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# Feasibility Study of Carbon Dioxide Capture from Power Plants and other Major Stationary Sources and Storage in Iranian Oil Fields for Enhanced Oil Recovery (EOR)

Mohammad Soltanieh\*

*Department of Chemical and Petroleum Engineering, Sharif University of Technology, 11365/8639, Tehran, Iran*

Amir Mohammad Eslami

*Islamic Azad University, Science and Research Unit  
Hesarak, Tehran, Iran*

Adnan Moradian

*Electric Power Research Center  
Ministry of Energy  
Tehran, Iran*

## Abstract

Iran, with a record of over one century of oil production, is currently one of the major oil producing countries of the world. Several of the old fields have been depleted to an uneconomical level of production which requires significant amount of natural gas for re-injection so that currently over 100 million cubic meters of natural gas is re-injected daily to maintain or enhance oil production to an economical level. It is estimated that in order to maintain oil production, over 200 million cubic meters of natural gas will be needed daily by 2015. However, due to the increased level of domestic and export demands for natural gas, EOR with natural gas is prohibitive and therefore portions of this amount of natural gas can be substituted by carbon dioxide. At the same time over 100 million tons of carbon dioxide is emitted from thermal power plants of Iran with annual consumption of approximately 35000 million cubic meters of natural gas among other fuels. The amount of CO<sub>2</sub> which is produced in power plants in the vicinity of oil fields with relatively short pipelines for CO<sub>2</sub> transport, however, provides only approximately 12.5 % of the gas required for injection. It is expected that the power production will have an annual rate of increase of about 11% during the next 10 years which will produce more greenhouse gas and consumes more natural gas. Considering the estimated oil reserves of Iran, even one per cent of EOR is equivalent to approximately 5 billion

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\* Corresponding author. Tel.: +98 21 6616 5417; fax: +98 21 6602 2853.

E-mail address: [msoltanieh@sharif.edu](mailto:msoltanieh@sharif.edu)

barrels of enhanced oil recovery. Depending on the oil well structure and the pressure of operation, it is estimated that with one ton of CO<sub>2</sub> injection, there will be from 2 to 8 barrels of oil enhance oil recovered. With the increasing price of oil and the possibility of utilizing the Clean Development Mechanism (CDM) of the Kyoto Protocol, the economy of EOR with CO<sub>2</sub> becomes more favourable.

*Keywords: carbon dioxide capture and storage, power plant, enhanced oil recovery*

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## Introduction

The Iranian on-shore oil fields have experienced an annual depletion in productivity between 9 to 11 percent which can be enhanced by secondary or tertiary recovery. Considering that most of the reservoirs are of the carbonated fractured type containing heavy crude, the selection of the optimum secondary or tertiary recovery method is of great importance. In 2004 the total recoverable oil reserve of Iran was 136.99 billion barrels out of the total reserve of 580 billion barrels. The reducing trend of production of some of the southern oil fields of Iran is shown in Figure 1.

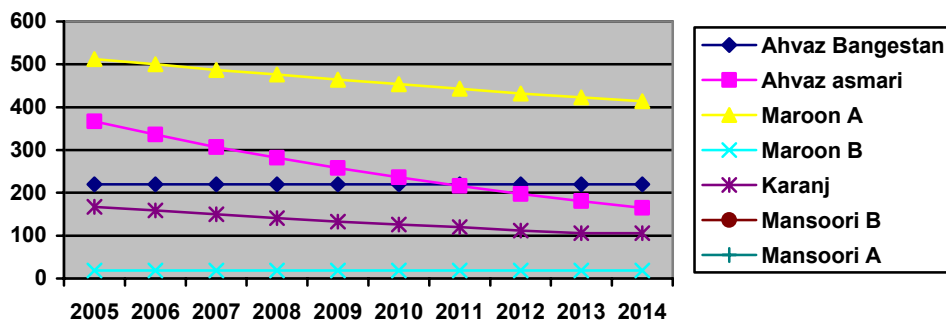


Figure 1. The trend of oil production in some Iranian oil fields during 2004-2014 (1000 barrels).

It is estimated that in a 20-year period from 1995 to 2014, approximately 217 million cubic meters per day of natural gas or associated gas will be needed to sustain the oil production. This amount of gas will be supplied through South Pars, North Pars, Aghar Dalan, Sylatun, Ghalae Nar and Pazanan oil fields. Based on two scenarios, one with underestimation and the other with overestimation, it is anticipated that in 2025, these oil fields require between 124 and 204.2 billion cubic meters of gas per year for EOR.

## Trend of CO<sub>2</sub> emission from stationary sources in Iran

The emission of CO<sub>2</sub> from the energy sector of Iran has had a sharp increasing trend in recent years. The emission of CO<sub>2</sub> has increased from 240.36 million tons per year in 1994 to about 381.9 million tons in 2005, showing a growth of 58.8 percent. In 2005 the power generation and industrial sector alone have contributed to more than 40.5 percent of the total CO<sub>2</sub> emission. In this year emission from power plants was about 95.793 million tons and emission from steel, cement and chemical industries was about 58.937 million tons. Figure 2 shows the emission trend of CO<sub>2</sub> in power plant from 1994 to 2005. It can be seen that the average annual growth rate of CO<sub>2</sub> emission has been 7.9 percent compared with the overall growth rate of 7.2 percent in all sectors. It is anticipated that with this level of growth rate the emission of CO<sub>2</sub> from power plants in 2025 will reach to 247 million tons per year and the overall emission of all sectors will reach to 930 million tons annually, which are alarming figures.

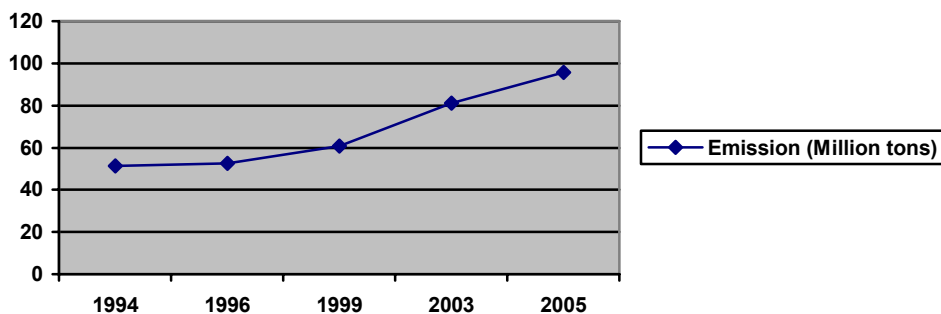


Figure 2 CO2 emission trend from power plants of Iran during 1994-2005.

### Geographical distribution of sources and sinks

Thermal power plants and large stationary sources such as steel, cement and chemical industries which have hydrogen plants are the major sources of emission that are considered in this study. Since the information on power plants were readily available and these sources have major contribution to CO<sub>2</sub> emission, in this feasibility study quantitative analysis was focussed on this sector; other sectors were discussed qualitatively only. Table 1 shows the type, the nominal and production capacity of the power plants in Iran.

Item	Type of power plant	Nominal annual capacity (Million kWh)	Actual annual production (Million kWh)	Capacity factor (%)
1	Steam cycle	124,067	85,403	68.9
2	Gas turbine	508,080	17,262	34.0
3	Combined cycle	52,612	32,894	62.5

Figure 3 shows the geographical distribution of major stationary sources with emission of more than one million tons per year in Iran. From this figure it can be seen that in south-west of Iran and near the Persian Gulf there is favourable proximity between sources of CO<sub>2</sub> and sinks for injection of CO<sub>2</sub> for the purpose of EOR.

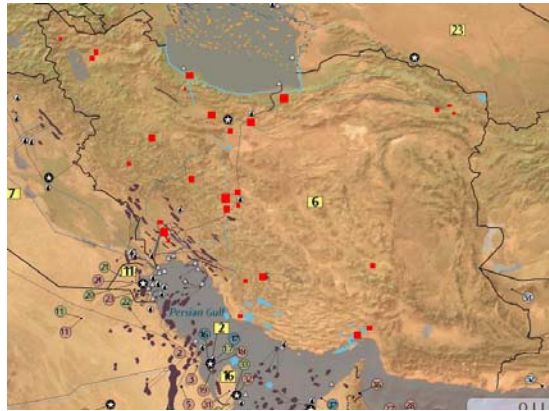


Figure 3. Geographical distribution of major stationary sources in Iran. Red squares indicate the power plants and the purple areas indicate the oil fields.

### Suitability and selection of reservoirs for CO<sub>2</sub> injection

In site selection for injection of CO<sub>2</sub> the miscibility of the gas with oil is of great importance. Compared with the miscible case, in the immiscible case the amount of C<sub>7+</sub>, well depth, well pressure and temperature are of less importance. The immiscible ones are also more suitable for heavy oils whereas for oils with API gravity of more than 25, the miscible ones are advantageous.

In order to assess the suitability of reservoirs of the Khuzestan Province in south-west Iran where most on-shore reservoirs are located, information of 11 reservoirs were collected and it was found that 5 of them are suitable reservoirs for CO<sub>2</sub> injection with respect to the type of reservoir and the distance to major sources of CO<sub>2</sub> emission. Other information such as the in-situ amount of oil, production capacity, reservoir's porosity, thickness of the core, area of the reservoir, oil viscosity and density, reservoir pressure, saturation water, the amount of carbon dioxide and hydrogen sulphide and the heavy hydrocarbons were also investigated.

The efficiency of oil displacement increases as the initial saturation of oil increases. It is therefore recommended that the saturation of oil should be more than 30% for CO<sub>2</sub> EOR to be effective. Among different reservoirs that were under study, Ahwaz reservoir has higher saturation and thus a good candidate for CO<sub>2</sub> injection. Viscosity of oil in most of the reservoirs under investigation was suitable for CO<sub>2</sub> injection except for three of them which have too small viscosities for this purpose. Based on this screening step, the volumes of all suitable reservoirs were estimated, and from the information on the reservoir porosity and oil saturation the maximum amount of carbon dioxide that can be stored in these fields was calculated. The effective volume of the reservoir, UPV, was calculated from:

$$UPV = QV \cdot (S_i - S_o)$$

Where QV is the total volume of the porous medium, S<sub>i</sub> is the initial saturation index and S<sub>o</sub> is the final saturation index. Among the reservoirs under the study, Ahwaz reservoir has the highest free (effective) volume. Our estimation shows that, this reservoir with porosity of 0.14, initial pressure of 5700 psig and initial saturation of 0.4 can store up to 1,400 million tons of carbon dioxide. Ahwaz area's major Bangestan reservoirs are located in vicinity of the city of Ahwaz in south-west of Iran. These reservoirs have been explored in the period from 1958 to 1968. Production from these fields started in 1971 and since then about 100 wells were drilled in that area. These reservoirs consist of Ilam and Sarvak formations which are mainly of carbonated type with very limited fractures. Thus most of the produced oil comes from the reservoir matrix. Initial pressure of this reservoir was more than 5500 psig. At this high pressure, miscibility condition would be achieved even by injection of relatively dry gases which

indicates that in further development of these fields miscible gas injection should be considered. In 2005 the amount of natural gas for injection in this field was 11.173 million cubic meters per day, whereas only 2.653 million cubic meters of associated gas was available in the nearby fields. Considering the expansion project planned until 2020, the associated gas needed for re-injection will be approximately 5.44 million cubic meters per day; which is far below the amount needed for EOR as mentioned above.

## Case Study

Ramin power plant located at 25 kilometres north-east of the city of Ahwaz was selected as the source of CO<sub>2</sub> and the Ahwaz oil fields were selected as the storage site to study the feasibility of CO<sub>2</sub> storage for EOR. Ramin power plant contains 6 units of 350 MW steam turbines with the total nominal capacity of 1890 MW and the actual production capacity of 1748 MW. The average thermal efficiency of the power plant is about 37.2%. The plant consumes 70,000 cubic meters of natural gas per hour which produces about 4,8 million tons of CO<sub>2</sub> per year. A picture of this power plant is given in Figure 4.



Figure 4. A picture of Ramin power plant near Ahwaz

The amine absorption plant using MEA solvent with the feed supplied by the power plant was simulated by a suitable software. This plant was designed for a capacity of 149.6 million cubic meters per day. A compression station to supply the pressure needed for transport of CO<sub>2</sub> and to provide the necessary pressure for reinjection was also designed for this feasibility study.

## Economic Evaluation of the Project

It is estimated that the cost of separation, transport and injection of CO<sub>2</sub> will be around millions US\$1,071.7. This cost does not take into account the benefit gained from EOR nor does it take into account the environmental benefits as a result of CO<sub>2</sub> avoided. Several scenarios for the price of oil per barrel were considered including: \$ 28, \$ 35, \$ 45, \$55 (IEA price model for September 2008), \$77 and \$85 (the average 2008 price). For two scenarios of EOR of 20,000 barrels per day and 33,600 barrels per day which are based on the current practice of EOR with natural gas injection, the seven scenarios assumed for the price of oil as mentioned above and with two options of “with” and “without” carbon trading or CDM, our estimate shows that the rate of return of the investment varies from 1 to 6.5 years. At the current price of oil (\$85) and without carbon trading, the rate of return is only 1.06 years.

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## Conclusions

This study shows that carbon dioxide capture and storage is feasible for Iran for several reasons:

1. There are large stationary sources of carbon dioxide emission at reasonable distances from Iranian oil fields.
2. The production of many oil reservoirs has been depleted, which require enhanced oil recover (EOR) for both domestic use and export.
3. There are suitable reservoirs with respect to the type and capacity for CO<sub>2</sub> injection and storage in the area.
4. Of the total CO<sub>2</sub> emission of 4.8 million tons in Ramin power plant near the city of Ahwaz in south-western Iran, about 3.92 million tons (81%) can be captured and stored in Ahwaz oil fields.
5. Our estimate shows that EOR can significantly improve the economy of the project with additional benefit if the avoided CO<sub>2</sub> emission can be traded or sold as a CDM certified emission reduction (CER).

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