaysia, Dulang Oil Field (ref. [11])

CO_2-EOR Offshore Brazil – The Pre-salt Layer

Background

Brazil's Pre-Salt area is currently the international pioneer in pursuing deep water offshore CO_2-EOR. The Lula Field is a super-giant deep water oil field located in the Santos Basin of Brazil.

According to ref. [9], given the innovative strategies being pursued by Petrobras, the Lula Field serves as a most valuable case study of using early application of advanced CO_2-EOR technology to optimize the development of a major offshore oil field. Significant preparation steps taken at Lula, as discussed further in this section of the report, include: intensive reservoir characterization, testing of alternative enhanced oil recovery options, and rigorous monitoring of pilot flood performance. Lula was discovered by Petrobras in 2006 in ultra-deep waters, between 1650 and 2,200 meters (5,400 and 7,200 feet), approximately 180 miles south-east of Rio de Janeiro. Lula's carbonate reservoir is overlain by a thick 1,800 meters (6,000 feet) salt column and holds moderately light, 28-30° API oil with a high solution gas-oil ratio. The associated gas in the reservoir contains 8% to 15% of CO_2.

Table 1. FPSO units with CO_2 re-injection on the pre-salt layer offshore Brazil

First oil year	Unit name	Operator	Country	Owner
2011	FPSO Cidade de Angra dos Reis MV22 (Pilot 1)	Petrobras	Brazil	Modec
2012	FPSO Cidade de Sao Paulo MV23 (Pilot 2)	Petrobras	Brazil	Modec
2013	FPSO Cidade de Paraty (Pilot 3)	Petrobras	Brazil	SBM
2014	FPSO Cidade de Ilhabela (Pilot 4)	Petrobras	Brazil	SBM
2014	FPSO Cidade de Mangaratiba MV24 (Pilot 5)	Petrobras	Brazil	Modec
2015	FPSO Cidade de Itaguai MV26 (Pilot 6)	Petrobras	Brazil	Modec
2015	FPSO Cidade de Marica (Pilot 7)	Petrobras	Brazil	SBM
2016	FPSO Cidade de Saquerema (Pilot 8)	Petrobras	Brazil	SBM
2016	FPSO Cidade de Caraguatatuba MV27 (Pilot 9)	Petrobras	Brazil	Modec

Reference [9]. Petrobras – Aspects in CO2 management in Brazilian Pre-salt Oil and Gas production – April 2014
Reference [11]. PETRONAS – Flow Vol. 3 – 2015
Reference [12]. Masdar – CCUS Project, Abu Dhabi – 2016
Reference [17]. U.S. Department of Energy – CO2-EOr Offshore Resource Assessment – 2014
Reference [18]. IEA Collaborative Project on Enhanced Oil Recovery – Study on Applicability of CO_2-EOR to Rang Dong Field, offshore Vietnam – 2009

Pre-Salt CO_2-EOR highlights

Early Implementation of CO_2-EOR

According to ref. [9], Petrobras implemented a series of short-term EOR pilots at Lula with the intention of developing the entire field using CO_2-EOR, if the CO_2 pilot was successful. According to Petrobras, early implementation of CO_2-EOR would improve capital efficiency as it frees the operator from having to subsequently retrofit production systems and find platform space for CO_2 recycling. Early implementation of CO_2-EOR would also preclude halting operations and shutting-in oil production when undertaking CO_2-EOR later in the oil field's life.

Deepwater CO_2-EOR Technology

The technology deployed by Petrobras for Lula mirrors the methodology and design used in ARI's deep water CO_2-EOR resource assessment modeling. Similar to Petrobras, ARI (ref. [10]) uses a hub and spoke model to service multiple fields with subsea completions. Both Lula and ARI's offshore CO_2-EOR design utilize intelligent well completions, dynamic down hole monitoring, tracer injections and extensive CO_2 recycling.

Reservoir Characterization and Phased Development

Petrobras is following a phased development of the Lula Field, allowing for its field development and EOR strategy to evolve as reservoir characterization and performance data improve. Importantly, the company uses Extended Well Tests (EWTs) to define reservoir connectivity and other key characteristics, and a phased development program to formulate their EOR strategy without waiting for results from the operation of a water flood.

Figure 12. CO_2 compression topside module on FPSO at the Lula field – Heaviest module aboard

Choosing a Recovery Method at an early stage

Petrobras decided early in its field development cycle not to vent the CO_2 produced at Lula, but to use this gas for miscible CO_2-EOR. In addition, the high CO_2 content present in the associated gas dictated that corrosion resistant alloys be used in all production wells enabling a CO_2-EOR flood to use existing wells and infrastructure without major refurbishment.

First Development Phase

The first Lula EOR pilot consisted of one injection and one production well. In April 2011, Petrobras began injecting produced reservoir gas into the oil field at a rate of 35 Mcfd. After six months of gas re-injection, the hydrocarbon gas was separated from the CO_2 in the FPSO's membrane processing system and transported onshore for sale. The separated CO_2 was then re-injected into the reservoir at a rate of 12.3 Mcfd. A horizontal well was drilled in Q1 2012 and WAG injection, utilizing water and the high CO_2 concentration gas, commenced in the second half of 2012. The Lula EOR pilot included one gas injector, two WAG injectors, and multiple producers. Ultimately, as shown in Table 1, a range of pre-salt fields are using CO_2 injection.

Figure 13. Third generation[2] FPSO Cidade de Ilhabela on its way to the oil field

Reference [9]. Petrobras – Aspects in CO2 management in Brazilian Pre-salt Oil and Gas production – April 2014
Reference [10]. ARI – Optimization of CO2 storage in CO2 enhanced oil recovery projects – November 2010
[2] Third generation FPSO's means that topsides are complex and heavier than 20,000t partially due to the CO_2 processing system

The major takeaway from the Lula field case study is that early implementation of CO_2-EOR should be considered for giant, newly-discovered deep water offshore fields. As demonstrated by Petrobras, phased development, reservoir simulation and dynamic data acquisition, instead of waiting on the field's water flood performance, can be used to define how oil recovery will respond to CO_2-EOR.

CO_2-EOR North Sea

Background

Enhanced oil recovery using gas injection is not a new concept for North Sea oil fields. Many projects have been conducted to date including EOR projects in major oil fields such as Brent, Ekofisk and Stratfjord (see Table 2). However, these EOR projects have used hydrocarbon gas as the miscible agent instead of CO_2.

Today, North Sea oil field operators are interested in substituting CO_2 for natural gas as the injectant for EOR. A number of factors, including opportunities to sell the hydrocarbon gas and interest in capturing and storing CO_2 from power plants, are currently being considered for combining CO_2-EOR and CO_2 storage in the oil fields of the North Sea.

CO_2-EOR Projects for North Sea Oil Recovery and CO_2 Storage
A number of CO_2-based enhanced oil recovery projects have been considered for the North Sea, transporting the CO_2 from onshore power plants to offshore oil fields, including:

- **Draugen and Heidrun Oil Fields**. In 2006, Shell and Statoil announced plans for capture of CO_2 from onshore power generation with transport and injection of the CO_2 into two Norwegian sector offshore oil fields. Both companies had good technical and management pedigrees for implementing the project. Shell pioneered using CO_2 for EOR in the 1970s and Statoil was the first to store CO_2 offshore at the Sleipner field in the 1990s. At the time, the project would have been the world's largest offshore CO_2-EOR operation.

Table 2. Some of North Sea EOR experiences

First oil year	Field	Operator	Country	EOR Type
1971	Ekofisk	Conoco-Phillips	NORWAY	HC Miscible[3]
1971	Ekofisk	Conoco-Phillips	NORWAY	HC WAG Immiscible
1976	Beryl	Apache North Sea	UK	HC Miscible
1976	Brent	Shell	UK	HC Miscible[4]
1978	Thistle	Lundin Oil	NORWAY	HC WAG Immiscible
1979	Statfjord	Statoil	NORWAY	HC Miscible
1979	Stratfjord	Statoil	NORWAY	HC WAG Immiscible
1983	South Brae	Marathon	UK	HC WAG Miscible
1983	Magnus	BP	UK	HC WAG Miscible
1986	Gullfaks	Statoil	NORWAY	HC WAG Immiscible
1987	Alwyn North	Total	UK	HC Miscible
1992[5]	Snorre	Statoil	NORWAY	HC WAG Miscible
1992	Snorre A (CFB)	Norsk Hydro	NORWAY	HC FAWAG
1992	Snorre A (WFB)	Norsk Hydro	NORWAY	HC FAWAG
1993	Brage	Norsk Hydro	NORWAY	HC WAG Immiscible
1999	Smorbukk South	Statoil	NORWAY	HC Miscible
1999	Oseberg	Norsk Hydro	NORWAY	HC WAG Immiscible
1999	Siri	Statoil	DENMARK	HC SWAG[6]

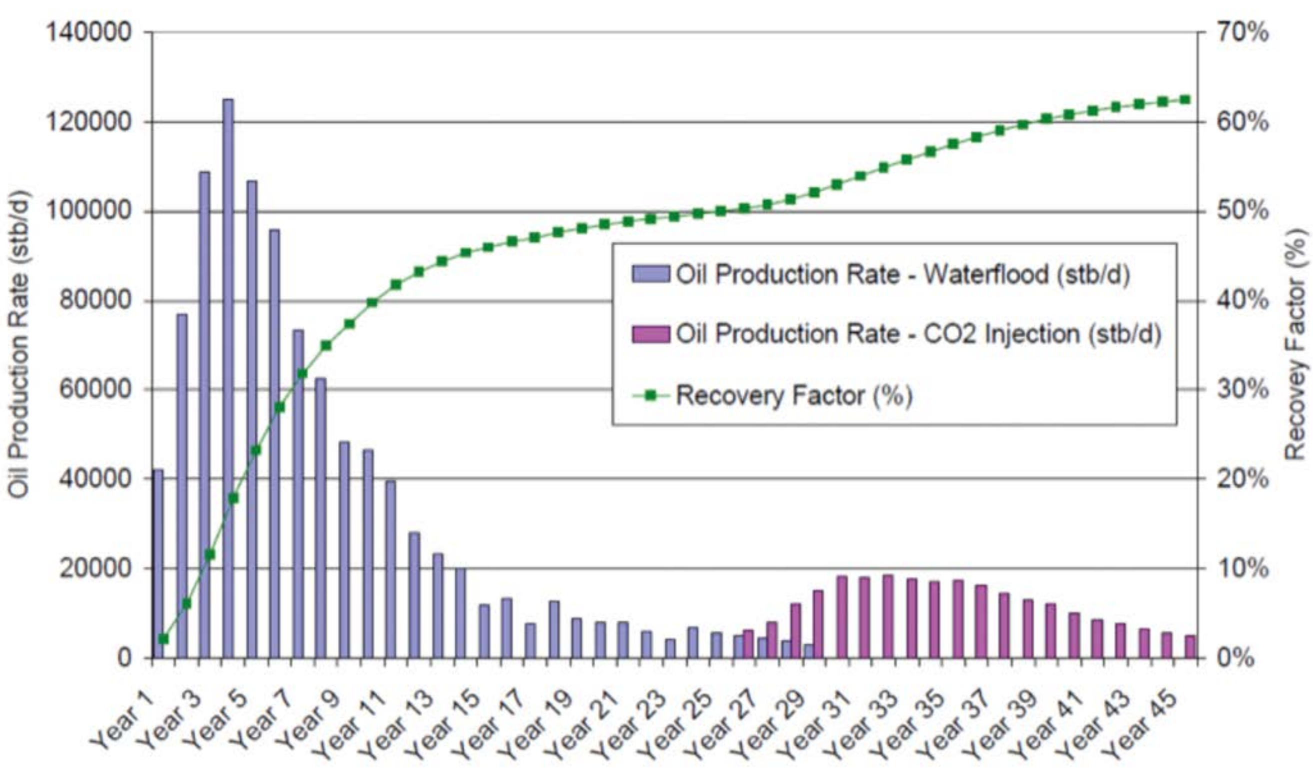
[3] Not currently operational
[4] In blowdown phase; not EOR project
[5] The Norwegian carbon tax was introduced in 1991
[6] Principally a gas-storage project

After completing a technical study, the operator estimated that CO_2 flooding at Draugen would provide only modest volumes of additional oil recovery and, without incentives or financial support for CO_2 capture, the modest additional oil would not justify the cost of storing CO_2 with CO_2-EOR. The CO_2-EOR project required retrofitting production wells, drilling six new subsea wells to target the flanks of the oil field, and building a CO_2 pipeline. In addition, the platform (and thus oil production) needed to be shut down for a year, further increasing the financial impact of the project.

Although the Draugen Project was deemed to not be commercially viable, Shell and Statoil did determine that it was technically feasible. Today's environment, with current low oil prices, still make future CO_2-EOR projects in North Sea oil fields economically uncertain, despite the improvement of CO_2-EOR technology and the incentives to capture CO_2.

- **Don Valley Project.** The recently formed company, 2Co Energy, proposed an innovative CO_2-EOR project involving capturing CO_2 from the Don Valley IGCC power plant and transporting the CO_2 300 km offshore to improve oil recovery and store CO_2 in two mature oil fields in the Central North Sea. Two offshore storage options were studied: the potential use of Talisman Energy Ltd's central North Sea oil fields for enhanced oil recovery (EOR), as well as deep saline formations in the southern North Sea. The offshore EOR/Storage feasibility study was completed as well as the final decision to use the saline storage site known as 5/42. In the summer of 2013 drilling appraisal was undertaken on this site. Initially, the Don Valley Project was named by NER300[7] (the new entrants' reserve), a €4.4 billion fund created by the European Commission to finance low carbon technologies, as a top prospect. However, the UK government did not pledge financial support for the

Figure 14. Typical CO_2-EOR Response in North Sea Oil Field



[7] According to the EU Emissions Trading System provisions for CCS schemes, in order to provide further incentives for the development of CCS projects, the Revised ETS Directive provides that up to 300 million EUAs (EU Allowance Unit of one tonne ofCO2) in the new entrants' reserve (NER) were made available until 31 December 2015 to help stimulate the construction and operation of up to 12 CCS demonstration projects

project, making the project ineligible for NER300 funding. The UK government cited the Don Valley Project's £5 billion price tag including (£1 billion for offshore facilities, £3 billion for the power plant with CO_2 capture) as a main reason for their decision. 2Co is currently studying the economic feasibility of moving forward without governmental funding.

- **Miller Oil Field.** BP had defined a program to capture CO_2 from the Peter head gas-fired power station, storing the CO_2 with CO_2-EOR in the Miller offshore oil field. The project failed to receive government support and the Miller oil field is now abandoned.
- **Danish Oil Fields.** Maersk Oil submitted a plan to the EU for capturing of CO_2 from an oil refinery and transporting the CO_2, by ship, to oil fields in the Danish sector of the North Sea. This project is currently also on hold.
- **Tees Valley.** Progressive Energy also submitted a proposal to the EU involving the construction of a new IGCC power station with pipeline transportation of the captured CO_2 to Central North Sea oil fields for CO_2-EOR. This project is currently also on hold.

CO_2-EOR Offshore Abu Dhabi

The Marine Operating Unit of Abu Dhabi National Oil Company (ADNOC) has begun to examine the viability of injecting CO_2 into its offshore fields to improve oil recovery. Currently about 5 Bcfd of natural gas is injected to enhance oil recovery from the Abu Dhabi oil fields and ADNOC is looking to replace the hydrocarbon gas injection with CO_2.

In 2010, ADNOC initiated a feasibility study to determine the commercial viability of CO_2 flooding in the low permeability Lower Zakum field off the coast of Abu Dhabi. Talks are underway between ADNOC and Masdar, an Abu Dhabi renewable energy technology company, to capture 800,000 metric tons of CO_2 per year from a steel plant in Mussafah, UAE and use this CO_2 for enhanced oil recovery. ADNOC then completed a successful two year CO_2-EOR pilot in the onshore Rumaitha field (injecting 1.2 Mcfd). The company plans to build upon its onshore EOR experience to implement CO_2-EOR in its offshore Persian Gulf oil fields to help achieve its goal of increasing oil production to 3.5 Mbpd from its current level of 2.8 Mbpd.

In October 2014, the Dubai-based Dodsal group won a Dh450 million contract to build a CO_2 compression facility and a 50-kilometre pipeline. Abu Dhabi also has rising local demand for gas and would like to replace its use in the energy sector with CO_2 to free it up for commercial uses. The emirate has one of the world's highest carbon footprints and would like to cut its emissions.

According to ref. [12], the Abu Dhabi CCS project completion is set for Q2 of 2016.

CO_2-EOR Offshore Vietnam

The only offshore CO_2-EOR application using anthropogenic CO_2 is in Rang Dong field, offshore Vietnam.

In 2007, a Joint Venture with Vietnam Oil and Gas Group (PETROVIETNAM), Japan Vietnam Petroleum Co., Ltd. (JVPC), and Japan Oil, Gas and Metals National Corporation (JOGMEC) completed a feasibility study that indicated that CO_2 injection into the oil fields in the South China Sea would increase oil recovery efficiency by 6.4% of oil initially in place compared with water flooding with a utilization efficiency of 3.4 incremental barrels per tonne of CO_2 injected (5.55 Mscf/stb) and would therefore provide storage for CO_2. To confirm the feasibility study's findings, the companies conducted a small scale CO_2 injection pilot test in June 2011. The pilot test consisted of a CO_2-EOR "Huff 'n' Puff" operation in the Rang Dong oil field, located 135 miles south-east of Vung Tau in Block 15-2 of the Cuu Long Basin. The pilot project was operated by JVPC with support from PETROVIETNAM and funding from JOGMEC.

The CO_2 was trucked by road to VungTau (163 tonnes) from a fertilizer plant near Hanoi. Then it was transported by ship to the Rang Dong oil field.

In 2012, the companies declared the pilot test had successfully confirmed the main objectives of the pilot – adequate CO_2 injectivity and increased oil production.

Three stage treatment:

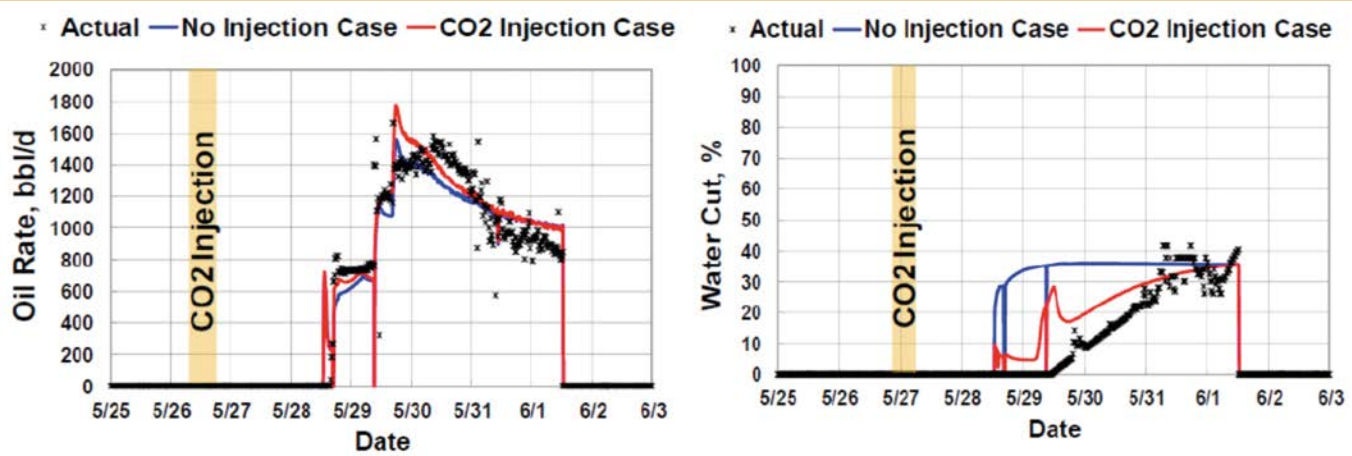
- Establish pre-test flow rate then log saturation profile (RST)
- Inject CO_2 (111 tonnes) over 7 hours, leave to 'soak' then log
- Flow well then log

The following facts were observed:

- Bottom-Hole Pressure ~3300 psia
- Minimum Miscible Pressure ~2980 psia
- Swelling and viscosity reduction mechanisms observed
- Oil rate increased from 950 to 1500 stb/d
- Water cut reduced from 50-60% to near zero
- 214 incremental stb of oil
- Utilization 1.9 incremental stb per tonne of CO_2 (or 9.8 Mscf/stb)
- Pre and post injection logging indicates saturation reduction

Reference [12]. Masdar – CCUS Project, Abu Dhabi – 2016

Figure 15. Rang Dong Oil field CO2-EOR data (ref. [18])



CO_2-EOR Offshore Malaysia

Petronas publicly announced that two-thirds of the country's original oil in-place of 17 billion barrels is at risk of being stranded (after completion of primary/secondary recovery) without implementation of advanced EOR (see ref. [11]).

Based on this, starting in November of 2002, Petronas initiated a four year CO_2-EOR pilot in the Dulang oil field. The oil field is located 130 km offshore from Terengganu, eastern Malaysia, in 250 feet of water. The offshore oil field is one of Malaysia's largest with 1.1 billion barrels of OOIP and an estimated primary/secondary recovery of 328 million barrels, including the use of water injection to combat falling reservoir pressure. The field's produced gas contains a high concentration of CO_2 (>50 percent).

Petronas determined that Dulang's initial reservoir pressure was nearly 1,000 psig below minimum miscibility pressure (MMP), ruling out miscible or near-miscible gas injection. As such, the company decided to conduct a pilot immiscible water-alternating-gas (IWAG) flood that would re-inject the CO2-rich produced gas back into the reservoir. The EOR pilot consisted of 3 producers and 3 injectors in the S3 Block of the Dulang Field. Petronas injected 4 Mcfd of CO_2 and 3.5 Mbpd of water in cycles lasting 3 months each.

After four years of operation, the IWAG EOR Pilot was terminated in 2006 and deemed a success by Petronas. The operator concluded that the offshore IWAG EOR Pilot was operationally manageable, significantly increased oil production, and reduced the water cut.

Reference [11]. PETRONAS – Flow Vol. 3 – 2015
Reference [18]. IEA Collaborative Project on Enhanced Oil Recovery – Study on Applicability of CO_2-EOR to Rang Dong Field, offshore Vietnam – 2009

Figure 16. Offshore oil fields, Malaysia

Field wide application of an IWAG flood was recommended, but has yet to be implemented.

More recently, Petronas signed two new production sharing contracts (PSCs) in 2011 with Shell Malaysia for evaluating thirteen EOR projects offshore Sarawak and Sabah, looking to increase average oil recovery in the fields from 36 percent of OOIP to 50 percent of OOIP, according to Shell.

Offshore CO_2-EOR Opportunities

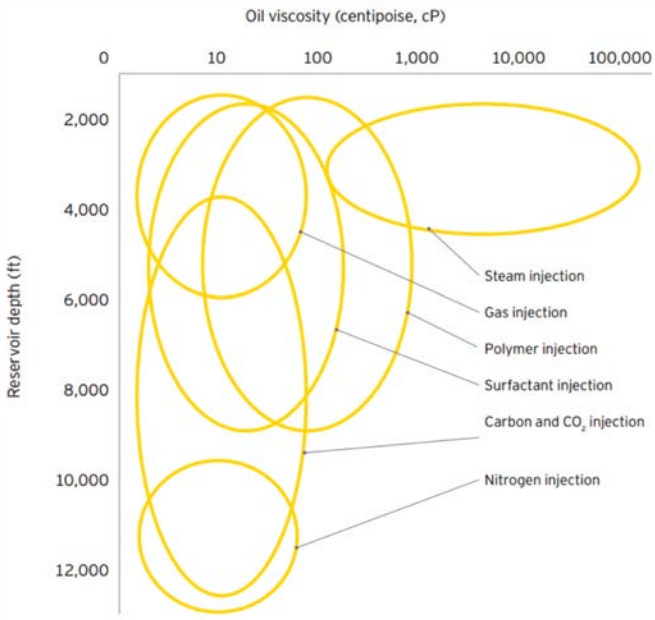
CO_2 EOR Challenges

Based on the information exposed above, it can be stated that the offshore CO_2-EOR Offshore faces the following challenges:

Project viability

Implementing an EOR project is a long and complex process given the advanced nature of the techniques as well as the uncertain nature of the tertiary production phase.

Figure 17. EOR methods and related technical factors (ref. [13])



Source: Enhanced Oil Recovery (EOR) Report, Royal Dutch Shell.

Reference [13]. Ernst & Young – Enhanced oil recovery (EOR) methods in Russia – time is of the essence 2013

Table 3. Criteria governing the potential use of an EOR method (ref. [13])

Method	Density (kg/cubic m)	Remaining recoverable reserves (% of initial recoverable reserves)	Rock type	Depth (m)	Permeability (mD)	Temperature (°C)	Expected extra ORF (%)
Nitrogen injection	>850	>40	Carbon	>2,000	190	–	n/a
Hydrocarbon injection	>904	>30	Carbon	>1,350	–	–	20 – 40
CO_2 injection	>904	>20	Carbon	>700	–	–	5 – 25
Polymer injection	>966	>70	Sand	<3,000	>10	<95	5 – 30
Surfactant injection	>946	>35	Sand	<3,000	>10	<95	5 – 30
Thermal/combustion under rapid oxidation	>1,000	>50	Sand	>50	>50	>40	n/a
Thermal/steam injection	>1,014	>40	Sand	<1,500	>200	–	10 – 60

Source: International Energy Agency.

Regarding CO_2 injection, there is a limited CO_2 supply at present except for fields where CO_2 amounts in associated gas are high enough (Lula field, Brazil). However significant quantities are likely to become available on 5-10 year timescale (i.e. early to mid-2020's) especially after COP21 in Paris whose measures are to be implemented from 2020 onwards.

In terms of brownfield opportunities the secondary recovery factor in shallow waters is already quite high (even up to 60%) therefore the target is smaller and may not be suitable if CO_2-EOR modules are not put in place before fields become too mature. All in all, existing facilities are usually incompatible with high CO_2 content in fluids (corrosion issues, etc.), and there is limited room for additional weight or space for new facilities.

Implementation (Capital Expenditure)

Offshore CO_2-EOR entails some capital expenditures compared to onshore, which need to be considered:

- CO_2 reception facilities and controls (compression modules, etc.)
- Flow lines to injectors (CO_2 and water) and control valves
- Gas/liquid separation facilities capable of handling high content CO_2 in produced fluids
- Separation of CO_2 and hydrocarbon gas (or just separate enough for fuel gas)
- Dehydration and compression of produced gas for reinjection (increasing CO_2 content in produced gas)
- Start-up CO_2 pumps
- Production well tubing needs to be replaced with CRA materials (to deal with produced CO_2)
- Baseline measurements for subsequent monitoring

Reference [13]. Ernst & Young – Enhanced oil recovery (EOR) methods in Russia – time is of the essence 2013

Figure 18. EOR cost components (ref. [14])

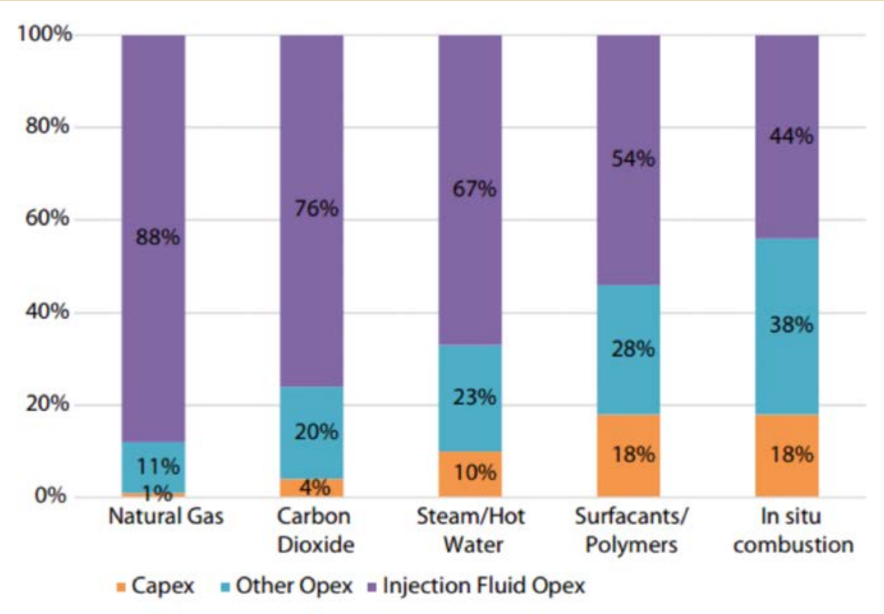
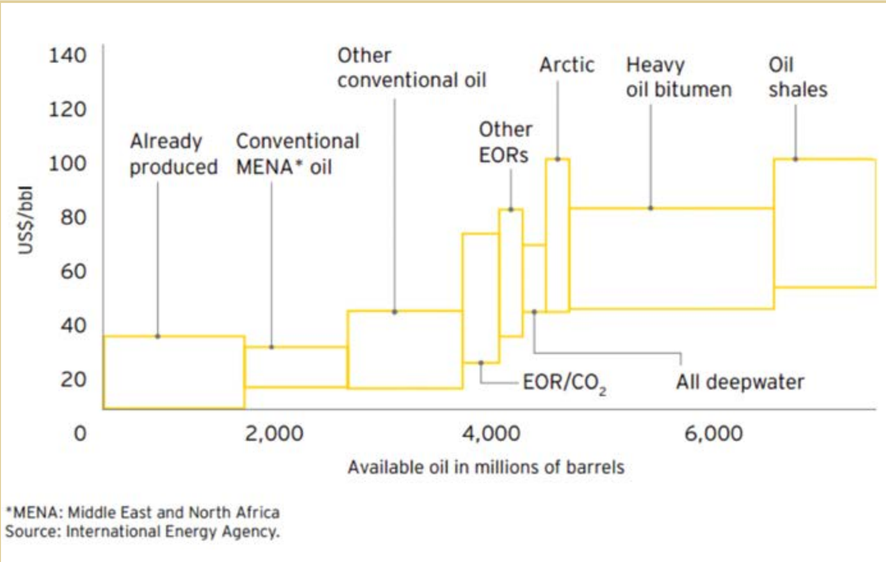


Figure 19. Typical oil production costs (ref. [13])



Offshore CO_2-EOR next steps

Four important "next steps" could help the offshore industry address the above key challenges:

1. Royalty Reductions

Royalty reductions for storing CO_2 with EOR in shallow and deep water oil fields could serve as incentive for accelerated application of CO_2-EOR technology. This is the case, for instance, on the Norwegian Continental Shelf where a carbon tax (upper cap of approximately $58[8] per tonne of equivalent CO_2) is levied from all the Oil and Gas activities.

2. Flagship Offshore CO_2-EOR Projects

Nothing beats "learning-by-doing". So there is an urgent need for offshore CO_2-EOR projects in regions where nothing has been done yet. The focus would be on learning and cost reductions with the results shared with the offshore industry.

3. Advanced Subsea Technology for mature fields

There is need for continued sponsorship of research for improving subsea technologies essential for deep water CO_2-EOR. Especially for brownfield projects where there are weight, space and power limitations.

4. Affordable CO_2 supplies

The offshore CO_2-EOR industry would benefit greatly from investments in advanced CO_2 capture technologies that reduce the cost of capturing CO_2 emissions and expand the supply of CO_2.

Reference [13]. Ernst & Young – Enhanced oil recovery (EOR) methods in Russia – time is of the essence 2013
Reference [14]. Sevin & Capron. Seizing the EOR opportunity – Schlumberger Energy Perspectives – 2013

[8] Upper cap of the Norwegian carbon tax is NOK500 being approximately USD58 as of February 2016

Conclusions

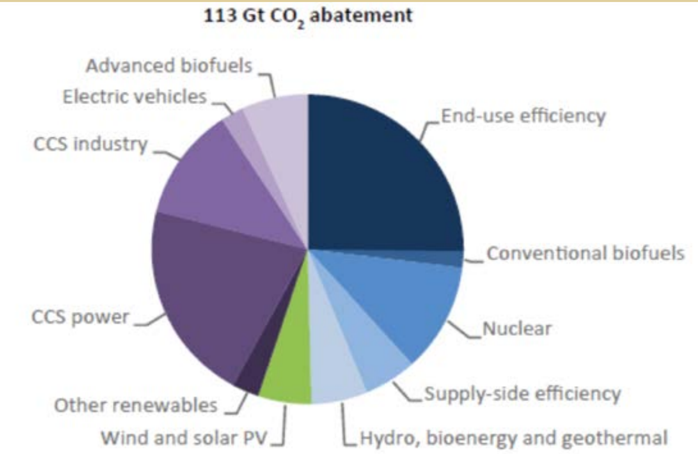
So, what the future holds for offshore CO_2-EOR and CCS is controversial considering the current scenario (low oil price, inexistent offshore carbon policies and availability of other EOR techniques with higher recovery factors). The Major Oil and Gas companies' position (see letter from June 2015 in ref. [5]) and the resolution from the COP21 held in Paris in December 2015 (ref. [6]) suggests that different carbon pricing measures might be applied worldwide in the medium/long term (2020 onwards); meaning that fossil fuels (even natural gas) would eventually need to be backed by CCS technologies which can lead to a potential need for CO_2 offshore storage and thus trigger offshore CO_2-EOR.

The following text is extracted from the EU's Energy Roadmap 2050 in ref. [3]:

"If carbon capture and storage (CCS) is available and applied on a large scale, gas may become a low-carbon technology, but without CCS, the long-term role of gas may be limited to a flexible backup and balancing capacity where renewable energy supplies are variable. For all fossil fuels, carbon capture and storage will have to be applied from around 2030 onwards in the power sector in order to reach the decarbonisation targets. CCS is also an important option for decarbonisation of several heavy industries and combined with biomass could deliver 'carbon negative' values. The future of CCS crucially depends on public acceptance and adequate carbon prices; it needs to be sufficiently demonstrated on a large scale and investment in the technology ensured in this decade, and then deployed from 2020, in order to be feasible for widespread use by 2030"

The International Energy Agency (IEA) in ref. [2] provides the following information for CO_2 abatement considering their 450 Scenario.

Figure 20. Global cumulative CO_2 emissions reductions by measure 2015-2040 ref. [2]



In terms of offshore CO_2-EOR, it seems that it may provide a viable path for the future, provided that:

- Supply of CO_2 is (in all probability) developed from national CCS programs
- Initial CCS projects are planned for storage only, but proximity and availability of CO_2 provide opportunities for EOR initially possible in the smaller/medium sized fields
- Offshore reservoirs are found a safe place to store the capture CO_2 after field abandonment
- If successful and prompt installation, redevelopment of mature fields may occur
- CO_2-EOR decisions are made at an early stage of concept development for newly discovered fields
- New specialist CO_2 operators emerge
- Once EOR phase is complete there is still some extra opportunity to store additional CO_2
- Adjustment of carbon pricing regime takes place to make offshore EOR economic
- Regulation around CO_2 storage (over and above Oil & Gas regulations) does not become a significant burden

Reference [2]. IEA – World Energy Outlook 2015
Reference [3]. EU – Energy Roadmap 2050 – 2012
Reference [5]. Major Oil Companies Letter to UN – UNFCCC http://newsroom.unfccc.int/unfccc-newsroom/major-oil-companies-letter-to-un/
Reference [6]. Adoption of the Paris Agreement - https://unfccc.int/resource/docs/2015/cop21/eng/l09.pdf

Nomenclature

Bcfd: Billion cubic feet per day

BIGCC: Biomass Integrated Gasification Combined-Cycle

CCS: Carbon Capture and Storage

CRA: Corrosion Resistant Alloy

EOR: Enhanced Oil Recovery

ETS: Emissions Trading System

FAWAG: Foam Assisted Water-Alternating-Gas

FPSO: Floating Production Storage and Offloading unit

IGCC: Integrated Gasification Combined-Cycle

IRCC: Integrated Renewables Combined-Cycle

Mbpd: Million barrels per day

Mcfd: Million cubic feet per day

OOIP: Original Oil-In-Place

RST: Reservoir Saturation Tool

Stb: Stock tank barrel

SWAG: Simultaneous Water-Alternating-Gas

UNFCCC: United Nations Framework – Convention on climate change

WAG: Water-Alternating-Gas ■

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Research of Cybersecurity at Oil and Gas Industry

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Key Words:
Oil & Gas, cybersecurity, cyberattacks, IT, OT.

Abstract:
Cybersecurity is the set of technologies, procedures, processes and services intended to protect assets depending in any way on an Information or Operational Technology platforms. In the Oil & Gas industry technology is present in every part of the value chain. Some of the most critical infrastructures, pipelines and operations are now being controlled by digital networks. For Oil &Gas companies, cybersecurity is no longer merely an information risk but a corporate responsibility.

Cyber-attacks in IT (Information Technology) have different targets: data bases, mobiles, iPads, Cloud, Wi-Fi, USB devices, radio control… On the other hand, Operational technology (OT) covers another important part of the company technology such as sensors, SCADA systems, software and other controls that operate pipelines, power plants, and transmission and distribution grids. Cyberattacks imply considerable costs. The estimated average financial losses per company attributed to cybersecurity incidents within the oil and gas sector is $4M.

The new security models address the convergence of operational technology (OT) and information technology (IT). Yet Oil & Gas companies continue to rely on compliance with outdated policies and guidance. IT, OT, networking and physical security still act as islands, thus exposing weaknesses to potential attackers.

This paper analyses the cybersecurity situation in Oil & Gas industry, the cyberattacks occurred, and how the companies faced them, as well as summarizes the current Regulation in the European Union and the USA. Based on this analysis, this paper tries to predict the scope of cyber security in the Oil & Gas sector in the coming years: how cybersecurity will evolve and how cyberattacks will be.

Introduction

Nowadays, Information Technology is present in every company of every sector. IT helps companies to improve services, optimize processes and increase profits. However, this IT dependency turns the industry into a vulnerable industry. It is one of the main concerns of the companies, to be protected against cyber-attacks. In fact, the cyber-crime is on the top 10 of business risk, according to the Allianz Risk Barometer 2015:

The Allianz Risk Barometer 2015 survey was conducted among global businesses and risk consultants, underwriters, senior managers and claims experts. There were a total of 516 respondents from a total of 47 countries.[1]

Oil & Gas industry is not an exception. Oil & Gas companies have a high dependency on Information Technology, and every indicator shows that this is a growing trend. IT is present in every part of the oil value chain, from geophysics data acquisition on the exploration side of the business to financial information of the companies. This situation, in addition to the fact that Oil & Gas is an strategic sector in the global economy, makes Oil & Gas companies a cyber-attacks target. It's an unavoidable duty of companies, to have their IT system well protected.

State of the art

Recent History of Cybersecurity in the Oil and Gas Industry

Today, the increase of frequent and visible cyber events (computer viruses, network denial of service attacks, cybercrime, malicious insiders, etc.) has made cyber a 'top of mind' issue in society.

The widespread use of digital devices in business has created a suitable environment for cyber espionage and deployed malware to steal corporate data.

These "unmasking" may result in the loss of confidence in the services and global corporations as well as in the emergence of the idea of global services analogues, but within the boundaries of the states.

Employees are the favorite target of cybercriminals. Malicious correspondence is sent primarily to those of of Public Relations and Human Resources.

In May 2013, hacking group Anonymous announced its intention to throw security attacks against the oil & gas sector. The main objectives of such attacks were companies in the oil industry, telecommunications, scientific research, aerospace and other fields related to the development of high technologies. For that reason, European Union started a new and advantage strategy.

The highest percentage of cyber-attacks take place in the energy sector, 32%, well above the industrial one (27%), Health (15.6%), Telecommunications (14.6%), Public Administration (13.5%) or financial sector (3.1%) [2].

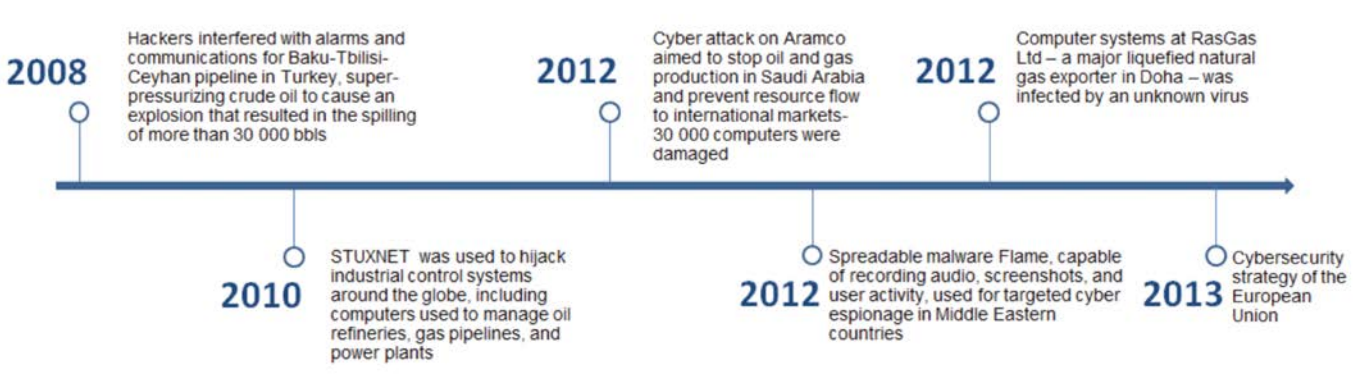
Oil and gas networks can be especially likely to suffer from internal incidents as many devices in such networks run 24 hours a day, seven days a week, and often lack the security updates and antivirus tools required to protect them against vulnerabilities. Adversaries are definitely taking advantage of this characteristic.

Figure 1. Top business risk 2015 Source: Allianz Risk Barometer

			2014 Rank	Trend
1	Business interruption and supply chain	46%	1 (43%)	-
2	Natural catastrophes	30%	2 (33%)	-
3	Fire/explosion	27%	3 (24%)	-
4	Changes in legislation and regulation	18%	4 (21%)	-
5	Cyber crime, IT failures, espionage, data breaches	17%	8 (12%)	▲
6	Loss of reputation or brand value (e.g. from social media)	16%	6 (15%)	-
7	Market stagnation or decline	15%	5 (19%)	▼
8	Intensified competition	13%	7 (14%)	▼
9	Political/social upheaval, war	11%	18 (4%)	▲
10	Theft, fraud, corruption	9%	9 (10%)	▼

1.Top business risk 2015 ,ALLIANZ 2015
2 US ICS-CERT (Industrial Control Systems Cyber Emergency Response Team).2014

Figure 2. Recent Cybercrime events.



Source: Internal Analysis

The state of the oil and gas industry is more perilous than ever, and energy and utilities companies must take new steps to defend themselves from cyber-attacks.

In 2014, the number of security incidents detected in the Oil and Gas sector in US was lower than in the power and utilities one. However, the estimated average financial losses per company attributed to security incidents within the oil and gas sector was $4M while in the power and utilities sector, it was $1.2M.

The threat of cyber-attacks is real but the oil and gas industries and utilities sector do not seem to be spending an important amount of money to face it. According to PwC, companies in the utilities industry spend an average of $3.7M per year on information security while oil and gas firms spend $5.7M annually on average. [3]

Experts from multinational companies say that thanks to the fact that infrastructure and IT systems are similar everywhere, the US data can be extrapolated to other Western countries, such as Spain, with similar technological development, attacks on the Internet or theft of confidential information's management, as, indeed, on the Internet there are no boundaries.[4]

The British government estimates that oil and gas companies in the UK have already lost ~GBP400M per year as a result of cyber-attacks. [5]

Table 1. Impact of Security Incidents in the Energy Sector

	O&G Sector	Power & Utilities Industry
Number of security incidents	5.493	7.391
Financial losses on average	$4 Million	$1.2 Million
Information Security spend	$5.7 million annually	$3.7 million annually
Spend onIntrusion-detection tools	64%	55%

Source: PWC

[3] PwC. "The Global State of Information Security Survey 2015"
[4] Energy News. Enrique Martin GMV ,2014
[5] Cyber-attacks: Effects on UK Companies. Oxford Economics July 2014
[6] RIS: Repository of Industrial Security Incidents, 2011

Type of incidents at the Oil & Gas Industry

The Repository of Industrial Security Incidents contains a database of cyber-security incidents that have affected process control, industrial automation or Supervisory Control and Data Acquisition (SCADA) systems. This information for the Oil industry has been recorded since 1992 and EEUU accounts for almost 40% of it.[6]

Table 2. Incidents in Oil & Gas Industry

Title	Year	Country
CIA Trojan Causes Siberian Gas Pipeline Explosion	1982	Russian Federation
Oil Company SCADA System Impacted by RF Interference	1989	United States
Olympic Pipeline Rupture and Subsequent Fire	1999	United States
Hacker Takes Over Russian Gas System	1999	Russian Federation
Accidental Remote Uploading of PLC Program	2000	Canada
Code Red Worm Defaces Automation Web Pages	2001	United States
Electronic Sabotage of Petroleum Company's Gas Processing Plant	2001	United States
Anti-Virus Software Prevents Boiler Safety Shutdown	2001	United States
Virus Infection of Operator Training Simulator	2002	Canada
Electronic Sabatoge of Venezuela Oil Operations	2002	Venezuela
Whitehat Takeover of DCS Consoles	2002	Canada
Control System Infected with SQLslammer Worm	2003	Unknown
Blaster Infects Onshore Oil Production Control System	2003	United States
Virus/Worm Infects New Oil Platform	2003	Norway
MUMU Infection of Operator Training System	2003	United States
MUMU Infection of Fiscal Metering System	2003	United Kingdom
MUMU Infection of Leak Detection System	2003	United Kingdom
Welchia Worm Infects Automation Network	2003	United States
SQL Slammer Impacts Drill Site	2003	United States
Slammer Impacts Offshore Platforms	2003	United States
Slammer Infected Laptop Shuts Down DCS	2003	United Kingdom
Telco Shuts Off Critical SCADA Comms	2003	Canada
Worm attack on Drilling Control system	2004	United Kingdom
Sasser Worm Infection in Process Control System.	2004	United Kingdom
Two Viruses Cause Near Miss With Process Control Networks (PCN) in Africa	2004	Chad
Ping Sweep Caused DOS on PCN Firewall	2005	United Kingdom
Hacker Disabled Offshore Oil Platforms	2008	United States
Refinery Explosion and Fire Caused by Non-Functioning Computerized Level Monitoring System	2009	United States
Trans-Alaska pipeline spill	2010	United States
Computer Glitch Prevents Return of Gas Service	2011	Israel
Shamoon virus knocks out computers at Qatari gas firm RasGas	2012	Qatar
Process Control Network Infected with a Virus	2012	
Gas Company Virus Infection	2012	
Computer Virus Targets Saudi Arabian Oil Company	2012	Saudi Arabia

Source: RIS

[6] RIS: Repository of Industrial Security Incidents, 2011

Table 3. Industry Threats

Threat Source	Percentage of industrial network incidents	Incident Type	Location of Source
Hackers and terrorists	9.4%	Intentional	External
Malware	30.4%	Unintentional	External
Insiders	10.6%	Intentional	Internal
Human Error	11.2%	Unintentional	Internal
Device and software failure	38.4%	Unintentional	Internal

Source: Repository of Industrial Security Incidents, 2011

Incidents have happened everywhere and in all the areas of the oil industry value chain, from drilling and exploration systems to computers at headquarters.

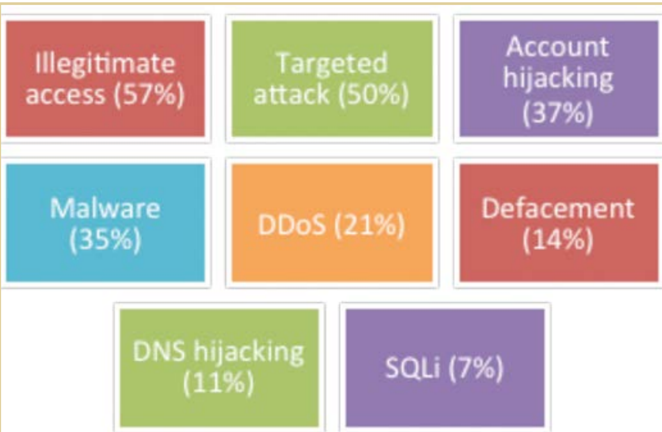
Most cybersecurity threats and incidents are unintentional and occur within industrial networks. In the next table there is a summary of the main threats per incident.

Industry research shows that internal – not external – sources make up more than 60% of all cybersecurity threats.

Some recent studies have evaluated which are the attack techniques that oil and gas companies are most concerned about, and the result is in the figure 3 shows that the Illegitimate access it is the most important in companies.[7]

Nowadays it is important to know what would be the main prime concern if a mayor cyber intrusion was to occur. figure 4 represents the result of a recent survey where the system downtime it is the main prime concern.

Figure 3. Recent Cybercrime events



Source: Oil & Gas iQ

Figure 4. Cyber intrusion preoccupation

Source: Oil & Gas iQ

[7] Oil & Gas iQ , 2014

Incidents Scope

The scope of the incidents covers a wide range of threats and focuses on seeking access to IT infrastructure, both business and control systems, including the following methods among others:

- Access to and use of the Internet facing devices data acquisition (SCADA) ICS / Supervisory Control and unauthorized
- Zero-day vulnerabilities in control system devices and software
- Infections of malware in networks control system with air holes
- SQL Injection by exploiting vulnerabilities in web applications
- Network scanning and probing
- Lateral movement between network areas
- Campaigns targeted spear-phishing; doing a bad advertisement of security of the company. Bad Brand reputation
- Strategic Website compromises; key names, contacts

Most of the incidents are classified as having an "unknown" access vector. In such cases, the organization confirmed their compromise; despite this, forensic evidence does not point to a method of intrusion because of the lack of detection and surveillance capabilities within the network compromised.

Cybersecurity Solutions

Oil companies should feel that their systems are beyond the reach of attackers. Cybersecurity is becoming an increasingly prevalent threat within modern day business and operations. There is an ongoing digitalization in operations and services resulting in more vulnerability within the organization's framework. With some of the most critical infrastructure, pipelines and operations now being controlled by digital networks, Cybersecurity is no longer merely an information risk but a corporate responsibility.

With cyber-attacks becoming more sophisticated, targeted and malicious, many factors will play a crucial role to favor an organization's ability to prevent, detect, respond and mitigate a breach. The monitoring and surveillance centers are useful to acquire greater expertise while sharing the cost of tools and equipment in all technologies.

Cybersecurity could be grouped as a set of technologies, procedures, processes and services intended to protect assets depending in any way on ICT platforms. New security models that address the convergence of operational technology (OT) and information technology (IT) seem to be the key. Yet oil & gas companies continue to rely on compliance with outdated policies and guidance. IT, OT, networking and physical security still act as islands, thus exposing weaknesses to potential attackers.

IT Technology

Since each industry has a different understanding and definition of terms, at oil and gas business IT can be defined as a widely part because of the amount of Terabytes of data that they already have.

For that reason, this part must have tools and solutions to defend and protect IT infrastructure and systems. IT assesses data such as those stored on servers, or sent by emails and stored on mobile devices and even information backed up on USB memory sticks.

Cyber-attacks in IT have different targets: data bases, mobiles, iPads, Cloud, wi-fi, usb devices, radio control systems…

The next list presents an example of companies and solutions to intercept attacks:

a) Symantec – '*Symantec Enterprise Vault*' has already been used in the oil and gas business at ENPPI.
b) Fire Eye – A key product '*Network Threat Prevention Platform*' was used by the Energy Ministry of Saudi Arabia in 2011. It is based on detection and prevention of numerous attacks.
c) Palantir – '*Palantir Cyber*' provides enterprises with the unified view necessary to correlate incidents of cyber-attacks across data sources and monitor cyber threats in real time.
d) Splunk – '*Splunk software*' bases their use in investigation and incident response, complex correlation, proactive alerting and auto-remediation.
e) Fidelis – '*XPS, Resolution1 endpoint*' solutions help to detect, investigate and stop advanced attacker at every stage of the attack lifecycle.
f) INDRA -- 'COMSec' provides secure voice communications and data in commercial mobile devices over wireless.

OT Technology

On the other hand, Operational technology (OT) covers another important part of the company technology such as the sensors, SCADA systems, software and other controls that operate the pipelines, power plants, and transmission and distribution grids.

The following list provides an example of how companies and solutions intercept attacks in OT:

1) MICROSOFT -- '*Microsoft Upstream Reference Architecture*' Case Study: Chevron, PEMEX.
2) MOTOROLA -- It secures operations control, uncompromising security for the radio network, complete security services.
3) CISCO -- '*Cisco Secure Ops*' Solution .Case Study: Company that Produces 3M+ barrels of oil and natural gas daily and with more than 90,000 employees.
4) IBM -- '*Internet Security System*' offers solutions for identity and access management, security information and event management, database security, application development, risk management, endpoint management, next-generation intrusion protection.
5) N-DIMENSION -- '*N-Sentinel*', cloud-based managed security services that maintain continuous vigilance in the detection of cyber threats and vulnerabilities, helping critical energy infrastructures take time action in protecting their networks, data and assets from risks.
6) INDRA -- 'i-CSOC', cybersecurity operations center offers service lines of MSSP, Labs, Cyberintelligence, CSIRT, Training and Cloud.

Regulation

European Regulation

The beginning of the Cybersecurity policy in the European Union (EU) is in the joint communication of the Council and the Commission COM (2000) 890. Afterwards, different communications, documents and also norms of the corresponding institutions, have been issued in order to establish a common policy and regulation about cybersecurity.

On 23th of November 2011 in Budapest was signed the Convention on Cybercrime, Treaty No.185. Until now it is the most universal document about cybercrime. It is the only cyber treaty that aims at harmonizing universal rules of national criminal law and criminal prosecution of crimes related to Internet. It has been confirmed by USA and 23 European countries.

In relation to protection against cyberattacks, the EU has published several documents, like the COM (2006) 251 "Strategy for a secure information society" and the COM (2010) 245 "European Digital Agenda".

The EU also has focused on the protection of Critical infrastructures. The EU has developed the European Programme for Critical Infrastructure Protection (EPCIP). These critical infrastructures are the assets, facilities, systems, networks or processes that are essential for the security and the functioning of a society and economy.

Among others, the oil & gas sector, and specifically the gas production, transport and distribution as well as oil products production, transport and distribution facilities, are considered critical infrastructures. Based on EPCIP, each European country regulates the operations and fixes the requirements for operators of these infrastructures.

It should be noted the obligation of designing a cybersecurity plan that fulfills the standard security requirements, and the obligation of notifying when a cyberattack occurs to the nationals Computer Emergency Response Team (CERT). [8]

Nowadays, the two most recent and important documents are the Cibersecurity Strategy of the European Union of 2013, JOIN(2013) 1, and the Directive for Network and Information Security (NIS).

Cibersecurity Strategy of the European Union

The EU vision presented in this strategy is articulated in five strategic priorities, which address the challenges highlighted above:

- Achieving cyber resilience.
- Drastically reducing cybercrime.
- Developing a cyberdefence policy and capabilities related to the Common Security and Defence Policy (CSDP).
- Develop the industrial and technological resources for cybersecurity.
- Establish a coherent international cyberspace policy for the European Union and promote core EU values.

Directive for Network and Information Security (NIS)

The NIS Directive provides legal measures to boost the overall level of cybersecurity in the EU by:

- Increasing the cybersecurity capabilities in the Member States.
- Enhancing cooperation on cybersecurity among the Member States.
- Ensuring a high level of risk management practices in key sectors (such as energy, transport, banking and health).

Once adopted and implemented, the NIS Directive will benefit citizens, as well as government and businesses, who will be able to

[8] Computer emergency response team (CERT-EU) 2015

rely on more secure digital networks and infrastructure to provide their essential services at home and across borders. [9]

European agencies

The two main agencies of cibersecuriy in Europe are the European Union Agency for Network and Information Security (ENISA) and the European Cybercrime Centre (EC3).

ENISA was set up in 2004 and is the EU's response to the cybersecurity issues of the European Union. ENISA was set up to enhance the capability of the European Union, the EU Member States and the business community to prevent, address and respond to network and information security problems. In order to achieve this goal, ENISA is a Centre of Expertise in Network and Information Security and is stimulating the cooperation between the public and private sectors. As such, the Agency is a 'pace-setter'. [10]

The European Cybercrime Centre (EC3) was created in 2013 as part of Europol. The EC3 was set up to strengthen the law enforcement response to cybercrime in the European Union (EU) and to help protect European citizens, businesses and governments. Its establishment was a priority under the EU Internal Security Strategy.[11]

USA regulation

Recently Enacted Legislation:

- P.L. 114-113, Cybersecurity Act of 2015, signed into law December 18, 2015. Promotes and encourages the private sector and the US government to rapidly and responsibly exchange cyber threat information.
- P.L. 113-274, Cybersecurity Enhancement Act of 2014, signed into law December 18, 2014. Provides an ongoing, voluntary public-private partnership to improve cybersecurity and strengthen cybersecurity research and development, workforce development and education and public awareness and preparedness.
- P.L. 113-282, National Cybersecurity Protection Act of 2014, signed into law December 18, 2014. Codifies an existing operations center for cybersecurity.
- P.L. 113-246, Cybersecurity Workforce Assessment Act, signed into law December 18, 2014. Directs the Secretary of Homeland Security, within 180 days and annually thereafter for three years, to conduct an assessment of the cybersecurity workforce of the Department of Homeland Security (DHS).

USA agencies

USA has a solid structure to watch the national cybersecurity (Figure 5, next page):

The Office of Cybersecurity and Communications (CS&C), within the National Protection and Programs Directorate, is responsible for enhancing the security, resilience, and reliability of the Nation's cyber and communications infrastructure. [12]

It should be pointed the Department of Homeland Security, who is the responsible for protecting the Nation's critical infrastructure from physical and cyber threats. Cyberspace enables businesses and government to operate, facilitates emergency preparedness communications, and enables critical control systems processes. Protecting these systems is essential to the resilience and reliability of the Nation's critical infrastructure and key resources and to our economic and national security. As it was mentioned before, certain Oil & Gas infrastructures are considered critical and are under the cybersecurity regulation.[13]

Future trends

Cyber-attacks

According to the recent activities and incidents in terms of cyber-attacks, there are two main areas in which they will evolve in the next years: extortion and hacktivist.

Online Extortion

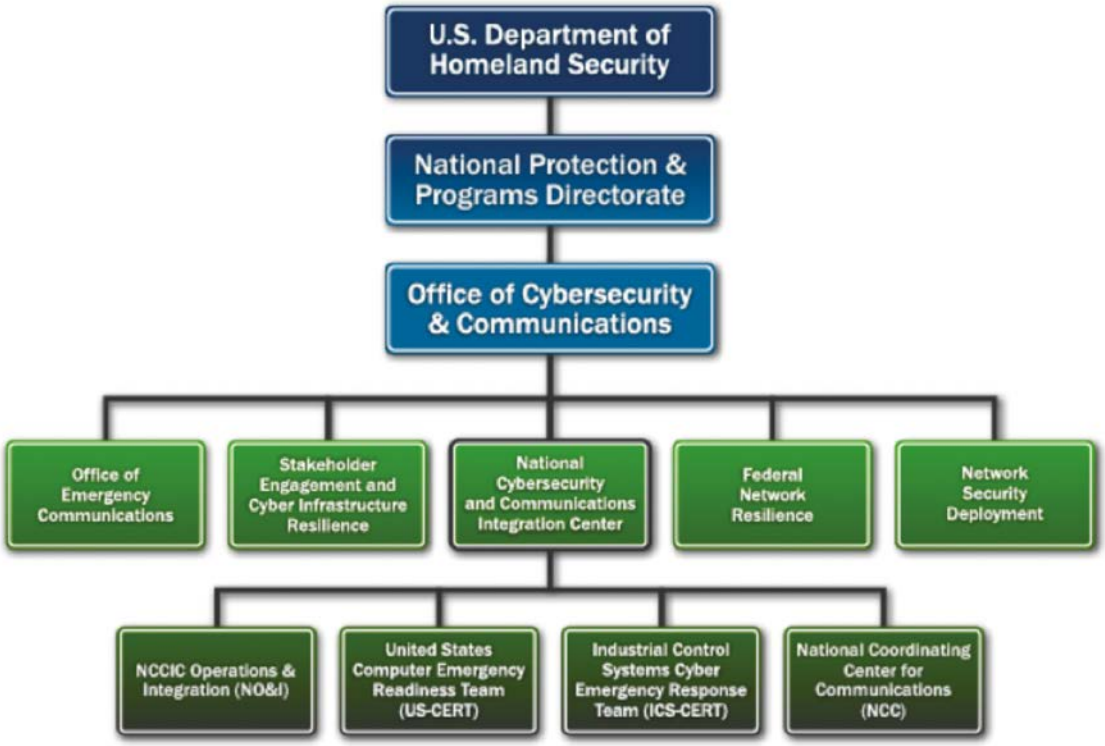
Instead mastering the technical aspects of the operation, online threats will evolve to master the psychology behind each scheme.

In the last 10 years, cyber extortionists made use of different tools:

- Ransomware is a type of malware that prevents or limits users from accessing their system. This type of malware forces its

[9] European Commission 'EU Strategies' Dec 2015
[10] European Union Agency for Network and Information security (ENISA) 2015 (website)
[11] Europol 'The European Cybercrime Centre (EC3)' 2013
[12] United States Computer Emergency Readiness Team (US-CERT) 2016
[13] Homeland security 'Office of Cybersecurity and Communications' October 27, 2015

Figure 5. USA structure of national cybersecurity



Source: USA Cert Gov website

victims to pay the ransom through certain online payment methods in order to grant access to their systems, or to get their data back. The ransomware tricks online users to make them fall for their tactics. This was done by exploiting one's fears to coerce victims into paying the ransom.

- The rogue/fake AV trap was set up to target those who feared computer infection. Earlier variants of ransomware locked screens of users, tricking them into paying to regain access.
- Crypto-ransomware, cybercriminals aimed for the most valuable part of one's system, the data.

Using these techniques, cyber extortionists will treat with damage the reputation of the entire enterprise or any of their employees. Reputation is everything, and threats that can ruin a business' reputation will prove to be effective and—more importantly— lucrative.

Another point is the use new social engineering lures. There will be a significant increase in tricks that use new social engineering lures. Using advanced ploys, the employees will be persuaded to transfer money to a cybercriminal-controlled account. These malicious schemes will be based on the knowledge of ongoing business activities and intercepting the communications between business partners, like the tactics used in the past by the cybercriminals behind the cyberattacks like Cuckoo Miner (active campaign against financial and banking institutions) or Predator Pain (malware use to steal information from victims' computers).

Hacktivists

Data breaches will be used to systematically destroy hacktivists' targets. In the next years, we will see more hacktivists going the route of "destructive" attacks by going for data that can potentially damage their target's integrity.

In the past, the hacktivist used default tactics like web defacement and DDoS attacks to ruin targets. However, the recent success of high-impact breaches, driven by a common goal of exposing incriminating information like questionable corporate practices, classified messages, and suspicious transactions will drive cybercriminals to add data breach methods to their arsenal of tactics.

Regulatory trends

Cybersecurity regulation will become a global movement. Governments and authorities will work together in order to act faster and give a rapid response to cyberattacks.

Cooperation and partnership among cybersecurity agencies will be key factor to struggle against cybercrime, as occurred in the combat against SIMDA in April 2015. SIMDA is the family of password-stealing trojans can give a malicious hacker backdoor access and control to the computers. They can then steal your passwords and gather information about the computer. It was necessary the common effort of different agencies and companies as INTERPOL or Microsoft, to takedown SIMDA.

The Internet hasn't had a solid regulation but, in the next years, will see a significant change in the attitude of governments and regulators that will suppose a strong regulation. Governments will be more active in protecting the Internet and safeguarding its users.

Future business investments

According to the security company Trend Micro, in the next years companies will reinforce their structure focusing on cybersecurity. Enterprises will finally realize the need for a job designation that focuses solely on ensuring the integrity of data within and outside the enterprise. Whether the company creates a separate Data Protection Officer (DPO), Chief Risk Officer (CRO) or includes this among the tasks of the Chief Information Security Officer (CISO) depends on company size, budget and other factors, but the set of responsibilities will be the same.

The iron cage put up by the EU Data Protection directive will mandate a high standard of protection on data and the role of the DPO/CISO will be vital in ensuring the integrity of data and compliance with rules and regulations of countries where company data is stored. DPOs and CISOs must be experts in data protection and data security regulations and must know how these should be effectively implemented.

Awareness around data protection will pave the way to a significant shift in the enterprise mindset and strategy against cyber-attacks. We will see more enterprises taking on the role of the 'hunter' instead of the 'hunted', in that they will begin to make use of threat intelligence and next-generation security solutions with custom defense to detect intrusions earlier. [14]

How should companies protect themselves?

It is globally estimated that cyber-attacks against oil and gas infrastructure will cost owners $1.87 billion by 2018. [3]

Application of international safety standards such as ISO 27001 standards will provide guidelines on which it will be possible to build a secure enterprise.

1. Know your critical assets – Identify your organization's business objectives and high-value assets, then lead risk assessments to find any vulnerability.

2. Protect your IT, radio network and OT environments – Establish defenses to block intruders before they reach your critical business assets, and educate your employees to recognize and avoid phishing attacks.

3. Detect potential threats before they occur – Use the right tools to get a comprehensive view of your security environment and monitor potential threats both externally and internally.

4. Respond and recover – With the speed and intelligence of many of today's cyber-attacks, cyber breaches may still occur, even in the most secure infrastructure. Having a contingency plan in place can help you respond immediately if a breach should occur.

5. Build a culture of Security – Cybersecurity practices are reflexive and excepted among all energy sector stakeholders.

In order to protect oil and gas operations, engineers and network designers must identify new cybersecurity measures. The following measures are designated to reduce cyber-security risk:

[3] PwC. "The Global State of Information Security Survey 2015"
[14] Trend Micro. 'The Fine Line. 2016 Trend Micro Security Predictions', 2015

Table 4. Measures to Reduce Cybersecurity Risk

#S1	#S2	#S3	#S4	#S5
• Adopting a framework.	• Defining the organization, roles, activities and responsibilities of cybersecurity.	• Making an inventory and classification systems from the point of view of cybersecurity.	• Analyzing and managing the risk. • Defining an incident management procedure.	• Including cybersecurity requirements in any project from the beginning.

#S6	#S7	#S8	#S9	#S10	#S11
• Raising awareness and creating culture related to cyber-security.	• Implementing perimeter defense systems..	• Forecasting cybersecurity audits.	• Monitoring and correlating events systems	• Collaborating actively in forums and specialized working groups in order to create a culture of security.	• Including cybersecurity requirements in any project from the beginning.

Vision and Barriers

By 2020, resilient energy delivery systems were designed, installed, operated, and maintained to survive a cyber-incident while sustaining critical functions.[15]

- Cyber threats are unpredictable and evolve faster than the sector's ability to develop and deploy countermeasures.
- Security upgrades to legacy systems are limited by inherent limitations of the equipment and architectures.
- Performance/acceptance testing of new control and communication solutions is difficult without disrupting operations.
- Threat, vulnerability, incident, and mitigated information sharing is insufficient among government and industry.
- Weak business case for cybersecurity investment by industry.
- Regulatory uncertainty in energy sector cybersecurity.

[15] U.S DOE 'Roadmap to achieve Energy Delivery Systems Cybersecurity', 2014

Conclusions

After the analysis of the current situation of cybersecurity and their influence in Oil&Gas industry, there arise different conclusions: the low companies concern about cybersecurity, the future stronger regulation and the real threat of cyberattacks and the cyberterrorism.

First of all, despite that cybercrime is a real threat, Oil&Gas companies are not concerned enough. The investment on that area are not very significant because is an inversion that doesn't have an economic return. It's an inversion to prevent against hypothetic cyberattacks and companies don't carry it out. Furthermore, cyberattacks are not usually published, so there is no clear and reliable information about how probably a cyberattack is.

In the same way, companies should invest money and time in a *cyberculture*. Building this formation in their employees they ensure prevention, anticipation and quickly intervention in order to make certain in a future attack. This culture must be integrated with governments focusing in the same common idea and trying to extend in all population.

On the other hand, it's important to take into account the regulation tendency. There is a clear tendency of increase and develop deeper the regulation about cybersecurity; especially for critical sectors. Without any doubt, Oil&Gas is a strategic sector for every country so earlier will have a specific regulation for this kind of companies. The regulation will request of how companies protect their data, the customer and user information and how they protect their system against cyberattacks. Governments will set the cybersecurity requirements for the companies that operate in their countries. Besides the IT systems and their cybersecurity of the shall be carefully audited by governmental agencies. In conclusion, a strong investment in cybersecurity will be unavoidable.

Also it's remarkable the threat of cyberterrorism. A cyberattack can produce a complete shutdown of an entire company that implies huge economic losses. Moreover, IT system control the security of several infrastructures as pipelines or refineries, a bad intentioned use of these tools can provoke material damage or even cost human life.

Acronyms

ICT: Information and communication technology

SCADA: supervisory control and data acquisition

DCS: distributed control systems

PLC: programmable logic controller

RTU: remote telemetry unit

DNS: Domain Name System

MSSP: Managed Security Services Provision

CSIRT: Computer Security Incident Response Team

DDoS (Distributed Denial of Service attack) is an attempt to make an online service unavailable by overwhelming it with traffic from multiple sources

SQLi (SQL Injection) it is one of the many web attack mechanisms used by hackers to steal data from organizations

Ransomware: is a type of malware that prevents or limits users from accessing their system. This type of malware forces its victims to pay the ransom through certain online payment methods in order to grant access to their systems, or to get their data back

Cuckoo Miner: is a currently active campaign against financial and banking institutions ■

Tuneable Task – Specific Surfactants for EOR under Different Salinity Ranges

Ana Estefanía Álvarez Álvarez y
Borja Rodríguez Cabo

Key Words:
EOR, Surfactant, Sulfonation, Tailor made

Abstract:
Nowadays, the demand of crude oil continuously increases. However, the findings of crude oil reservoirs are limited, and it becomes necessary to improve the oil production in the already known reservoirs. Chemical EOR has been shown as an effective alternative to meet this necessity. Nonetheless, the current economic situation worldwide and the decreasing trend of crude oil prices requires new processes and/or chemicals that could make the economic viability of EOR projects feasible.

In this work, the influence of two key sulfonation parameters (free oil and free sulfuric acid contents) on the compatibility and brine tolerance is shown. This could make LAS (Linear Alkylbenzene Sulfonate) surfactants versatile for different EOR projects, reducing the research, inversion in facilities and production costs, and conferring economic viability to the chemical EOR. Moreover, by selecting a suitable catalyst for production of the precursor, LAS with higher viscosity can be obtained. The polymer concentration (if used) of the final formulation would be reduced or eliminated, improving once more the economics of the process.

The impact of Shale, fundamentals and geopolitics on the crude oil imports mix: Analysis of three key countries

Bosco Martén Miranda y
José Manuel Arroyo Rivera

Key Words:
Shale, Fundamentals, Geopolitics, Imports mix

Abstract:
Traditionally, the oil sector has kept a narrow relationship with oil fundamentals and geopolitical events due to its strategic relevance to the countries. Geopolitical conflicts, wars and technological developments have forced countries to change their oil suppliers, provoking a shift in the crude oil worldwide flows.

The objective of this paper is to analyze, under a new approach, the evolution of the oil imports mix of 3, strategically selected, key consuming countries (United States, Spain and India) in the period between 2005 and 2015; based on both the geopolitical events and market fundamentals, including increases and decreases in the refinery capacity and consumption, and the new role of United States as an oil shale producer.

The methodology selected to achieve the objective consists of developing a deep individual analysis of each country and supporting our ideas with graphs in order to visually help the understanding of the paper. We will be able to observe the importance that the different oil producing countries and geographical areas have over the 3 selected countries during this period in order to have a better knowledge of the distribution of the imports mix and the relationships between them.

Furthermore, besides doing an individual analysis, we will also analyze it from a global perspective, including a comparison between the different import dynamics and identifying common points and differences.

The analysis concludes with the identification of the drivers which impacted in the import dynamics, such as Iran and the end of the oil exports ban, among others.

Investing in New Refining Technologies
Key Drivers of Successful Investments

Alejandro de Mur Prior y
Alberto de la Fuente González

Key Words:
Keywords: refining, investment, new technologies, operations, efficiency

Abstract:
The oil industry is navigating through a difficult period of falling oil prices and uncertainty in refining margins which is forcing companies to cut investments to a minimum and carefully scrutinize every dollar spent. Within this context of limited cash availability, investments in refining must be selected carefully and executed properly in order to maximize their profitability and minimize payback periods. This article analyzes different factors to take into account in order to make well-informed investment decisions, as well as the key levers which ensure the success of investments by implementing processes and mechanisms which maximize operational efficiency. The latest conversion technologies in particular are analyzed to shed light on the determinant competitive issues refineries need to consider, and the operational capabilities required to achieve a lasting competitive advantage and justify the impact of the initial investment.

Knowledge Management applied to refineries maintenance: a new approach

Manuel Hurtado Hernández

Key Words:
Maintenance, Knowledge Management, Tacit Knowledge, Explicit Knowledge, Knowledge Platform, Competitive Advantage

Abstract:
Maintenance is an activity that assures competitiveness and makes possible that all the actives of the company achieve their expected function. Maintenance is very important due to its connection to many other aspects of the organization like production, amortization or energy consumption. Nowadays, Oil & Gas companies need to improve refineries maintenance competitiveness to face increasing competition, costs and management models that are too traditional in this field.

Refineries maintenance activities are strongly based in self-experience, maintenance professionals' knowledge is mainly Tacit Knowledge. Unfortunately, Tacit Knowledge, based on experience and difficult to transmit due to its complexity, does not turn into Explicit Knowledge, independent from the individual because is based on documents, software or any other type of technology.

In general, we can say that the more experienced employees know better about the maintenance of the system and this experience is gained through the years. If the employee leaves the company, this know-how leaves with him.
The loss or damage of Tacit Knowledge leads directly to economic losses.

The new method of Knowledge Management proposed in this paper transforms Tacit Knowledge into Explicit Knowledge to make it available to all the members of the organization leading to an improvement in time, money and energy efficiency in the maintenance activities of the company.

First, we identify all the valuable Tacit Knowledge available in the organization. Secondly, we transform this Tacit Knowledge into Explicit Knowledge: the invisible becomes visible. Finally, we make it available to everybody in the organization using the possibilities of the new Digital era.

As a result, Knowledge Management becomes a competitive advantage.

Interconnections; Leading the development of the unconventional gas value chain

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Key Words:
Unconventional gas, Value chain, Capacity, Prices, Interconnections, Energy trilemma

Abstract:
The best way of promoting the unconventional gas is by adapting itself to the existing Value Chain model used for the conventional gas.
By overcoming the specific particularities that are derivative from the origin of the raw material, the extraction of the natural gas, the transmission system as well as the strategy followed for the development and maintenance of the infrastructures should not be differentiated.
There are three main reasons which motivate this argumentation:

1. The final using of the natural gas (both conventional and unconventional) is exactly the same.

2. Even if the origins of the gas are different, this should not prohibit that the supply chain used for the conventional gas was not be used by the unconventional gas to be transported to the final users.

3. The unconventional gas could play an important role in the common objective of guaranteeing the security of supply and the market integration thanks to the development of new international connections.

This is way, the objective of this document is to analyze the value chain of the unconventional gas and to justify the importance of the international connections, traditionally associated to the conventional gas value chain, for the promotion of a raw material that, even if it is not as known as the conventional one, it can also be part of the energetic mix which guarantees the security of supply, the market integration and the economic competitiveness.

The role of R&D in improving refining and petrochemical companies' resilience against market volatility and changes in legislation by proper knowledge management

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Key Words:
Hydrotreatment, Catalyst, Kinetic model, Oil basket

Abstract:
Nowadays, the refining-petrochemical companies have to maximize the practical valorization of their knowledge in order to develop competitive advantages facing the sudden changes of exogenous factors: raw materials pricing, development of new catalysts and changes on specifications from new products and/or new legislations.

Regarding the practical valorization of their know-how, it should be pointed out the strategic need of optimizing the efficiency of their catalytic processes by:

a) Developing predictable process models based on integrating information from industrial plant and laboratory pilot plant

b) Use the information of the validated models to select the best combination of catalysts and crude oil basket

In this article, it will be presented an example about how the changes in exogenous factors (expressed by changes in legislation of fuels, such as changes in terms of sulphur specification and the introduction of new opportunity crudes in the refinery) can be confronted through and adequate knowledge management system. By properly managing knowledge (industrial data and research results), an economically valuable tool can provide a relevant competitive advantage.

Choosing the best strategy to get profit from the future oil market

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Key Words:
Oil storage, future market, contango

Abstract:
As a consequence of the oil crisis in 2014, we are currently experiencing a period of low oil prices. This, together with a global economic crisis, has led to the emergence of a unique economic environment where singular business opportunities have been developed. These opportunities are based on the optimistic trend in the oil future market together with the capacity of oil storage.

The aim of this paper will be to study the best way to take profit from this unusual environment, identifying the key levers for this business and adapting the different strategies that could be taken depending on investor's profile.

Firstly, the main facts driving to this singular market situations are highlighted. The different market indicators are asses. Oil spot price and future market, interest rates and storage capacity among others, explain the unique environment that occurs now.

Secondly will be discuss about the different inversion strategies that can be taken. We are going to explain two of them. The first one involves a long and safe position, with high leverage and assured profits. The second one is shorter and more risky. It needs less financial capacity but could arise higher profits. This parts will include an economical comparison between both methods.

Is there a single approach which could be chosen as the most profitable? Which strategy should be implemented, according to each company profile, to take profit from actual contango scenario?

Improving refinery margin by increasing conversion. Bottom of the barrel technologies

Alba Soler Estrella

Key Words:
Bottom of the barrel, Increase conversion, Improve refinery margin

Abstract:
New European Directive 2012/33/CE, published in 2012 and transposed to Spanish Law in 2015 (RD290/2015), obligates to reduce sulfur content in Marine Bunker Fuel to 0.1% wt in ECA areas and 0.5% wt worldwide. Besides, a falling demand for fuel is expected.

Both challenges can be converted into an opportunity: increasing conversion, competitiveness and economics of Spanish refineries.

This paper is focused on a project for one of these refineries, with a Hydroskimming conversion scheme, with elevated high sulfur fuel exportation (> 1,000 kt/year).

An analysis of the state of the art bottom of the barrel technologies has been developed. The most mature and cheaper technology with the target of increasing distillates yields and decreasing fuel production is a Delayed Coker.

A study to determine the technical scope (new units and modifications of the existing ones, plot plan requirements, coke management), allow us to determine the final investment and profitability of the project.

The results of implementing the new project in the refinery are:

- A crude basket change into a heavier, sour and cheaper one
- An increase in refinery conversion
- An increase in medium distillates production
- A decrease in fuel production, solving the problem of bunker new regulation

Tapered optical fiber sensors for detection of pollutant spills in seawater

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Key Words:
Contaminants, spill; optical fibers; detection; sensors; marine facilities; response.

Abstract:
Historical data proves that the oil&gas industry can produce major impacts on the marine environment. The strategy to protect our seas must imperatively be based on the prevention of spills, big, medium or small. Nevertheless, accidents may happen, and the early detection of any spill is a key point to act fast and reduce and minimize the harmful impacts.

Detection devices exist on the market, but it is hard to find a real-time, non-expensive and non-single use technology. That is the reason why the research and development of new technologies is so important on this industry sector. The goal of this paper is to explain a new kind of sensor, based on the well-known technology of the optical fiber, able to detect in real time the presence of hydrocarbons and other hazardous and noxious substances, frequent on the oil&gas industry. Furthermore, this optical fiber sensor needs a protection structure that guarantees that it stays on the water surface, where most of the pollutants spilled spread, and that protects it from external agents. This protection structure will also be studied in this paper.

The optical fiber technology, as well as its structure, is easy to install, relatively cheap and versatile, since it could be implemented in almost any maritime facility. Moreover, many devices can be installed, connected by the optical fibers, in order to sensor big areas (such as ports).

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