CARBON DIOXIDE RESOURCE ASSESSMENT – OIL AND GAS FIELDS OF CALIFORNIA

Stephen D. Thomas

Golder Associates Inc.

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Golder Associates Inc.
2200 6th Avenue, Suite 600
Seattle, Washington 98101
Telephone: (206) 267 1166
Fax: (206) 267 1167

TECHNICAL MEMORANDUM

TO:	Larry Myer, Ph.D. – CIEE	**DATE:**	December 16, 2008
CC:	Paul R. LaPointe, Ph.D.	**OUR REF:**	063-1282.500
FR:	Stephen D. Thomas, C.HG.		
RE:	**CARBON DIOXIDE RESOURCE ASSESSMENT – OIL AND GAS FIELDS OF CALIFORNIA**		

1.0 INTRODUCTION

WESTCARB (the West Coast Regional Carbon Sequestration Partnership) is one of seven research partnerships co-funded by the U.S. Department of Energy (DOE) to characterize regional carbon sequestration opportunities and to develop action plans for pilot-scale validation tests. WESTCARB is exploring opportunities in a six-state region (California, Oregon, Washington, Nevada, Arizona, and Alaska) for removing carbon dioxide (CO_2) from the atmosphere by enhancing natural processes and by capturing it at industrial facilities before it is emitted; both will help slow the atmospheric buildup of this greenhouse gas (GHG) and its associated climatic effects.

A key part of the project is identifying subsurface locations to store the captured CO_2; such sinks include deep geologic formations such as oil and gas reservoirs, and saline formations that are essentially leak-proof. These potential sinks will then be matched with the major CO_2 sources such as the main utilities and industrial emitters. In addition to identifying subsurface locations, an estimate of the total storage capacity of these locations needs to be made.

Golder Associates, Inc. (Golder) has been contracted to determine estimates for the storage capacity (or resource) of depleted and active onshore oil and gas reservoirs for the state of California. using historical production and current (2005) reserve data. Estimates were made on a field level and do not include State- or Federally-owned offshore fields. The following document provides the methodology used for capacity estimation and the results of the numerical analysis.

2.0 METHODOLOGY

2.1 Overview

The principles used to estimate CO_2 storage capacity of oil and gas reservoirs are outlined in publications prepared for the Department of Energy's National Energy Technology Laboratory (DOE, 2008). The fundamental assumption for estimating the storage resource is that the volume in the reservoir that was occupied by the produced hydrocarbons (oil or gas) becomes fully available for

CO_2 storage. Estimation also assumes that the CO_2 will be injected into the depleted oil and gas reservoirs until the reservoir pressure is brought back to the original reservoir pressure.

2.2 Previous Resource Estimates

In 2006, the California Department of Conservation (CDOC) developed estimates for onshore CO_2 resource storage potential using volumetric information for fields and basins. This involved calculating the volume of each field beneath a threshold depth, applying reservoir properties such as porosity) and assuming a subsurface CO_2 density of 700 kg/ m^3 (equivalent to an average depth of 800 meters). The results are summarized below:

TABLE 1

Summary of Oil and Gas Storage Estimates using Volumetric Methodology

Fields Group	No. Fields	Storage capacity	
		Millions of metric tons(1)	*Giga metric tons* (2)
Oil	176	3,563	3.56
Gas	128	1,666	1.67
Total		5,229	5.23

Notes: (1) – Mt; (2) – Gt.

2.3 Revised Methodology

2.3.1 Overview

A revised methodology was selected to perform the resource estimate calculations. This methodology is presented in the Dept. of Energy's Guidance Manual (August 2008; pages 9 through 12) and is based on using production and reserve records (rather than volumetric data). High and low estimates were made for both onshore oil and gas reservoirs in California on a field basis based on historical production and field pressure and temperature data obtained from the 2005 annual oil and gas report by the CDOC (CDOC, 2005). The sum of the estimates obtained from oil and gas data gave a total estimate for the CO_2 storage capacity in a given California field. Estimates were also obtained for each California basin by summing the estimates of the fields within each basin, and for the entire state of California. The specific methods for oil and gas and oil reservoir records are described in the following sections.

2.3.2 CO_2 Capacity Estimation of Oil Reservoir

The theoretical mass of CO_2 ($M_{CO2,t}$) that can be stored in an oil reservoir can be estimated from the historical volume of oil produced (V_{prod}) and the estimated volume of oil remaining in the reservoir ($V_{reserves}$) using the following equation:

$$M_{CO2,t} = \rho_{CO2,r} \frac{V_{prod} + V_{reserves}}{B_f}$$

where B_f is the volume formation factor of the reservoir and $\rho_{CO2,r}$ is the in situ density of carbon dioxide. Based on the gas law the mass can be expressed in terms of the pressure and temperature as follows:

$$M_{CO2,t} = \frac{\left(V_{prod} + V_{reserves}\right) \cdot P_r \cdot T_s \cdot Z_{CO2,s}}{B_f \cdot P_s \cdot T_r \cdot Z_{CO2,r}}$$

Since multiple pressures and temperatures were given for each field, a high mass estimate and low mass estimate was made for each field. High mass estimates were obtained assuming a volume formation factor of 1.2 and by applying the pool pressure and temperature that resulted in the highest mass when applied to the entire field. Low mass estimates were obtained by assuming a volume formation factor of 1.5 and applying the pool pressure and temperature that resulted in the lowest mass estimate when applied to the entire field.

2.3.3 CO_2 Capacity Estimation of Gas Reservoir

The theoretical mass of CO_2 ($M_{CO2,t}$) that can be stored in a gas reservoir can be estimated using the following equation:

$$M_{CO2,t} = V_{NR,r} \cdot \rho_{CO2,r}$$

where $V_{NG,r}$ is the volume of natural gas originally in the reservoir (i.e. the volume of the reservoir occupied by gas) and $\rho_{CO2,r}$ is the in situ density of carbon dioxide both of which are pressure (P) and temperature (T) dependent. By using the gas factor for natural gas (Z_{NG}) for both surface conditions (s) and reservoir conditions (r), the gas law (PV=ZnRT) can be used to estimate gas reservoir volume from gas surface volume, where the surface volume is the sum of the produced gas (V_{prod}) and the estimated reserves ($V_{reserves}$), with the following equation:

$$V_{NG,r} = \frac{\left(V_{prod} + V_{reserves}\right) \cdot P_s \cdot T_r \cdot Z_{NG,r}}{P_r \cdot T_s \cdot Z_{NG,s}}$$

The density of CO_2 at reservoir conditions can also be estimated using the gas law and the gas factor for CO_2 at both surface conditions and reservoir conditions with the following equation:

$$\rho_{CO2,r} = \rho_{CO2,s} \frac{P_r \cdot T_s \cdot Z_{CO2,s}}{P_s \cdot T_r \cdot Z_{CO2,r}}$$

Therefore, the mass of CO2 that can theoretical stored in the gas reservoir can be expressed as a function of the reservoir pressure and temperature as follows:

$$M_{CO2,t} = \left(V_{prod} + V_{reserves}\right) \frac{Z_{NG,r} \cdot Z_{CO2,s}}{Z_{NG,s} \cdot Z_{CO2,r}}$$

The gas factors for both natural gas and carbon dioxide are pressure and temperature dependent and were estimated for each reservoir using an Excel spread sheet used to estimate pressure, volume, and temperature properties of oil and gas (McMullan, 2007). Production volumes and reserve volumes were obtained for each field from data compiled in the 2005 annual oil and gas report by the California Department of Conservation (CDOC, 2005).

However, the data contained pressure and temperature data by pool (field subset) rather than by field. Therefore, each gas field contains multiple pressure and temperature data. Since multiple pressures and temperatures were given, a high mass estimate and low mass estimate was made for each field.

High mass estimates were obtained by applying the pool pressure and temperature that resulted in the highest mass when applied to the entire field, and low mass estimates were obtained by applying the pool pressure and temperature that resulted in the lowest mass estimate when applied to the entire field.

3.0 RESULTS

Table 2 summarizes the total oil and gas records obtained for 2005 by basin, and Figures 1 and 2 show the total oil and gas (produced and reserve) for each basin graphically. Three basins – the Central Valley, Los Angeles and Ventura – contribute 86 percent and 94 percent of the total oil and gas for the State, respectively.

Table 3 summarizes the low and high estimates for CO_2 resource potential for oil fields, gas fields and combined by basin using both produced and reserve capacities. The total resource estimates range from 0.31 Gt (low) to 1.17 Gt (high). The potential storage in oil fields contributes the majority of these total estimates (up to 99 percent). The largest potential is found in the Central Valley Basin (60 percent of the total for the high estimate) and Los Angeles (41 percent of the total for the low estimate).

- Low Estimate – from Oil Fields 0.30 Gt (metric tons x 10^9)
- High Estimate – from Oil Fields 1.16 Gt

- Low Estimate – from Gas Fields 0.003 Gt
- High Estimate – from Gas Fields 0.005 Gt

- Low Estimate – from Oil and Gas Fields 0.31 Gt
- High Estimate – from Oil and Gas Fields 1.17 Gt

The revised estimates are therefore significantly smaller than those developed using the volumetric approach by CDOC (see Table 1; Section 2.2). The new oil (high) estimate is approximately 33 percent of the original oil field volume, and the new gas (high) estimate is 0.3 percent of the original value.

4.0 REFERENCES

Bachu, S. 2008. Comparison between Methodologies Recommended for Estimation of CO_2 Storage Capacity in Geological Media by the CSLF Task Force on CO_2 Storage Capacity Estimation and the USDOE Capacity and Fairways Subgroup of the Regional Carbon Sequestration Partnerships Program, Phase III Report.

CDOC, 2005. Annual Report of the State of the Oil & Gas Supervisor, California Department of Conservation, Division of Oil, Gas, & Geothermal Resources, Publication No, PR06

DOE, 2008. Methodology for Development of Geological Storage Estimates for Carbon Dioxide. Capacity and Fairways Subgroup of the Geologic Working Group of the DOE Regional Carbon Sequestration Partnerships; August, 2008.

McMullan, J. (2007). PVT Properties of Oil, Gas, and Water Add-in for Microsoft Excel. http://www.enrg.lsu.edu/pttc/pvt/

Attachments;

Tables

Table 2 Summary of Oil and Gas Production and Reserves by Basin (2005)
Table 3 Summary of Carbon Dioxide Resource Estimates by Basin

Figures

Figure 1 Reported Oil Produced and Reserve (2005) – By Basin
Figure 2 Reported Gas Produced and Reserve (2005) – By Basin
Figure 3 Estimated Resource Potential in Oil Fields – By Basin
Figure 4 Estimated Resource Potential in Gas Fields – By Basin
Figure 5 Total Oil and Gas Fields Resource Estimate – Low Estimate
Figure 6 Total Oil and Gas Fields Resource Estimate – High Estimate

TABLES

TABLE 2

Summary of Oil and Gas Production and Reserves by Basin (2005)

Basin	No. Fields	Oil Produced *(bbl x 10^9)*	Oil Reserve *(bbl x 10^9)*	Oil – Total *(bbl x 10^9)*	Gas Produced *(Tcf)*	Gas Reserve *(Tcf)*	Gas – Total *(Tcf)*
Central Valley	276	13.64	2.26	15.90	22.28	2.08	24.36
Cuyama	9	0.72	0.04	0.76	0.572	0.02	0.59
Eel River	2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
La Honda	4	0.27	<0.01	0.28	0.31	0.01	0.32
Livermore	2	<0.01	<0.01	<0.01	0.12	<0.01	0.12
Los Angeles	70	5.73	0.19	5.92	6.26	0.11	6.37
Orinda	2	2.70	0.34	3.04	1.24	0.08	1.32
Salinas	11	0.12	0.01	0.13	0.01	0.01	0.02
Ventura	87	3.01	0.16	3.17	4.54	0.08	4.63
Totals	**463**	**26.2**	**3.00**	**29.2**	**35.32**	**2.40**	**37.7**

Note: bbl = barrels; Tcf = trillions of cubic feet
Source: CDOC, 2005

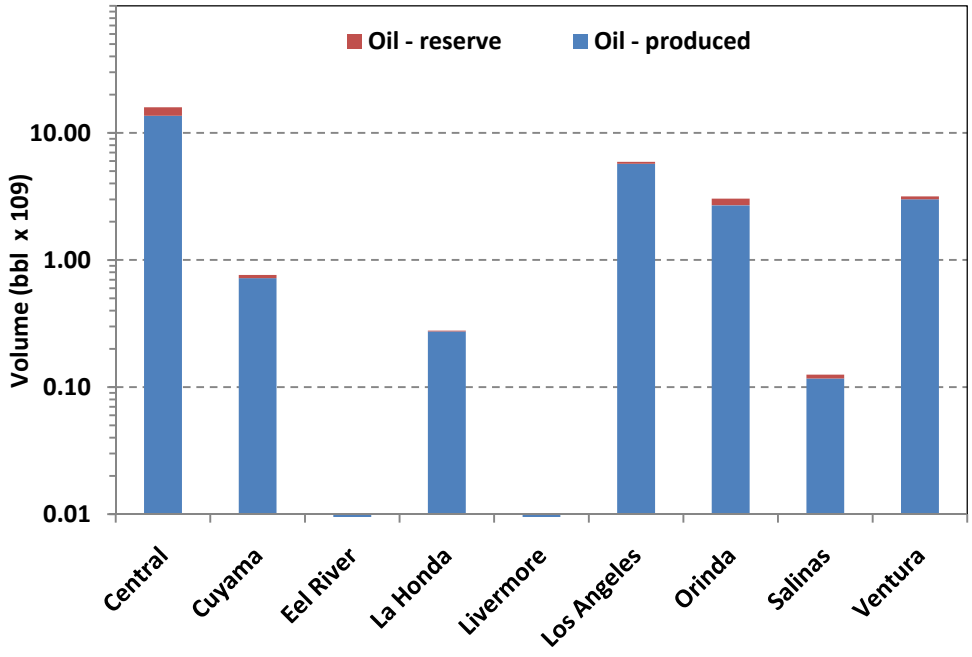
TABLE 3

Summary of Carbon Dioxide Resource Estimates by Basin

Basin	No. Fields	Oil		Gas		Total	
		Low Estimate	*High Estimate*	*Low Estimate*	*High Estimate*	*Low Estimate*	*High Estimate*
Central Valley	276	112,899.4	700,833.9	1,842.6	3,285.9	114,742.0	704,119.8
Cuyama	9	7,638.4	39,424.4	55.2	113.2	7,693.7	39,537.6
Eel River	2	<0.1	<0.1	18.1	18.1	18.1	18.1
La Honda	4	89.3	113.7	0.1	0.1	113.8	89.3
Livermore	2	78.0	169.0	28.0	35.0	105.9	204.1
Los Angeles	70	125,130.8	297,173.8	705.1	1,076.5	125,835.9	298,250.4
Orinda	2	0.1	0.6	0.1	0.1	0.2	0.7
Salinas	11	4,493.0	7,353.1	5.8	6.3	4,498.8	7,359.4
Ventura	87	54,455.2	115,640.2	380.7	643.8	54,835.9	116,274.9
Totals	**463**	**304,784**	**1,160,709**	**3,036**	**5,170**	**307,820**	**1,165,879**

Note: all units are millions of metric tons (Mt)

FIGURES



Source: CDOC, 2005

Golder Associates	TITLE: Reported Oil Produced and Reserve (2005) – By Basin				
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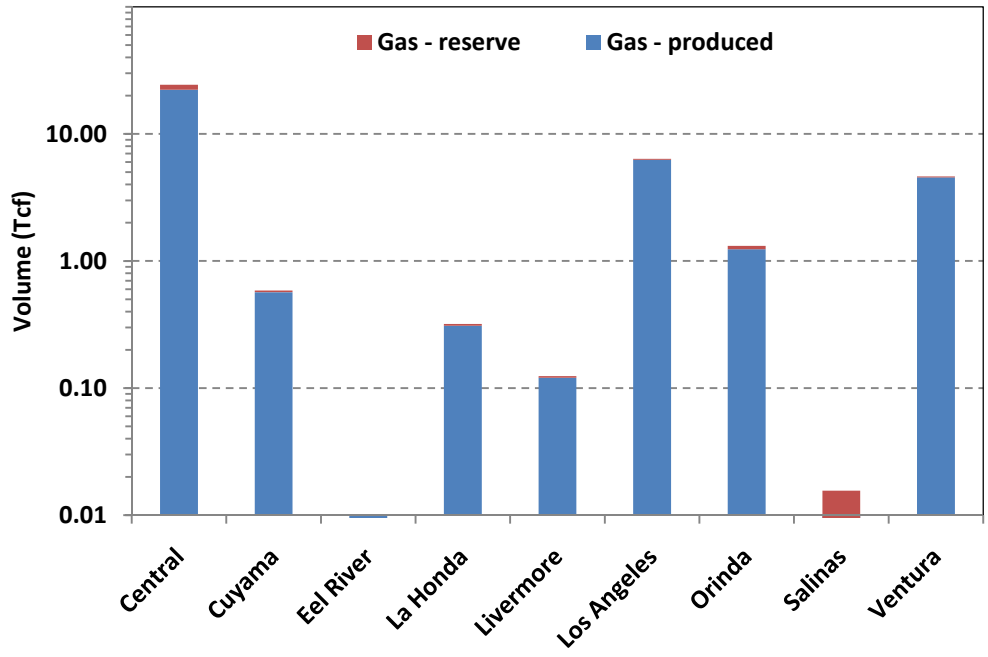

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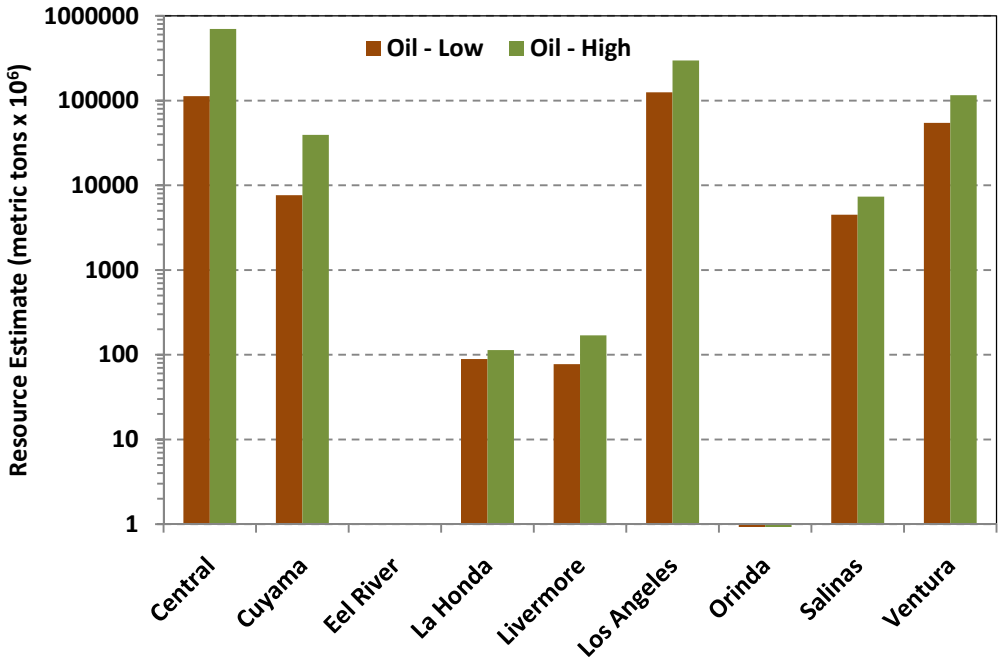

Golder Associates

TITLE: Estimated Resource Potential in Oil Fields – By Basin

WESTCARB – Resource Estimates for Oil and Gas Fields in California

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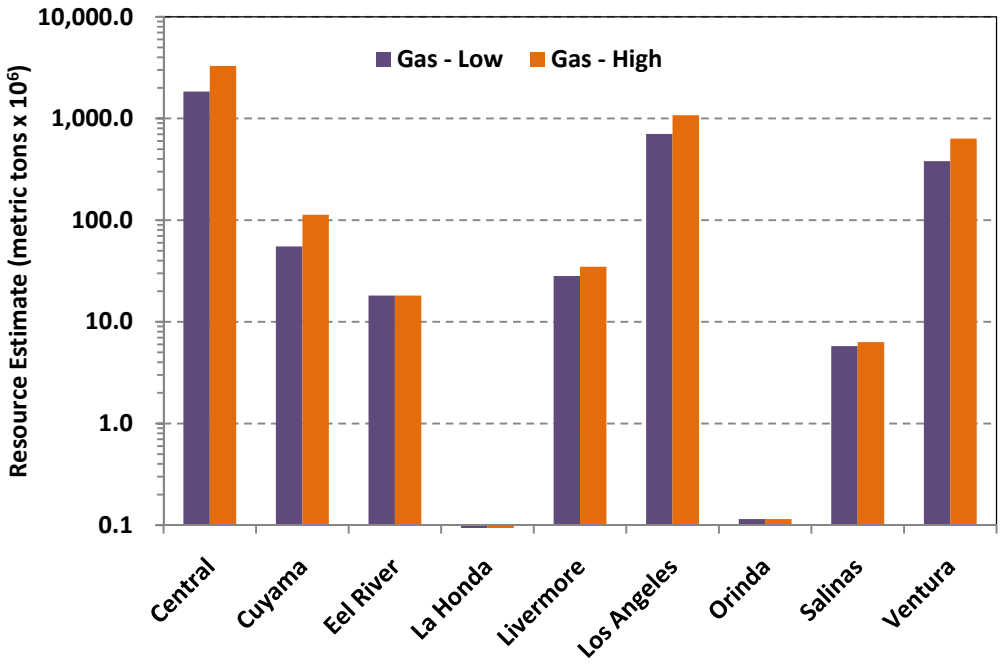

Golder Associates

TITLE: Estimated Resource Potential in Gas Fields – By Basin

WESTCARB – Resource Estimates for Oil and Gas Fields in California

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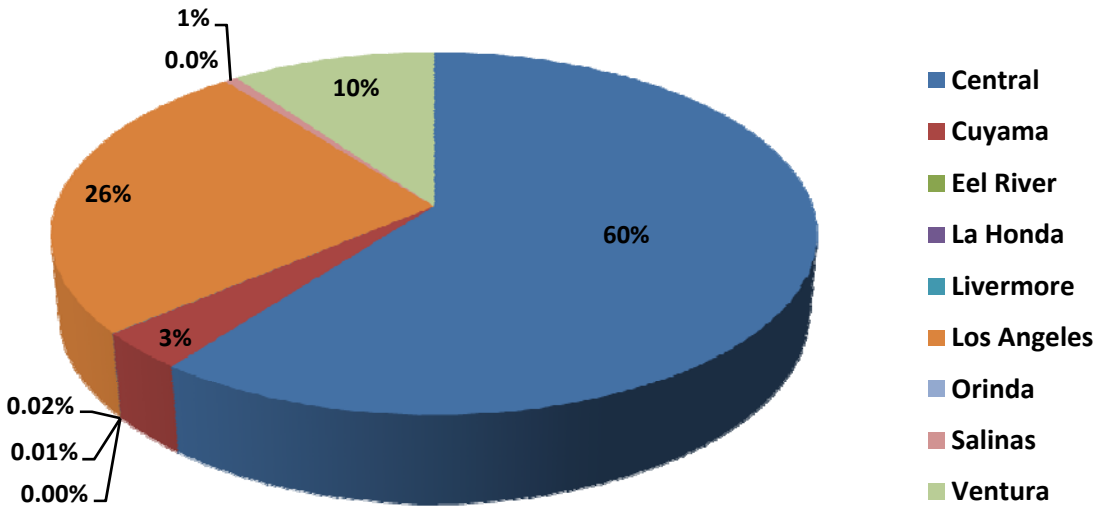

Golder Associates

TITLE: Total Oil and Gas Fields Resource Estimate – Low Estimate

WESTCARB – Resource Estimates for Oil and Gas Fields in California

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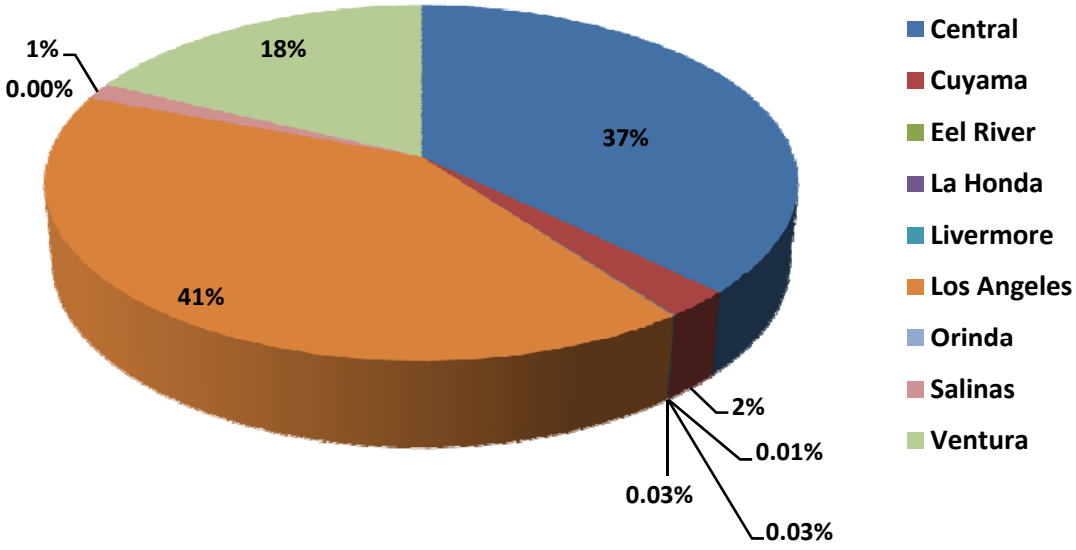

Golder Associates

TITLE: Total Oil and Gas Fields Resource Estimate – High Estimate

WESTCARB – Resource Estimates for Oil and Gas Fields in California

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