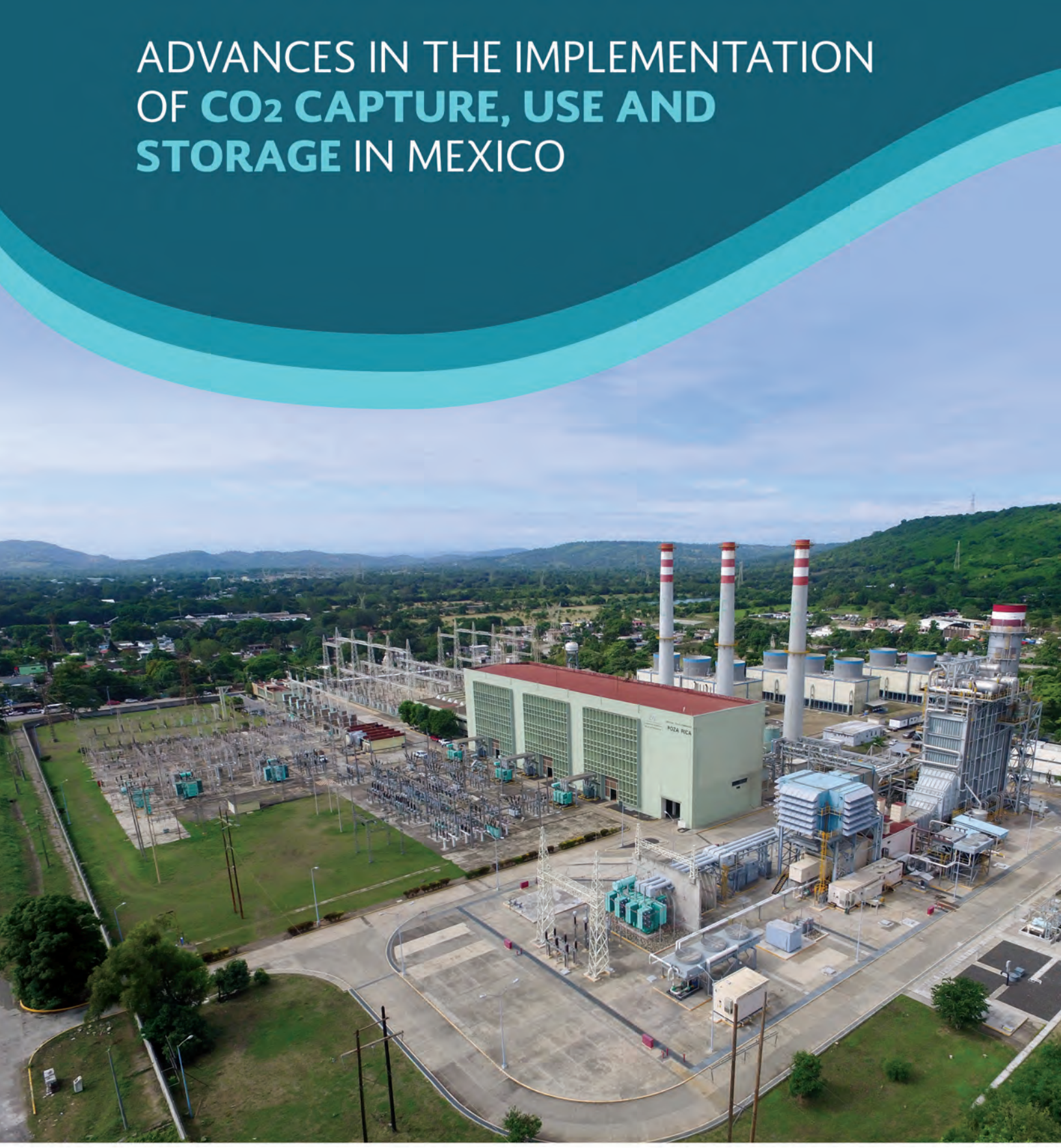
ADVANCES IN THE IMPLEMENTATION OF CO_2 CAPTURE, USE AND STORAGE IN MEXICO



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SECRETARÍA DE ENERGÍA

ESTADOS UNIDOS MEXICANOS

ADVANCES IN THE IMPLEMENTATION OF CCUS IN MEXICO

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The publication of this document was financed by the Carbon Capture and Storage Trust Fund (CCSTF) operated by The International Bank for Reconstruction and Development (IBRD)/The World Bank (WB) as part of the support for the project "Carbon Capture, Utilization and Storage Development in Mexico". The content of the document, as well as the accuracy and veracity of the data included in it, are responsibility of the Mexican Ministry of Energy (Secretaría de Energía), author, editor and owner of the copyright of this report.

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MESSAGE FROM THE SECRETARY OF ENERGY

Mexico's Energy Reform came into force In December, 2013. It includes mechanisms to promote the energy transition and the use of energy generation technologies that are environmentally friendly.

Under this premise, it is necessary to develop projects to reduce the emissions associated with the activities of the sector, considering that the demand for energy is expected to continue growing in the future.

During the Conference of the Parties (COP) 21 held in Paris in December, 2015, President Enrique Peña Nieto reaffirmed Mexico's commitment to transition to a low-carbon economy and to build a more resilient world.

Mexico's goal is that, by 2024, at least 35% of its power generation will come from clean energy. According to the provisions included in the National Determined Contributions for the Mitigation and Adaptation to Climate Change for the period 2020-2030, the country also assumed the international commitment to reduce greenhouse gas emissions by 22% in 2030 and by 50% in 2050. These goals are part of the Transition Strategy to Promote the Use of Cleaner Technologies and Fuels, which is one of the guiding instruments of our domestic policy.

In response to the recommendations of the International Energy Agency, we promote Carbon Capture, Use and Storage (CCUS). With its associated technologies, it is possible to reduce emissions from the use of fossil fuels in power generation and in industrial processes.

This publication presents the advances made in the field of CCUS in Mexico over the past years. We are firmly committed to promote the development of clean energy as part of our energy transition.

Pedro Joaquín Coldwell

Secretary of Energy

January 2018

The global energy sector faces new challenges associated with the energy supply and the diversification of the energy mix which make it necessary to generate electricity through clean technologies to reduce the impact on the environment and promote a sustainable low-carbon industry.

The study "Energy Technology Perspectives" by the International Energy Agency (IEA) indicates that in 2013, fossil fuels dominated the energy matrix, comprising 81% of the world's primary energy demand [1]. Even with the agreed upon premise to keep the temperature rise below 2°C at the global level, it is estimated that fossil fuels will represent 60% of the energy used worldwide in 2040.

However, it is clear that many developed countries have set goals to reduce the use of this type of fuel and to deploy more clean energy technologies in their processes, which will help to balance the increase in the energy demand of developing countries. In this sense, the new business schemes implemented in the energy sector will have important implications for decision making in energy generation projects and industrial processes.

Thanks to **CCUS** current projects, 37 million tons of CO_2 are captured every year.

What is CCS/CCUS?

CCS (Carbon Capture and Storage) or CCUS (including "Use") technology refers to a set of techniques which include the CO_2 capture from industries that use fossil fuels for their processes, as well as its separation, transportation and geological storage in deep saline formations, non-exploitable coal beds or in oil fields.

Combined with the use of renewables and better energy efficiency, CCS technology plays a key role in the reduction of greenhouse gases (GHG) emissions.

Stages, CCS chain includes four stages:

1 CAPTURE

CO_2 is captured in stationary emission sources;

2 TRANSPORTATION

Through pipes or by trucks, ships or trains;

3 STORAGE AND USE

Injection in supercritical state into geological formations for its permanent confinement or use in enhanced oil recovery (EOR).

4 MONITORING

Sophisticated monitoring technics are used before, during and after its sequestration and/or use.

CCUS is a technology that allows the achievement of a significant reduction in CO_2 emissions derived from the use of fossil fuels, not only those produced by the power sector, but also in different industrial sectors such as iron and steel, refineries, petrochemicals and cement production, among others.

According to the IEA models, CCUS can contribute with 12% of the reduction of cumulative emissions needed to reach the global goal of 2°C by 2050; meaning that CCUS would contribute with the mitigation of 6 billion tons of CO_2 per year by that year [2].

The potential of this technology has not been exploited yet to the fullest and it has presented difficulties in being recognized as a useful mitigation tool, even with the support that governments have provided for its development.

In the next decade, CCUS applied to the electricity generation could be cost-competitive with other clean technologies which contribute with clean power generation to the grid, representing a market opportunity, when applied in processes of enhanced oil recovery (CO_2 – EOR).

So far, all CCS (Carbon Capture and Storage) and CCUS (Carbon Capture, Use and Storage) projects have provided valuable experiences in the operation of large-scale capture systems, the handling of large volumes of CO_2 injected underground, as well as the monitoring of its behavior in the subsoil to ensure its permanent confinement.

APPLICATIONS OF THE TECHNOLOGY [2]

	**Industrial Sectors**	In many industrial sectors, the deep reduction of emissions is only possible through CCS. Steel and cement industries, chemicals, fertilizers, hydrogen and refineries are the main targets.	**Success stories:** The Shell Quest CCS Project in Alberta, Canada. The first project to reduce emissions derived from the processing of oil sands. The first large-scale project in the steel sector is located in Abu Dhabi, United Arab Emirates
	**Natural Gas Processing**	The excess CO_2 in natural gas flows must be separated from the gas before it is sold. This CO_2 can be stored or used instead of being vented.	**Success stories:** The Gorgon Project, Australia, will become the largest storage project in the world with 3 million tons (Mton) of CO_2 stored per year.
	**Natural Gas Combined Cycle Plants**	In regions where gas prices are low, such as the United States, CCS applied to NGCC plants may be more favorable than for coal-fired plants.	Mexico is betting on this sector in accordance with its national strategic plan to promote the use of fuels such as natural gas in electricity generation.
	**Coal-fired Plants**	Issues related to the cost of fuels in the electricity sector are key factors, which is why CCS is particularly attractive in the Asian market.	**Success stories:** The Boundary Dam CCS Integral Project, in the coal-fired plant of Saskpower, Canada. The first CCS plant constructed at a commercial scale in the world.
	**Bioenergy CCS (BECCS)**	This combination offers a permanent net reduction of CO_2 from the atmosphere or "negative emissions" through the use of biomass and the capture and storage of the CO_2 generated during its combustion.	The first projects for the production of biofuels are already under development in the United States.
	**Enhanced Oil Recovery with CO_2 (CO_2 -EOR)**	For EOR and permanent storage, it is necessary to implement measures to monitor and verify the permanency of CO_2 underground.	EOR has been an important driver of many CCS projects, particularly in North America and the Middle East.

The global portfolio of CCS/CCUS projects continues to expand and diversify. There are currently 15 projects in operation and 7 more about to start operations during 2017-2018 [3].

1972
- Val Verde Natural Gas Plant

1986
- Shute Creek Gas Processing Facility

1989
- Enid Fertilazer CO_2-EOR Project

1996
- Sleipner CO_2 Storage Project

2000
- Great Plains Synfuel Plant and Weyburn-Midale Project

2008
- Snohvit CO_2 Storage Project

2010
- Century Plant

2013
- Air Products Steam Methane Reformer EOR Project
- Coffeyville Gasification Plant
- Lost Cabin Gas Plant
- Petrobras Campo Cuenca de Santos

2014
- Boundary Dam CCS Project

2015
- Shell Quest Project
- Uthmaniyah CO_2-EOR Project

2016
- Abu Dhabi CCS Project (p1)

2017
- Petra Nova Carbon Capture Project
- Alberta Carbon Trunk Line (Actl) With Agrium Stream
- Actl With North West Sturgeon Refinery CO_2 Stream
- Gorgon Carbon Dioxide Injection Project
- Illinois Industrial CCS Project
- Kemper County Energy Facility
- Yangchang Integrated CCS Demonstration Project

1.- Val Verde Natural Gas Plants
2.- Enid Fertilazer CO_2-EOR Project
3.- Shute Creek Gas Processing Facility
4.- Sleipner CO_2 Storage Project
5.- Great Plains Synfuel Plant and Weyburn Midale Project
6.- Snohvit CO_2 Storage Project
7.- Century Plant
8.- Air Products Steam Methane Reformer EOR Project
9.- Coffeville Gasification Plant
10.- Lost Cabin Gas Plant
11.- Petrobras Campo Cuenca de Santos
12.- Boundary Dam CCS Project
13.- Shell Quest Project
14.- Uthmaniyah CO_2-EOR Project
15.- Abu Dhabi CCS Project (Phase 1)
16.- Petra Nova Carbon Capture Project
17.- Alberta Carbon Trunk Line with Agrium Stream
18.- Actl with North West Sturgeon Refinery CO_2 Stream
19.- Gorgon Carbon Dioxide Injection Project
20.- Illinois Industrial CCS Project
21.- Kemper County Energy Facility
22.- Yangchang Integrated CCS Demonstration Project

Modified from the Global CCS Institute

Why CCUS?

Considering that the modern economy has been built on the basis of fossil energy systems, which at least for the remainder of the first half of this century will still be important for our prosperity, the continued use of these fuels will depend on the capacity of technologies to reduce and capture emissions of GHG, in combination with other technologies which allow us to generate energy and have cleaner industrial processes. The strategy must be comprehensive and taken care of from several fronts.

The Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC) states that the mitigation goals, set at the global level, cannot be met without the inclusion of CCUS, highlighting that the cost of mitigation would increase by 138% without it. For its part, the IEA has indicated that to reach the 2°C scenario (2DS) by 2040, it is necessary to capture and store at least 4 billion tons of CO_2 per year [4].

To achieve the committed reduction of GHG emissions, the deployment of CCUS will be necessary so that, together with the development of renewables and energy efficiency, the needs of the energy and industrial sectors can be met.

The Paris Agreement, presented at the COP21 in 2015, focuses on actions to mitigate climate change after 2020 and represents a clear and unquestionable commitment of political leaders to transit to a low-carbon economy.

Global commitments provide a clear direction and pace of the actions that must be considered to achieve the mitigation goals; however, large strategic investments are required from the public and private sectors to bring these technologies to the market.

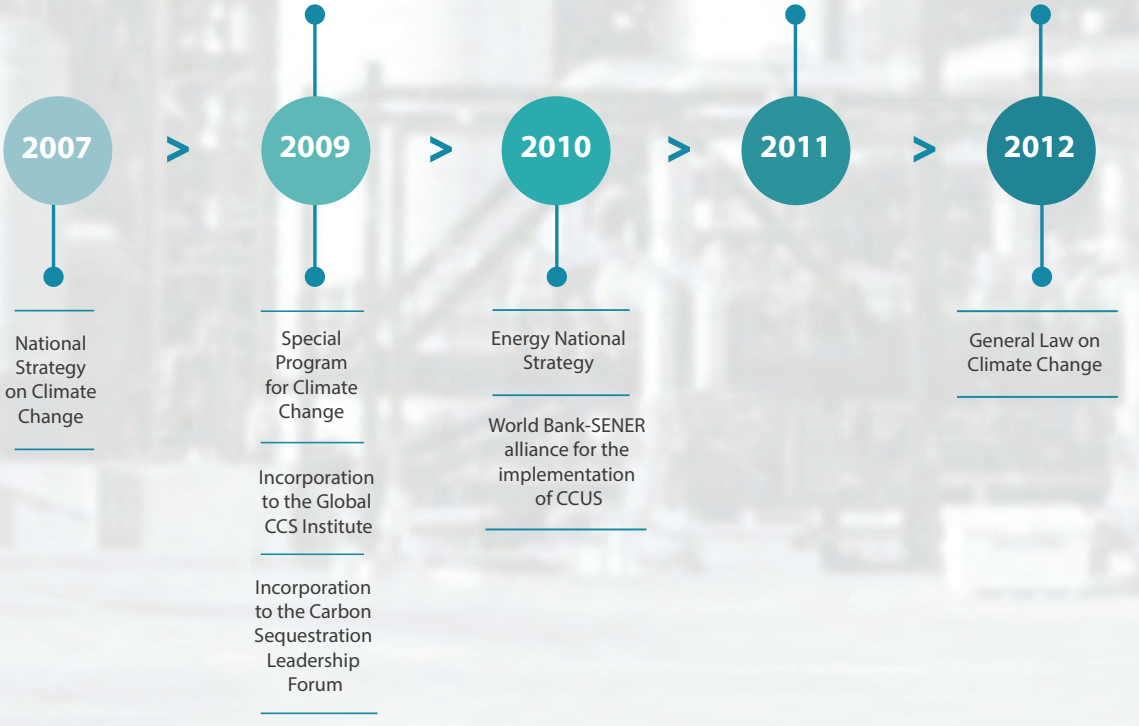
According to the IEA, in order for CCUS technology to effectively contribute to the fulfillment of the planned goals in the 2DS, it is estimated that investments in this technology must be ten times larger than the current amounts [5]. It is necessary to identify where CCS/CCUS play an important role and represent a cost-effective market opportunity that encourages public-private investments, creating a low-emission industry.

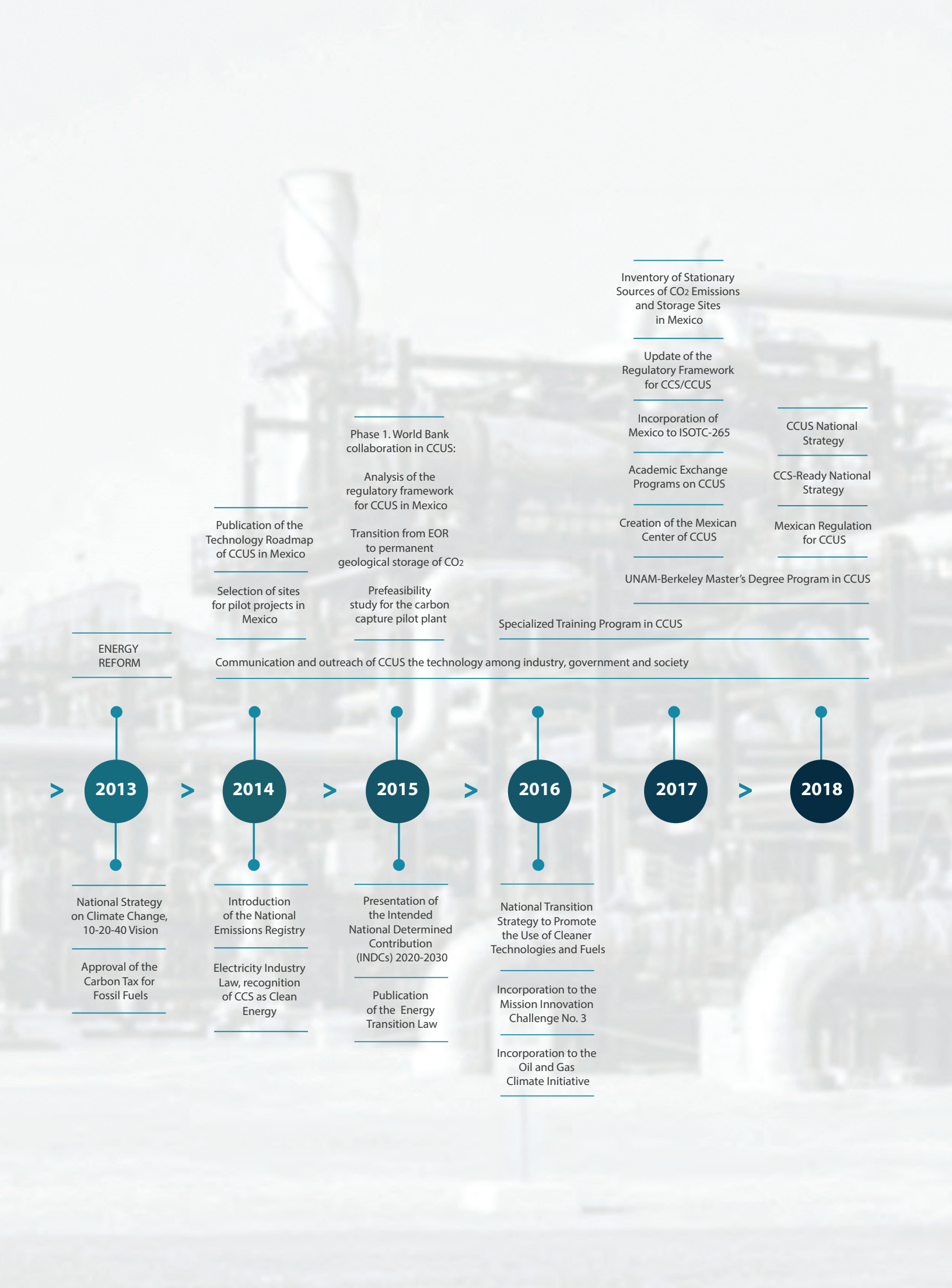
In the case of Mexico, in 2013, power generation contributed 19% of total GHG emissions, while the oil and gas sector contributed 12%, and the industrial sector 17% [6]. Total CO_2 emissions in Mexico derived from the use and burning of fossil fuels, represent 1.37% of global emissions, placing the country in 13th place internationally.

In 2016, 20.31% of the electricity in the country came from clean sources, equivalent to 21,179 MW, that is 28.81% of installed capacity [7], representing a significant progress toward the set goal of clean energy by 2024 at national level. The above embodies an opportunity for the implementation of CCUS technology to diversify the energy mix and for the decarbonization of power generation from fossil fuels, as well as the creation of value throughout the energy sector, contributing at the same time to GHG reduction, and to technological development and innovation.

CCS /CCUS is a proved technology and it is commercially available.

THE CRITICAL PATH OF CCUS IN MEXICO




Inventory of Stationary Sources of CO_2 Emissions and Storage Sites in Mexico
Update of the Regulatory Framework for CCS/CCUS
Incorporation of Mexico to ISOTC-265
CCUS National Strategy
Academic Exchange Programs on CCUS
CCS-Ready National Strategy
Phase 1. World Bank collaboration in CCUS:
Analysis of the regulatory framework for CCUS in Mexico
Transition from EOR to permanent geological storage of CO_2
Publication of the Technology Roadmap of CCUS in Mexico
Creation of the Mexican Center of CCUS
Mexican Regulation for CCUS
UNAM-Berkeley Master's Degree Program in CCUS
Selection of sites for pilot projects in Mexico
Prefeasibility study for the carbon capture pilot plant
Specialized Training Program in CCUS
ENERGY REFORM
Communication and outreach of CCUS the technology among industry, government and society
2013
2014
2015
2016
2017
2018
National Strategy on Climate Change, 10-20-40 Vision
Approval of the Carbon Tax for Fossil Fuels
Introduction of the National Emissions Registry
Electricity Industry Law, recognition of CCS as Clean Energy
Presentation of the Intended National Determined Contribution (INDCs) 2020-2030
Publication of the Energy Transition Law
National Transition Strategy to Promote the Use of Cleaner Technologies and Fuels
Incorporation to the Mission Innovation Challenge No. 3
Incorporation to the Oil and Gas Climate Initiative

THE CRITICAL PATH OF CCUS IN MEXICO

Regarding Mexico's power generation based on fossil fuels, natural gas predominates over coal, oil, diesel or petcoke [8], that is why CCUS has potential for reducing emissions in this sector. In accordance with the recommendations of the IEA and the best international practices, the importance and impact of implementing CCUS technology to achieve a successful energy transition has been considered, guaranteeing the energy supply while aligned with the fulfillment of the GHG reduction goals.

Therefore, the first actions started 10 years ago to incorporate this technology into the national energy mix:

Between 2008 and 2009, Mexico became a member of the Global CCS Institute (GCCSI) and the Carbon Sequestration Leadership Forum (CSLF); Mexico also recognized CCUS as one of the measures to mitigate climate change in forums, such as the North American Leaders Declaration on Climate Change and Clean Energy (August 2009) and the Clean Energy Ministerial Meetings (since 2010).

In February 2010, the Energy National Strategy (ENE) [9] was published with the purpose of coordinating the sector's main stakeholders and to define how to deal with the challenges faced at global and national levels in terms of energy. One of the three axes of

Courtesy of Shell International: Proyecto Shell Quest, Canadá

the ENE highlights the pursue of environmental sustainability through savings in the final energy consumption, and the exploitation of natural gas and power generation with clean technologies [10].

With the purpose of deepening the knowledge in CCUS technology, a study entitled "The Status of Carbon Capture and Storage Technologies in Mexico" [8] was carried out **in 2011**, The study determined that due to the high potential for the use of CO_2 for EOR in mature fields, Mexico should not only bet on carbon capture and storage (referred to as CCS) but also on its use, therefore adopting the acronym CCUS: Carbon Capture, Use and Storage.

In 2012, the "Mexican Atlas of CO_2 Geological Storage" was published [11] as part of a trilateral project within the North American Carbon Sequestration Atlas (NACSA) [12]. At the same time, the General Law of Climate Change (LGCC) came into force, representing a milestone in Mexico's environmental policy. It established the creation of the Climate Change Fund, the Inter-Secretarial Commission on Climate Change and the National Climate Change Strategy [13]; it also established the definition of concurrent actions in the matter of climate change such as: promote research, technology transfer and innovation in the field and facilitate the transition to a competitive and sustainable low-carbon economy. This Law puts Mexico as the leader, among developing countries, in policies aimed at mitigating climate change.

During 2013, a working group integrated by the Ministry of Energy (SENER), the Ministry of the Environment and Natural Resources (SEMARNAT), Petróleos Mexicanos (PEMEX), Comisión Federal de Electricidad (CFE), the Mario Molina Center (CMM) , the National Autonomous University of Mexico (UNAM) and the National Polytechnic Institute (IPN), developed a Technology Roadmap which constitutes a strategic proposal for the implementation and development of CCUS in the country, from its incubation phase to commercial scale. The Carbon Tax was approved in November of that year. The Energy Reform, whose main objectives are to promote development with social responsibility, protecting the environment, ensuring the energy supply and the restitution of proved reserves, came into force in December, marking an historical turn in the country's energy sector.

The Technology Roadmap of CCUS (TRM-CCUS) in Mexico was published in March **2014** [14] and, since that time, it has represented a planning mechanism to allow the development of this technology in the country.

In the same year, the National Emissions Registry came into force dictating that all companies in the energy, industry, transport, agriculture, waste management, commerce and services sectors that generate GHG emissions above 25,000 tCO_2e are required to submit an annual report [15]. Another element of great importance is the Electricity Industry Law [16] where, for the first time, the technology of "geological capture and storage or biosequestration of carbon dioxide" is recognized as Clean Energy, just as renewable energies or nuclear energy.

With the TRM-CCUS underway, and under the leadership of SENER, important actions were deployed strengthening the commitment and collaboration between the Government and the Mexican energy sector. At the same time, international organizations such as the World Bank, the GCCSI, the CSLF and APEC (APEC is defined after its acronym is used... it should be defined here if that's the case) joined Mexico's effort to promote this technology through workshops, technical advisory services and various collaboration programs.

CCUS went from being a technological proposal to becoming a project in development.

2015 became a milestone year regarding global climate change thanks to the Paris Agreement. In March, the Intended Nationally Determined Contributions (INDCs) were presented, where more than five countries, including Mexico, considered CCS technology as part of their portfolio. At the same time, within the framework of collaboration with the World Bank, three key studies were developed which sought to establish the starting points for CCUS in terms of regulation, the combination of enhanced oil recovery projects with permanent storage of CO_2, as well as the characteristics of the first CO_2 capture pilot project in the country. At the end of that year, the Energy Transition Law [17] came into force with the objective of regulating the sustainable use of energy and the obligations in terms of Clean Energy and the reduction of pollutants by the power generation sector.

In 2016, major changes in the structure of Mexican institutions represented an important challenge, despite of which key actions were taken to open the way to a new stage in the implementation of CCUS in the country focused on the deployment of projects, capacity building and the creation of programs to enrich and strengthen Mexican institutions.

Courtesy of CFE: Central Termoeléctrica Poza Rica

Technology Roadmap of CCUS in Mexico (TRM-CCUS)

The critical path proposed in the TRM-CCUS constitutes a systematic and organized basis for the management of resources that allows the assimilation of this technology in the country; also, it seeks to promote economic and regulatory incentives which facilitate the flow of international resources and support, and the participation of the public and private sectors. It has, as a particular objective, the linkage of research activities, technological innovation, academic programs and productivity enhancement in all the topics that make up the CCS/CCUS chain.

Working Group

SENER and SEMARNAT have led the CCUS working group in Mexico, which in its origins in 2013 was integrated by PEMEX, CFE, the Mario Molina Center, UNAM and IPN; and has now evolved, into a committee encompassing 19 national organizations on research, academia, government and industry, leaders in different branches and areas of knowledge related to CCUS.

The objectives of this group are:

- To integrate the country's main stakeholders for CCUS;
- To identify strengths and weaknesses in CCUS in the global and national context;
- To present proposals to promote research, technological innovation and development of CCUS projects in Mexico;
- To have representation in the CCUS groups at the international level and promote this technology domestically.

Organization

Members are divided into two groups based on their skills, interests and experience: a technical group and a policy group. Each of these groups proposes and promotes the research and development in areas and topics of knowledge more closely related to the promotion of CCUS development in the country. Some of them are:

	AREAS	TOPICS
Technical Group	• Capture and Transportation	• Emissions sources: electricity generation and industrial processes • Capture technologies • CO_2 Separation and by-products • CO_2 Transportation • Range of projects (from pilot to commercial scale)
	• Storage • Monitoring	• Geological storage of CO_2 in deep saline aquifers • Geological storage of CO_2 in exhausted hydrocarbon fields • Enhanced Recovery of Hydrocarbons with CO_2 • Other uses of CO_2 • Range of projects (from pilot to commercial scale) • Deep, shallow and atmospheric monitoring
Policy Group	• Policies • Regulation • Academia • Society	• National standards and regulation • Communication and involvement with society • Environmental and social impact • Academic links and programs

Scope of the TRM-CCUS

Three years after the start of the TRM-CCUS, we have a wide range of activities focused on technology promotion, capacity building and progress in the development of pilot projects.

Activities carried out and underway, and next steps for the implementation of CCUS in Mexico include:

ACTIVITIES CARRIED OUT AND UNDERWAY	NEXT ACTIVITIES
Links with international organizations of Science and Technology related to CCS (from 2009 to date)	Creation of the Mexican Center of CCS (2017-2018)
Inventory of Stationary Sources of Emissions and CO_2 Storage Sites (from 2015 to date)	Incorporation to the ISO TC-265 for Carbon Capture and Storage (CCS) (started)
Site selection for CCUS pilot projects in Mexico (2014)	Construction of a pilot CO_2 capture plant in a combined-cycle natural gas facility in Poza Rica, Veracruz (2018-2021)
Estimation of the storage capacity of CO_2 in deep salt formations (from 2010 to date)	Development of the CCUS pilot project in southeastern Mexico (beginning in 2018)
CO_2-EOR strategy in Mexico carried out by PEMEX (2014-2015)	Analysis for the application of CCUS in industrial processes (starting 2017)
Plan for CO_2 capture in thermoelectric plants (2014 to date)	Academic exchange programs on CCS/CCUS (starting 2017)
CCUS National Strategy (2015 to date)	CCS-Ready Strategy (2018)
Berkeley-UNAM Master's Program in CCUS (2015-2020)	Adaptation and creation of regulations and policies for CCS/CCUS projects (starting 2017)
Specialized Training Program in CCUS for industry (started in 2016)	
Programs of communication and outreach about the technology among industry, government and society	

Courtesy of Shell International: Proyecto Shell Quest, Canadá

INTERNATIONAL COLLABORATION

Global CCS Institute

The Global CCS Institute is an international organization whose mission is to accelerate the development, demonstration and deployment of CCS technology as a key mechanism for mitigating climate change and ensuring energy supply. The main members are governments, international corporations, companies, research institutions and non-governmental organizations.

Mexico has maintained a close relationship with the GCCSI for more than 7 years and has received support to carry out workshops, training programs and technology dissemination programs, as well as getting specialized technical assistance.

Carbon Sequestration Leadership Forum

The CSFL is an international initiative against climate change at the ministerial level focused on the development of improved and profitable technologies for CCS. Its mission is to facilitate the development and deployment of CCS technologies through collaborative efforts which address the main technical, economic and environmental obstacles. It has 26 member countries, including Mexico, 18 of which are part of Mission Innovation (a global initiative to accelerate innovation in clean energy). It has a Fund focused on supporting member countries in their capacity building efforts, through which Mexico has received support for an academic-professional exchange program with the University of Adelaide and the Otway Project, in Australia, on the subject of deep saline aquifer storage, as well as financing for the workshops of the Specialized Training Program in CCUS.

Courtesy of PEMEX PEP: Campo Brillante, Veracruz

The World Bank

In 2011, the World Bank (WB) presented its Strategic Alliance with Mexico designed to deliver real solutions to the main challenges for the country's development. Among the main topics of the WB approach are financial and technical coordination and knowledge exchange services.

The CCUS project in Mexico is supported by the CCS Trust Fund, managed by the WB. As part of the first phase of the project, the aim was to promote this technology through studies and evaluations regarding CCUS regulation, CO_2 capture and use, as well as institutional strengthening. The objective of these activities is to let this technology become a tool to contribute to the achievement of the national goals on GHG emissions reduction.

During 2015, thanks to donations from the United Kingdom, Norway and Australia through the World Bank CCS Trust Fund, three key studies were conducted to determine the CCS potential in Mexico:

1) Analysis of the national CCS Regulatory Framework [18]

2) Pre-feasibility study for a pilot CO_2 capture plant [19]

3) Combination of EOR-CO_2 and permanent carbon storage projects (CCUS) [20]

Starting in 2016, work has been done on the procedures and necessary evaluations for the implementation of the second phase of the collaboration activities, which include capacity building, the construction and start-up of the pilot projects for CO_2 capture, the CO_2-EOR and permanent carbon storage project, and the adaptation of the regulatory framework for CCUS in Mexico, among other activities.

Mission Innovation (MI)

It is a global initiative founded by 20 countries, including Mexico which was unveiled during the COP21, which aims to double the investment in research and development to accelerate innovation in clean energy within the next five years.

To date, 22 countries are part of this Initiative, in addition to the incorporation of the European Union, which has a commitment to increase its investment levels from US$ 15 trillion to US$ 30 trillion by 2021.

During the COP22 held in Morocco at the end of 2016, MI announced the seven technological challenges in which the countries will focus their collaborative efforts. Mexico is leading Challenge #6 on Clean Energy Materials Innovation, and is part of Challenge #3 on Carbon Capture Innovation.

Oil and Gas Climate Initiative (OGCI)

In 2015, in preparation for the COP21, the world's most important oil and gas companies launched the Oil and Gas Climate Initiative (OGCI), in order to promote the reduction of GHG emissions. The Initiative supported by 10 companies: BP, CNPC, Eni, PEMEX, Reliance, Repsol, Saudi Aramco, Shell, Statoil and Total.

The OGCI is committed to making investments for a total of US$ 1 trillion over the next 10 years as a sign of the importance of innovation to face one of the greatest challenges of humanity, particularly due to the role played by technology to transform the conventional schemes used by the industry into more sustainable ones. CCUS is considered among these areas for investment.

CAPACITY BUILDING

With the support of the Asia Pacific Economic Cooperation (APEC) and in collaboration with the Global CCS Institute, a series of workshops were held in 2012. The first workshops aimed to disseminate the knowledge about the technology among students and professionals related to CCS, as well as institutes and government entities; these workshops evolved into more specific training courses where the technical principles of the technology were taught, and the global and national actions towards its development, including the experiences learned from the projects that were launched in recent years.

A master's program with specialization in CCUS has been created and incorporated to the Master's Program in Engineering and Geosciences at the National Autonomous University of Mexico (UNAM). This program started in summer of 2017 under the guidance of the Berkeley Energy and Climate Institute (BECI) of the University of California. The objective of this program is to increase the number of specialists in the subject and to train the leaders of the future projects in the country.

Likewise, the Specialized Training Program in CCUS was established for students, researchers and professionals in areas related to this technology. The program includes activities such as workshops, internships, webinars, among others; which are carried out thanks to the support of the Government of Mexico through the Sectoral Funds CONACYT - SENER, as well as the World Bank, the CSLF and the GCCSI.

MEXICAN CENTER OF CCUS

The Mexican Center of CCUS (CEMCCUS) will be part of the initiative for the creation of specialized centers focused on meeting the technological development needs of the country and will be aligned with the public policies and commitments of Mexico in the energy field. It will seek to take down the barriers faced by the country on the sustainable use of energy and the implementation of CCUS technology as a key activity to foster the energy transition. In this regard, it is intended that networks or strategic alliances will be integrated for: capacity building and training; the linking and expansion of the scientific-technological-business network; and the vision, strategy and prospective of energy and environment in Mexico.

The CEMCCUS will be responsible for proposing and developing strategic research and technological innovation activities in the areas of CO_2 capture and transportation, CO_2 geological storage, CO_2 use, as well as cross-cutting issues related to monitoring, regulation, communication and outreach, marketing and business (perhaps investment is better?). It will include the capacity building activities and the development of the first two CCUS pilot projects in the country.

PILOT PROJECTS

The strategy for the implementation of CCS in Mexico, contemplates the implementation of two pilot projects:

CO_2 CAPTURE PILOT PROJECT AT THE POZA RICA COMBINED-CYCLE NATURAL GAS POWER PLANT [19]

In 2015, the CFE, together with SENER and the World Bank, selected the Poza Rica Thermoelectric Power Plant, a combined-cycle natural gas power plant, for the implementation of the first CO_2 capture pilot project in Mexico, which will be carried out in collaboration with the World Bank. The objective of this project is to determine the efficiency of post-combustion systems based on amines for application in larger-scale projects, as well as to obtain information regarding the potential and the technical, economic and environmental characteristics of the application of CCS in systems which work with natural gas. This can be achieved through a generic plant with the flexibility to test several types of solvents to capture CO_2 contained in the combustion gases of one of the units of the plant, being the first project of its kind in the world outside the Technology Center of Mongstad (TCM) in Norway. The design and construction of the project is planned to begin in 2018.

PILOT PROJECT FOR PERMANENT CO_2 STORAGE THROUGH ENHANCED OIL RECOVERY IN THE *BRILLANTE FIELD* [20]

During 2014 and 2015, PEMEX conducted an analysis of the proposed fields for the implementation of enhanced CO_2 recovery processes (EOR-CO_2), of which the Brillante Field of the Production Asset s04 (in the past known as the Cinco Presidentes Asset) was chosen as the site to carry out the first CCUS pilot project. The objective of this project is to study the response of selected fields in southeastern Mexico to the stimulation with CO_2 to increase oil production while the gas is stored underground permanently. The CO_2 will be provided by the Cosoleacaque petrochemical plant where it is obtained as a by-product, without the need of a capture and separation system, and will then be transported to the field located 70 km away. During the life of the project, 34 MMMPC of CO_2 will be injected into the reservoir.

PUBLIC POLICY

During the last 10 years, the Government of Mexico and different scientific, technological and academic entities have joined efforts to define the actions and projects which provide a feasible solution to achieve its international commitment for GHG emissions reduction goals.

The initiative to incorporate CCUS represents an advance in the future of the energy sector in Mexico and the opportunity to develop new areas of knowledge, experience and business in our country, where the public and private sectors can develop integral projects in collaboration with national and international research and academic centers.

The need to have adequate regulations to monitor CCUS operations and ensure their correct performance, as well as the need to provide certainty to the population regarding the stability and behavior of CO_2 underground, have been taken into consideration. The initiative also seeks to inform and educate on the importance of energy in everyday life, the effects and consequences of climate change and the projects that are under development in the field of Clean Energy, including CCUS. Resources from federal funds and from the implementing entities themselves, such as CFE and PEMEX, as well as research centers and universities, have been allocated to this effect.

The support of international organizations has greatly promoted the development of CCUS technology, where collaboration with the World Bank and other international organizations, and multilateral working groups with governments of different countries, should be highlighted.

So far, investments for the development of this technology in the country have totaled around US$ 9 million, and investments of approximately US$ 80 million are expected in the next 4 years for the development of pilot projects, research and capacity building, among other relevant activities.

Undoubtedly, there are great challenges on the road ahead toward energy transition. Mexico has demonstrated its leadership and commitment in energy and environmental issues, reiterating its commitment globally. During the last 10 years, the development of CCUS technology has been strengthened and promoted as an alternative for the deep decarbonization of the fossil industry in the country.

The role of CCUS in the future of the energy sector represents an opportunity for technological development, and for the growth of a low-carbon and environmentally friendly industry, as well as the opportunity to strengthen other clean technologies, such as renewable and nuclear energy, ensuring the continuity of the energy supply and the sustainability of the industrial and energy sectors.

Courtesy of PEMEX PEP. Activo Cinco Presidentes

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Sites for consultation:

Global CCS Institute: https://www.globalccsinstitute.com/

Carbon Sequestration Leadership Forum: https://www.cslforum.org/cslf/

World Bank: http://www.worldbank.org/

Mission Innovation: http://mission-innovation.net/

Oil & Gas Climate Initiative: http://www.oilandgasclimateinitiative.com/