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Priority projects for the implementation of CCS power generation with enhanced oil recovery in Mexico

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ABSTRACT

In March 2014, Mexico launched its CCUS technology roadmap, outlining the actions to be taken up to 2024. One important action is the National Policy of Carbon Capture and Storage (CCS) ready and the identification of priority natural gas combined cycle (NGCC) with capture plants. This outcome could aid the creation of a technology roadmap for the design of new NGCC power plants and their operational requirements for EOR and for the reduction of CO_2 emissions. This article provides an overview of the opportunities for deploying CCS in new NGCC power plants in Mexico which were programed to begin operation throughout the period from 2016 to 2030. The attention is given to plants close to oil fields which are candidates for enhanced oil recovery (EOR), located in an inclusion zone suitable for storage. The Gulf of Mexico region, where potential EOR sites and the presence of industrial CO_2 sources are located, is within the inclusion zone for recommended sites for geological storage of CO_2. After identifying new power plants in the inclusion zone, this article analyses which existing plants could be retrofitted and which new power plants could be designed to be 'carbon capture ready'. In addition, the distance and the volumes of CO_2 are estimated.

1. Introduction

Mexico's installed electrical capacity is predicted to grow by 57,122 MW between 2016 and 2030, of which 20,453.7 MW of the installed capacity will correspond to Natural gas combined cycle (NGCC) (Mexican Ministry of Energy, 2016, page 16). NGCC is expected to be the dominant electricity generation source in 2030 with a share predicted to increase from 50.1% to 58.1% as shown in Fig. 1 (Mexican Ministry of Energy, 2016). Mexico intends to achieve, in parallel, a reduction of "its greenhouse gas emissions by 50% below 2000 levels by 2050" (SEMARNAT-INECC, 2016). For that reason, one of the strategies proposed to reach this objective is the application of carbon capture technology in fossil fuel power stations for the purpose of EOR in the oil industry, which relies on the availability of significant sources of industrial CO_2 in the Gulf of Mexico between 2020 and 2050 (Lacy et al., 2013). The additional 20,453.7 MW capacity of NGCC power plants is equivalent to 50.52 $MtCO_2/y$. It is reasonable to assume that a large fraction of this capacity needs to be installed with CCS. In March 2014, Mexico launched its CCUS technology roadmap containing recommendations for actions to be taken at a national level up to 2024 (Mexican Ministry of Energy, 2014) focusing on geological storage in deep saline aquifers and EOR projects. According to Lacy et al. (2013), carbon capture projects for the purpose of EOR rather than for geological storage in deep saline aquifers, are more likely to be initially developed in Mexico because of the cost offset associated with additional oil revenues. However, geological carbon storage could be needed, in a second phase, in order to reach Mexico's mitigation target. Storage zones have been identified by Dávila, et al. (2010) and The North American Carbon Storage Atlas, (2012), showing that most of the zones are located close to the Gulf of Mexico. Lacy et al. (2013) identified the main existing industrial and power plants that emit CO_2 in the Gulf of Mexico. However, there was no indication of the forthcoming CO_2 emissions from new power stations built over the period 2016–2030. The aim of this paper is to complete the initial work of Lacy et al. (2013) by providing an overview of the potential for incorporating CO_2 capture into the large number of gas-fired power plants expected to begin operation throughout the period from 2016 to 2030 for storing CO_2 in geological strata and CO_2 for EOR projects. An estimate is also provided for the CO_2 emissions of these new natural gas power stations.

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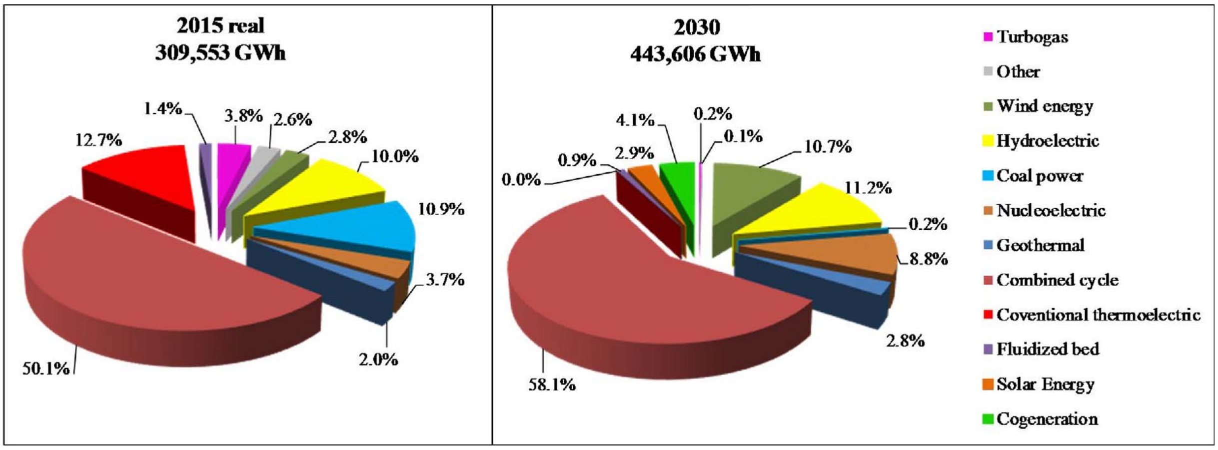
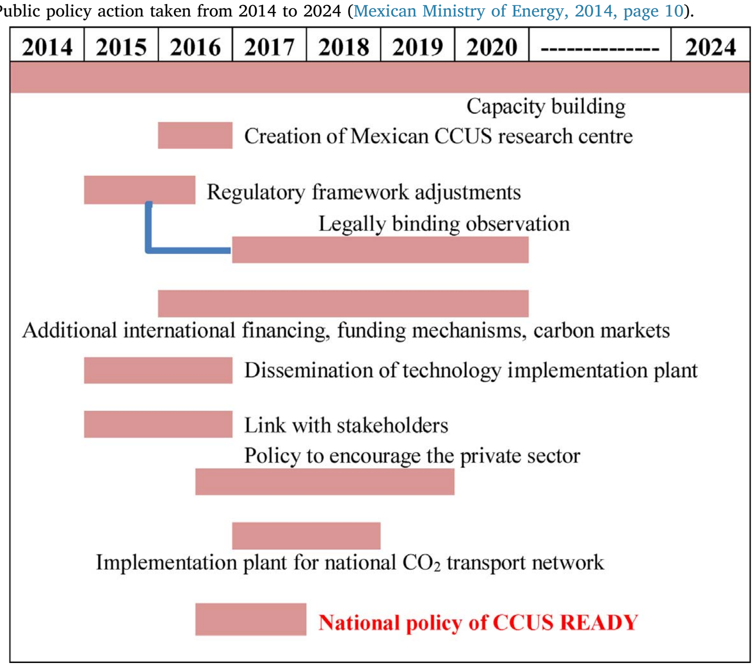


Fig. 1. Expected electricity generation in 2030. (Mexican Ministry of Energy, 2016, page 90).

Table 1
Public policy action taken from 2014 to 2024 (Mexican Ministry of Energy, 2014, page 10).



2. CCUS potential in Mexico

In Mexico there is a potential for simultaneous development of CO_2 for geological storage and CO_2 for EOR.

2.1. Gulf of Mexico: the region for EOR projects

Production from oil sites becoming depleted or less productive through traditional extraction methods could be extended by the injection of CO_2 for EOR. CO_2 injection for EOR into depleted oil fields improves hydrocarbon flow and recovery rates. Lacy et al. (2013) identified industrial plants with CO_2 emissions above 0.5 $MtCO_2/y$ located within 180 km of oil fields in the Chicontepec and Cinco Presidentes regions. A demand for up to 50 $MtCO_2/y$ for EOR in the Gulf of Mexico from the largest oil fields that are candidates for EOR was communicated to Lacy. This region is the largest emitter of CO_2 in Mexico, at around 20.1 $MtCO_2/y$ (Lacy et al., 2013).

A CO_2-EOR project could develop infrastructure and experience for deploying CCS in the future in order to reach the Mexican mitigation target. CO_2-EOR may provide two benefits: an increase in Mexico's oil production and a reduction in future GHG emissions (Lacy et al., 2013).

2.2. Regions for CO_2 storage

Dávila et al. (2010) presented a study on the geological carbon storage possibilities in Mexico. The country was divided into seven zones based on their characteristics, i.e. seismic, volcanic and tectonic hazards in combination with the surface geology and lithology. The North American Carbon Storage Atlas (2012) divided Mexico into two zones: the exclusion zone, which is not recommended for CO_2 storage; and the inclusion zone, which is characterised as being a stable area and may be suitable for CO_2 storage in saline formations deeper than 800 m (North American Carbon Storage Atlas, 2012). Within the inclusion zone, the provinces with CO_2 storage resource potential are Chihuahua, Coahuila, Central, Burgos, Tampico-Misantla, Veracruz, Southeastern, Yucatan, and Chiapas (North American Carbon Storage Atlas, 2012).

3. Mexican road map

In March 2014, Mexico launched its Roadmap for CCUS and its implementation began at a later date (Mexican Ministry of Energy, 2014). Actions to be taken in chronological order are as follows: incubation, public policy, planning, a pilot and demonstration scale projects in the oil industry, pilot and demonstration scale projects in power plants, and commercial scale projects (Mexican Ministry of Energy, 2014). The first two steps are related to creating agreements, a new regulatory framework for CCUS projects, and resources for training people, etc. The activities in this stage are described in chronological order in Table 1.

The adoption of a national policy to make new large CO_2 emitting industrial facilities as 'CCUS ready' is one of the important activities. By extension of the early definition of capture-readiness by IEAGHG (IEAGHG, 2007), this can be translated in this context to "A CCUS ready power plant is one that has been designed and built for incorporation with CCUS technology in the future". Given the rate and the magnitude of a programme for new-build gas-fired power stations of 20,453.7 MW plants by 2030, it is necessary and urgent to evaluate new power plants in Mexico, which will be supplying electricity over the next 30 years, in order to prepare them for CCUS. As mentioned in the Chinese road map, a CCUS-ready design would avoid the risks of compromising the national strategy for CCUS, and/or would avoid the construction of potentially stranded assets that cannot be retrofitted. It would also allow greater flexibility in the degree and timing of CCS deployment (Roadmap for Carbon Capture and Storage demonstration and deployment in the Republic of China, 2015). It is worth noting that very specific guidelines are made available by the government to project developers in the UK when they seek planning permission from the country's environmental agencies (DECC, 2009). These specific guidelines could constitute a useful starting point for the implementation of requirements fit to the purpose of Mexico's roadmap. The reader is referred to the UK Carbon Capture Readiness guidelines for technology specific details, although it is clear that some requirements would also apply to Mexico, such as the provision for viable CO_2 transport to a secure and suitable area for CO_2 storage, allocation of space for, and access to, the carbon capture equipment and an assessment of the technical feasibility of a retrofit with the carbon capture equipment.

Other important actions described in the Mexican road map are related to pilot and demonstration scale projects in power plants shown in Table 2 and the identification of priority capture plants. The CCUS roadmap focuses on post-combustion capture plant, and different solvents are planned to be tested and used in the demonstration project. Activities are described in Table 2 (Mexican Ministry of Energy, 2014). This information is useful in the evaluation of technologies for CCUS readiness and the retrofit of future gas-fired power plants.

4. Future new power plants suitable for CCUS

In this section, new-build power plant projects which began operation in 2016 are identified in order to define new projects suitable for incorporating carbon capture process, to determine how far away from oil fields these power plants would be located, and how much CO_2 would be generated. The identification of future power plants suitable for incorporating CO_2 capture is important for Mexico in order to reach its mitigation and CCUS target, as mentioned previously.

Before identifying the new power plants suitable for CCUS from 2016 up to 2030, definitions of capture ready and retrofit is given:

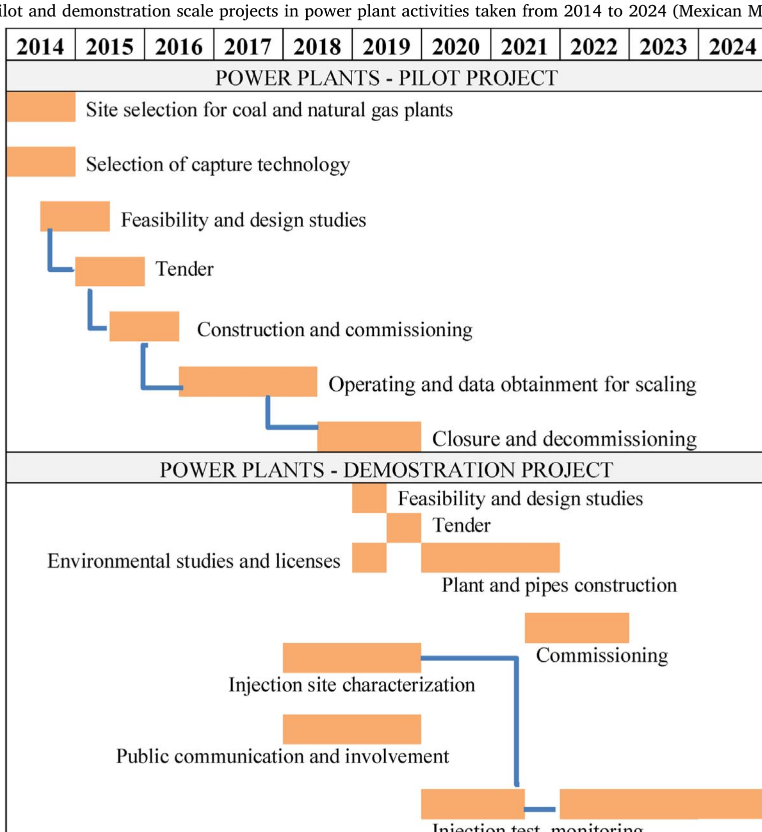
4.1. Capture ready

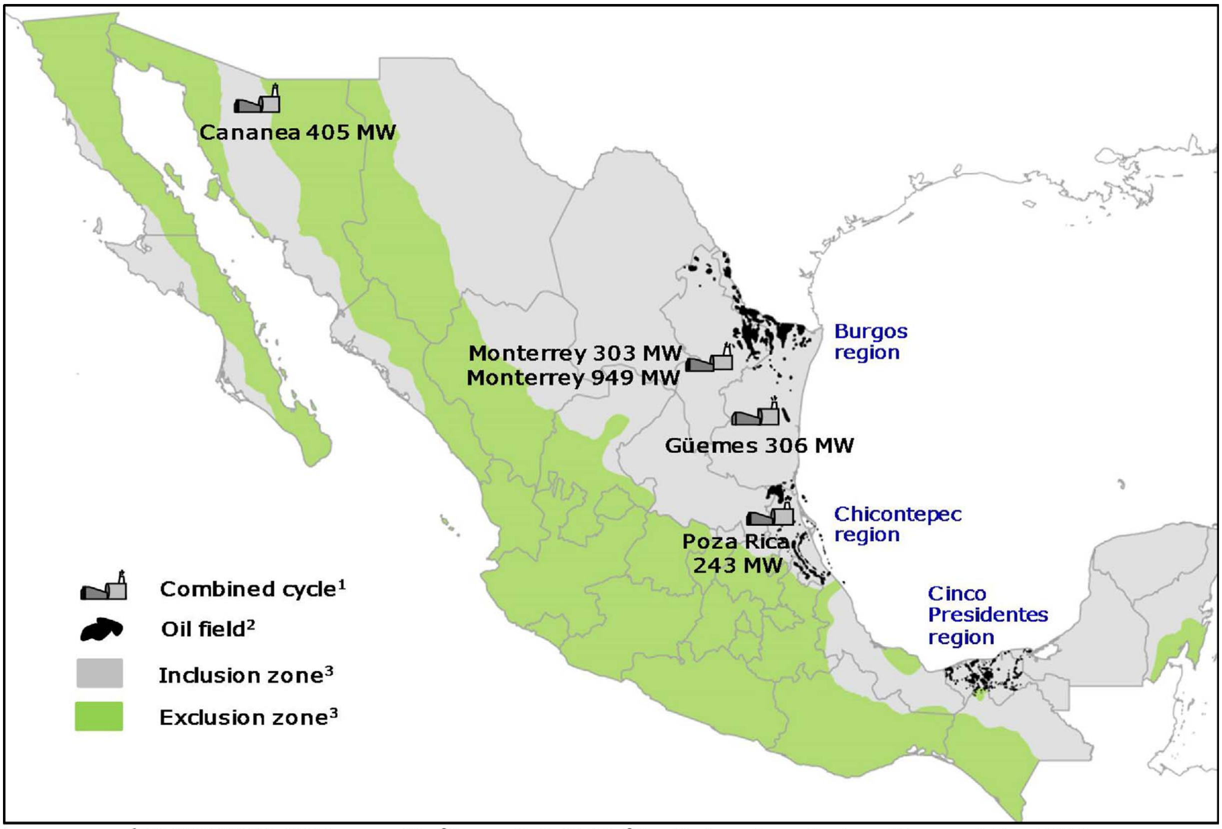
According to GCCSI, 2016, "capture ready plant focuses on identifying an appropriate location for the plant, developing a plant design that is technically capable of retrofit, allowing sufficient space for capture facilities, potentially pre-investing in some capture-related equipment, and ensuring that any potential roadblocks".

4.2. Retrofit

In the case of existing power plants, modification will be needed for incorporating CO_2 capture. There are two important actions that have

Table 2
Pilot and demonstration scale projects in power plant activities taken from 2014 to 2024 (Mexican Ministry of Energy, 2014, page 18).





[1]PRODESEN, 2016, page 81, [2]Lacy et al, 2013, [3]North American Carbon Storage Atlas, 2012

Fig. 2. Location of the new 2260 MW NGCC power plant projects, whose operation started in 2016 (PRODESEN, 2016).

to be evaluated for existing power plants before incorporated carbon capture: (1) Retrofit and (2) Repowering. The first action is related to some modifications in the power plant in order to make it suitable for incorporating CO_2 capture, such as modification for steam extraction in the crossover and in the LP steam turbine. The second action is related to compensating the drop in output when the capture plant is incorporated in an existing power plant. The power output decreases due to the extraction of steam to regenerate the amine and for CO_2 compression.

In this study, the new NGCC power plants which were programed to begin operation throughout the period from 2016 to 2030 are divided into four stages as described below:

The first state covers the new NGCC power plants which began operation in 2016. Seven units are expected to generate a total of 2571 MW.

Five units which would generate 2260 MW are located in the inclusion zone as shown in Fig. 2:

- Four of these units are less than 100 km from the oil fields which are candidates for EOR Burgos and Chicontepec. As their status in 2016 was under construction, it is clear that no actions relating to CCUS readiness were considered, thus they could be potential candidates for a retrofit with CCS and with CO_2 injection for EOR". It has been proposed to use CO_2 as an alternative fluid for shale fracturing in a region where fresh water is not abundant. It is possible that this could be an option for potential shale gas reservoirs located in the Burgos oil fields.
- One unit in Cananea, Sonora is located at a distance of approximately 1700 km from the Burgos oil fields. Transporting the CO_2 to Burgos oil field means that the pipeline would cross the exclusion zone. It is clear therefore that it would send its carbon dioxide to geological storage in non-hydrocarbon reservoirs for purely climate change purpose.

The second stage covers the NGCC power plants which are expected to begin operation in 2017 and 2018, their current status being under construction. The total power expected for these new NGCC is 5985 MW.

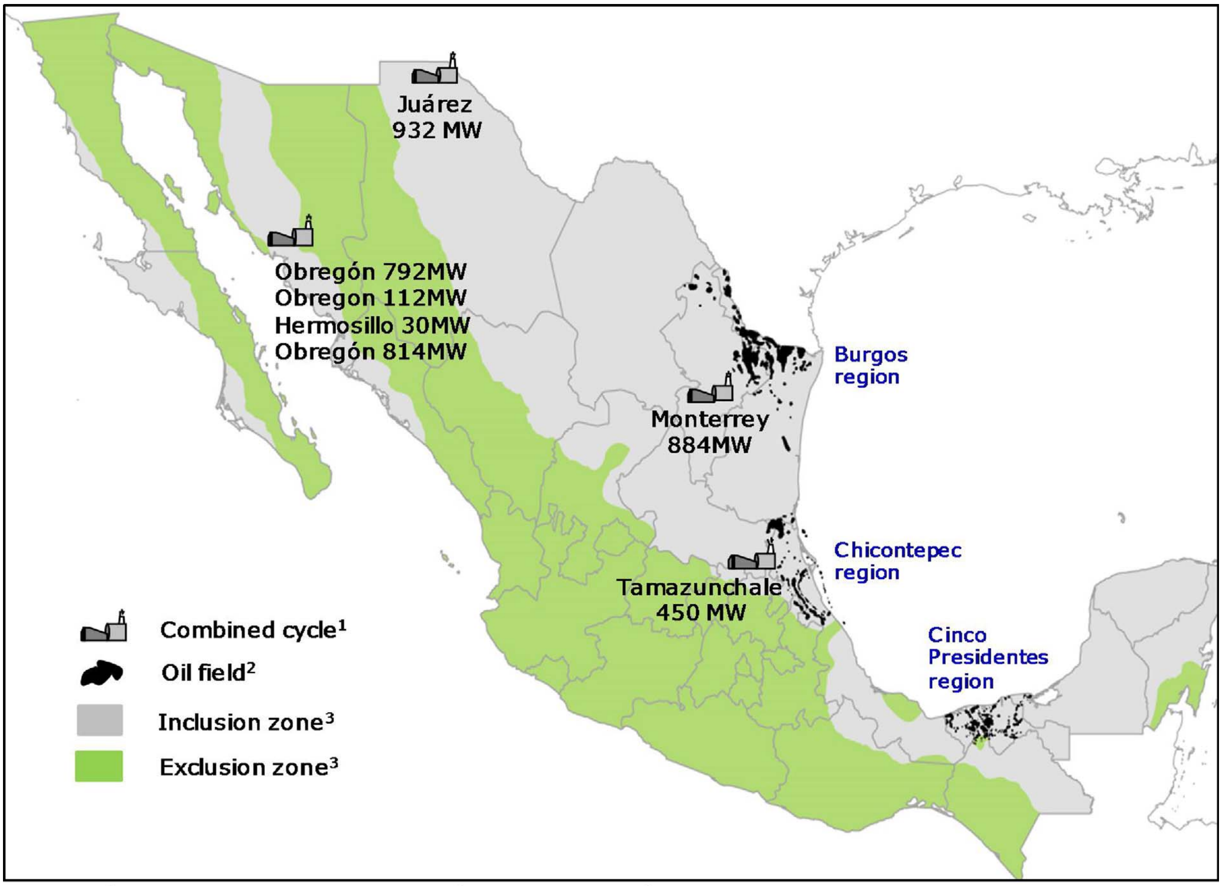
Seven units, accounting for 4014 MW, are located within the inclusion zones shown in Fig. 3. Likewise, projects included in this period were not considered for CCUS readiness as all of them are under construction:

- Two units are close to Burgos and Chiconepec oil fields. The Monterrey power plant with a capacity of 884 MW is located approximately 200 km from the Burgos oil field, and the Tamazunchale power plant with a capacity of 450 MW is located less than 100 km from the Chicontepec oil field. Both could be potential sources of CO_2 for CO_2-EOR. In addition, CO_2 may serve as an alternative fluid for shale fracturing.
- One unit, located in Juarez Chihuahua, is more than 1000 km from the Burgos oil fields. It may serve as a potential option to supply CO_2 to the oil field in Texas through a CO_2 pipeline or to send its CO_2 to geological storage in non-hydrocarbon reservoirs for purely climate change purpose.
- Four new power plants located in Obregon and Hermosillo, Sonora are within the inclusion zone, their CO_2 would be sent to geological storage in non-hydrocarbon reservoirs.

The third stage covers the NGCC power plants which are expected to begin operation from 2019 to 2020. The expected total power generated by these power plants in this period is 9326 MW.

Seven NGCC power plants which would generate 5755 MW are located within the zone suitable for storage as shown in Fig. 4.

- Three NGCC power plants: Monterrey, San Luis Potosí, and Tamazunchale are identified with the potential to incorporate CO_2



[1]PRODESEN, 2016, page 84-85, [2]Lacy et al, 2013, [3]North American Carbon Storage Atlas, 2012

Fig. 3. Location of NGCC power generation projects, whose operation will begin in 2017 and 2018 (PRODESEN, 2016).

capture and to use the CO_2 for EOR and as well as an alternative fluid for shale fracturing. It is worth noting that the new power plant located in San Luis Potosí could be a priority for incorporating CO_2 capture as it is candidate for CCUS readiness as indicated in Table 3.

- Two new NGCC power plants: Merida and Laguna are located in the inclusion zones but not close to the oil field. CO_2 from these power plants could be considered for geological storage in non-hydrocarbon reservoirs or they could be potential candidates for a retrofit with CO_2 injection for EOR in a second phase.
- Four new power plants located in Obregon and Hermosillo, Sonora are within the inclusion zone and very far from the oil field. The CO_2 generated by these power plants would be sent to geological storage in non-hydrocarbon reservoirs.

Finally, the fourth stage covers the new NGCC which are expected to begin operation in 2021 through 2030. The expected total power generated by these power plants is 2572 MW and would emit 6.34 $MtCO_2$/y. Although there is sufficient time to prepare these natural gas power stations for CCS readiness as their current status is not under construction, none of them would be located in the inclusion zone.

Table 3 reports the amount of CO_2 which would be produced only by the new NGCC projects located inside the inclusion zone for CCUS. It also identifies which plants could be candidates for a CCUS retrofit or to be made CCUS ready. The amount of CO_2 is calculated based on the report by the International Energy Agency Greenhouse Gas R & D Programme (IEAGHG, 2012) considering a load factor per new plant of 80%. A 910 MW net power NGCC produces 320 t CO_2/h. This value was used to extrapolate CO_2 production at different power capacities. In total, 29.64 $MtCO_2$/y would be generated solely by new projects located in the inclusion zone, with 90% of the CO_2 generated by these power plants being abated at the point of emission if a CO_2 capture process were incorporated. In Table 3 it is shown that only four units could be considered for CCUS readiness. Therefore, it is important and urgent to evaluate these power plants in a timely manner.

5. New power plant sources of CO_2 close to the oil fields of Burgos, Chicontepec, and Cinco Presidentes

The next step in this analysis is to address, at this early stage in the deployment of CCUS in Mexico, is whether the potential emission reductions achievable by capture-equipped power plants identified in the previous section – all located inside the inclusion zone of Figs. 2, 3, and 4 – matches the contribution that CCS power plants are expected to make for Mexico to meet its CO2 emission target i.e. "reduce its greenhouse emissions by 50% below 2000 levels by 2050" (SEMARNAT-INECC, 2016)".

If the capacity in the inclusion zone is not enough, then power plants located in the exclusion zone would have to be considered for incorporating CO_2 capture or converted to renewable energy generation. The optimum configurations for CCUS readiness of new plants, the retrofit and/or repowering of non-CCUS ready existing unit plants would have to be defined in a future work and is outside the scope of this analysis.

Table 4 indicates new power plants located within a short distance from oil fields in the Gulf of Mexico. Capturing 90% of the CO_2 emitted by these power plants would amount to approximately 13.35 $MtCO_2$/y, which can be supplied for EOR. The remaining CO_2 emissions generated by the power plants located further away from these oil fields could then be connected to existing EOR projects in a second phase, or geological storage in non-hydrocarbon reservoirs located in the inclusion

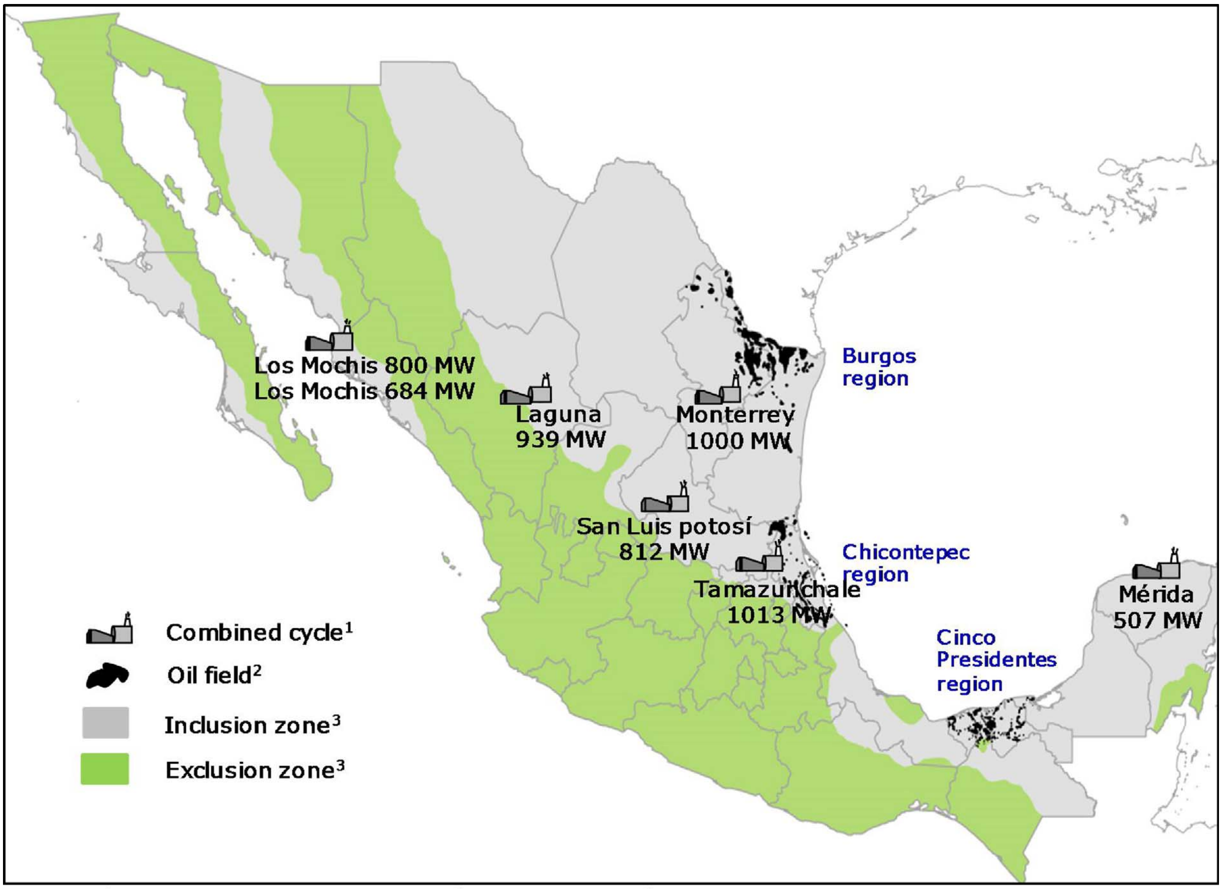


Fig. 4. Location of 5755 MW to be generated by new power generation projects whose operation will begin in 2019 and 2020 (PRODESEN, 2016).

Table 3
CO_2 emitted by new natural gas power plants located in the inclusion zone and potentially available for CO_2-EOR.

Power plant	Capacity MW	$MtCO_2/y$[a]	
NGCC to supply electricity demand from 2016			
Cananea	405	1.00	Retrofit
Poza Rica	243	0.60	Retrofit
Güemez	360	0.89	Retrofit
Monterrey	303	0.75	Retrofit
Monterrey	949	2.34	Retrofit
Projects to supply electricity demand from 2017			
Obregón	792	1.95	Retrofit
Juárez	932	2.30	Retrofit
Obregón	112	0.28	Retrofit
Hermosillo	30	0.07	Retrofit
Projects to supply electricity demand from 2018			
Obregón	814	2.01	Retrofit
Monterrey	884	2.18	Retrofit
Tamazunchale	450	1.11	Retrofit
Projects to supply electricity demand from 2019			
Monterrey	1000	2.46	Retrofit
Laguna	939	2.31	Capture ready
Los Mochis	800	1.97	Retrofit
San Luis Potosí	812	2.00	Capture ready
Los Mochis	684	1.69	Capture ready
Projects to supply electricity demand from 2020			
Tamazunchale	1013	2.50	Retrofit
Mérida	507	1.25	Capture ready
Total	12,029	29.64	

[a] Unabated CO_2 emissions.

zone could be implemented. In effect, the power plants reported in Table 4 could be considered as priority CCS-EOR projects as they will provide economic benefits from additional oil production and would provide experience and infrastructure for future CO_2 storage.

Lacy et al. (2013) identified 20.1 $MtCO_2/y$, emitted for existing power plants, industries, and refineries as potential primary sources, which, if added to the 29.64 $MtCO_2/y$ from new NGCC power plants located in the inclusion zone, could be used for EOR projects. It is evident therefore that the demand of CO_2 EOR in oil fields in the Gulf of Mexico, estimated at approximately 50 $MtCO_2/y$ (Lacy et al., 2013) could be supplied.

6. Alternatives for incorporating CO_2 capture in natural gas

In order to facilitate the incorporation of CCS in NGCC power plants in Mexico, it is important to develop an analysis of different technologies with regards to site-specific, regional and national factors.

Based on the extensive experience around the world using amine solvents, Mexico is developing experience in this area, as proposed in Mexico's roadmap for CCUS, and will continue to do so in the future. This indicates that the technology and alternatives suggested for Mexico will continue to be focused on amine-based post-combustion CO_2 capture.

The incorporation of post-combustion carbon capture in a natural gas power plant poses different challenges when compared to coal power plants, such as the higher volumes of exhaust gas, and lower CO_2 concentration of 3–4% compared to 10–15%. The resulting engineering challenges may have impacts on the capital and operational costs. Different concepts for NGCC power plants integrated to CO_2 capture process have been investigated with the potential to be applied in

Table 4
CO_2 emitted by new natural gas power plants located within the inclusion zones suitable CO_2-EOR located close to the oil field.

Power plant	Capacity MW	$MtCO_2/y$[a]	Approximately Distant from the oil field (km)		Scheduled to come on stream
Poza Rica	243	0.60	> 100 From Chicontepec	Retrofit	2016
Güemez	360	0.89	> 100 From Chicontepec	Retrofit	2016
Monterrey	303	0.75	200 from Burgos	Retrofit	2016
Monterrey	949	2.34	200 from Burgos	Retrofit	2016
Monterrey	884	2.18	200 from Burgos	Retrofit	2018
Tamazunchale	450	1.11	> 100 From Chicontepec	Retrofit	2018
Monterrey	1000	2.46	200 from Burgos	Retrofit	2019
San Luis Potosí	812	2.00	400 From Chicontepec	Capture ready	2019
Tamazunchale	1013	2.50	100 From Chicontepec	Retrofit	2020
Total	6014	14.83			

[a] Unabated CO_2 emissions.

Mexico: (1) Exhaust gas recirculation (National Energy Technology Laboratory, 2013), (2) Series membrane/solvent hybrid capture system (Merkel et al., 2012; Voleno et al., 2014; Swisher and Bhown, 2014), (3) Parallel membrane/solvent hybrid capture system (Merkel et al., 2012), (4) Natural gas combined cycle with duct firing (Li et al., 2012), (5) Sequential supplementary firing as a suitable option for CCS-EOR Mexico (González Díaz et al., 2016), and (6) absorber intercooling in the capture process (Darshan and Rochelle, 2014). These alternatives should be analysed for CCUS readiness and their implications for retrofit studied. These alternatives could be attractive especially for a power plant that is expected to incorporate carbon capture in the long term.

7. Conclusion

A series of new gas-fired power plants with a total capacity of 6014 MW is currently planned for construction in Mexico, less than 400 km from significant hydrocarbon reservoirs where CO_2 would be injected for EOR.

We propose that the next step for nine power plants located in the inclusion zone and close to the oil fields: one in Poza Rica, one in Güemez, four in Monterrey, two in Tamazunchale, and one in San Luis Potosi requires a technical feasibility study to assess whether they could be built as CCUS- ready or whether they could be cost-effectively retrofitted with CCUS. These power plants would supply CO_2 for the purpose of Enhanced Oil Recovery and could be considered as a priority CCS project in Mexico.

Overall, new gas-fired power stations built in the period 2016–2030 are expected to result in emissions of up to 29.64 $MtCO_2/y$. Based on the distance and location from the oil field, 14.83 $MtCO_2/y$ could be connected to EOR projects. As a result, they could supply a large fraction of the demand of CO_2 for EOR, estimated to be 50 $MtCO_2/y$ in Mexico (Lacy et al., 2013).

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