

THE FUTURE OF OIL IN MEXICO

/ EL FUTURO DEL SECTOR PETROLERO EN MÉXICO



Oil and Gas in Mexico: Geology, Production Rates and Reserves

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OIL AND GAS IN MEXICO:
GEOLOGY, PRODUCTION RATES AND RESERVES

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ABOUT THE STUDY: THE FUTURE OF OIL IN MEXICO/ EL FUTURO DEL SECTOR PETROLERO EN MÉXICO

The energy industry plays an important role in the Mexican economy, and energy trade is a major component to the U.S.-Mexico relationship. The Mexican government relies on the oil industry for 35 percent of total government revenues, including taxes and direct payments from Petróleos Mexicanos (Pemex), the state oil company. Mexico is the third-largest foreign crude oil supplier to the United States. However, with declining production and rising demand, Mexico could become a net oil importer in the coming decade. President Calderón pushed for energy sector reform in Mexico, but more reforms will be needed for Mexico to reverse its current path toward importer status. This study identifies the dynamics of the political trends in Mexico that will impact future energy policy. The aim of this study is to promote a better understanding of the challenges facing Mexico's oil sector and to enhance the debate among policymakers, the media and industry on these important issues.

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Abstract¹

Historically, Mexico has been one of the largest producers of oil in the world. At one time its production rate was second only to Saudi Arabia. But its existing reserves are low, and at the present rate of production, will last only about nine more years. The source rocks, for the most part, were deposited in the early Mesozoic. Differing geological episodes in different parts of the country, as well as differences in the type of kerogen, have resulted in the production of differing varieties of hydrocarbons. In the north, the Laramide orogeny resulted in a mountain chain, the Sierra Madre Oriental, that in geological terms is known as a fold and thrust belt. Paralleling this chain is a deep valley, known geologically as the foredeep, in which thick layers of sediment were deposited. The deep burial of source rocks led to their overmaturation and consequent generation of gas, which is produced in the Sabinas basin and in the western parts of the Burgos and Veracruz basins. The reservoirs that contain the gas are often Tertiary sands.

Almost all the production of oil at the present time comes from the Sureste (southeast) basin. This area was not subjected to an orogeny that produced a fold and thrust belt and a parallel foredeep. In the offshore parts of this basin, salt tectonics are most important in giving rise to structural and stratigraphic traps. The source beds containing oil-prone kerogens did not overmature and much oil was generated. However, production in the Sureste basin is declining, which is a source of much concern.

As far as the future is concerned, the Chicoutopoc basin with its large deposits of “in-place heavy oil” is an important target. The geological nature of the reservoir makes it difficult to apply conventional enhanced oil recovery (EOR) techniques. Barring sudden technological breakthroughs in the development of new EOR techniques, a process that is generally incremental, the recovery rates will only increase slowly, taking many years.

Exploration in the deep sea with the possibility of large subsalt reservoirs also holds much promise. Known technology is applicable, but even discoveries based on ongoing geophysical

¹ The expert help of Esther Rios in accessing various data sources and especially in compiling Table 1 is gratefully acknowledged.

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surveys will lead to production of oil in no less than three to five years in the most optimistic case. In any event, large investments will be necessary, and risks associated with these efforts will be large.

I. Introduction

Mexico is a country with high production rates of crude oil. As of 2010, it ranked seventh in the world ahead of Norway, the United Kingdom, Venezuela, Iraq, and Brazil. It produces more oil than it consumes. It exports the rest, which is obviously important for its economy. But it ranks only 17th in the world in total oil reserves. A comparison with Saudi Arabia is instructive. Mexico's production is about one-fourth of Saudi Arabia's, but its reserves are only about one-twentieth that of Saudi Arabia. The obvious consequence of high rates of production but low reserves is that the reserves will not last very long. At present rates of production, the estimated life of proven reserves is low—about nine years.

Most of Mexico's present production comes from Sureste basin. For many years the most prolific field in the Sureste basin was the super-giant Cantarell field. Production from the Cantarell field has been declining since 2004, a decline that has not been made up by new discoveries. (Fields discovered earlier—for example, on the “Golden Lane” in the Tampico-Misantla basin—had substantial production at one time. The Cerro Azul No.4 had the highest production rate of any field in the world in 1916. Production in these fields has also declined). Most Mexican oil exports go to the United States and constitute a major part of Mexico's total exports. The decline of Mexican oil production is particularly serious for the United States, which imports roughly 10 percent of its total oil imports from Mexico.

On the other hand, all of the produced natural gas is used domestically. Any changes in production (which are predicted not to be major) will not alter the export picture.

In the following paper, I examine the various oil and gas producing basins in terms of their geological history, source rocks and reservoirs, rates of production, and estimated reserves. I

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then describe some of the most prolific fields, and finally I summarize the present state of oil and gas production as well as future prospects.

The rates of production and the reserve estimates have been gathered from various sources listed in the bibliography. The reserve and production estimates used in this paper are based on the literature reviewed and cited in the bibliography at the end of this paper and do not represent independent assessments by the author.

(The following terms used in this paper are well established names for geologic ages: Paleozoic, Mesozoic, Tertiary, Quarterniary, Permian, Jurassic, Cretaceous, Oligocene, Miocene, Oxfordian, Kimmeridgian, Tithonian and Turonian.)

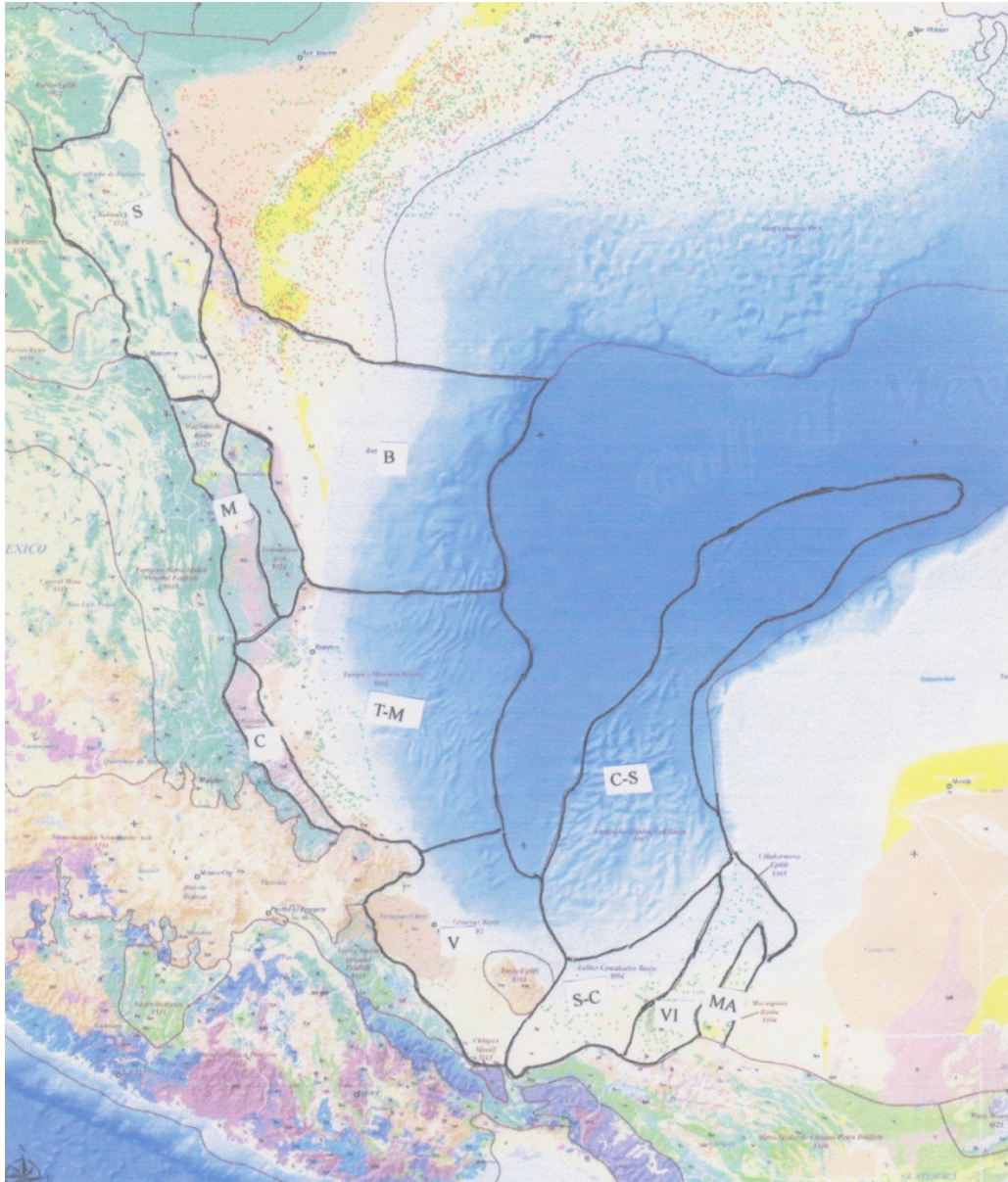
II. Location and Boundaries of Basins

Mexico has several oil and gas producing basins. The extent of the basins, their boundaries, and how they are divided into sub-basins are not always very clear. For our purposes, I have utilized maps from the U.S. Geological Survey (USGS) (Figure 1) and from Pemex (Figure 2). The descriptions, extent, and nomenclature in the two figures are not always identical. I discuss the similarities and differences.

Sabinas basin is similar in both Figures 1 and 2. Burgos is also similar, except that in Figure 1 it extends offshore, while in Figure 2, the deep Gulf of Mexico is considered a separate basin. In Figure 1, the Tampico-Misantla is shown as a single basin and Chicontepec basin is considered a separate basin. In Figure 2, Tampico and Misantla are considered separate basins, but Chicontepec is included within them. The Veracruz basin is the same in both figures. The Southeastern (Sureste) basin in Figure 2 consists of several sub-basins. Figure 1 shows them as separate basins: Saline-Comalcalco, Campeche-Sigsbee, and Macuspana basins and the Villahermosa uplift. In Figure 2 the Sureste basin is divided somewhat differently.

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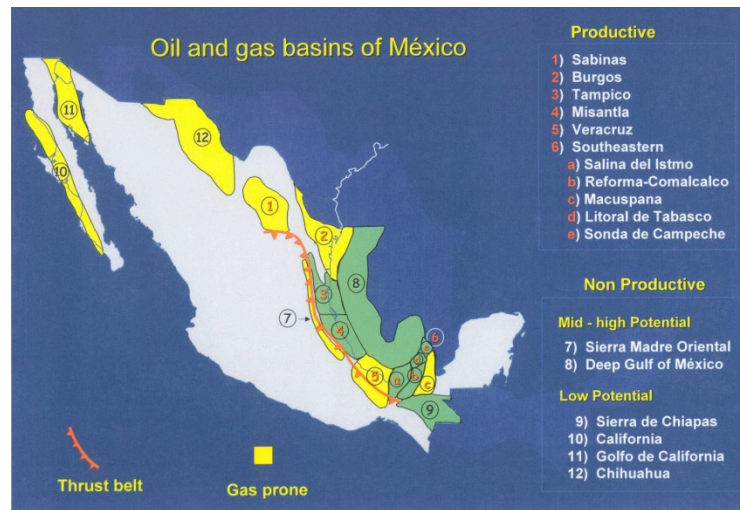
Figure 1. Mexico's Oil and Gas Producing Basins According to the USGS



Key: S=Sabins; B=Burgos; M=Magiscatzin; T-M=Tampico-Misantla; C=Chicontepec; V= Veracruz; S-C=Saline-Comalcalco ; VI=Villahermosa; M=Macuspana ; C-S=Campeche-Sigsbee. The last four basins are jointly referred to as the Sureste basin. The “deep Gulf of Mexico” is not considered separately but as a part of the coastal basins.

Source: United States Geological Survey (1997)

Figure 2. Mexican Basins According to Pemex



Source: Pemex Exploración y Producción (2001)

Only the Sabinas, Magiscatzin, and Chicontepec basins lie entirely onshore. The Campeche-Sigsbee basin lies entirely offshore. The other basins are partly onshore and partly offshore. The nonproducing Sierra de Chiapas, Chihuahua, Baja California, and the Gulf of California basins are not indicated in Figure 1 and are not discussed in this report.

III. Oil and Gas Producing Basins

Sabinas Basin

The Sabinas basin is located in northeastern Mexico in the states of Coahuila and Nuevo Leon. The basin has an area of 37,000 square kilometers (sq km) and contains more than 5,000 meters (m) of sediment. Drilling depths in the Sabinas basin vary from 1,800 to 4,500 m.

Sabinas is a foredeep basin created during the Laramide orogeny. To the east lies the Tamaulipas block, which is a basement complex containing schists and gneisses. To the west lies the Coahuila block, which contains rocks as old as Pennsylvanian.

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The Sabinas basin contains rocks ranging from the Triassic through the Paleogene periods. They underwent deformation during the Tertiary period and are highly faulted. The stratigraphic evolution is complex. Three supercycles are recognized with complex cyclical sedimentation. The Sabinas basin produces mainly nonassociated thermogenic gas. The source rocks are Kimmeridgian-Tithonian shales containing overmature kerogens. The reservoir rocks have low porosity and low permeability and are Upper Jurassic and Cretaceous in age.

Exploration in this basin began in the 1930s, and production peaked in 1979 at 160 million cubic feet (cu ft) per day. Most of the production comes from the three main fields: Monclova-Buena Suerte (discovered in 1974), Lampazos, and Merced. In 2006 the production of gas was 1.35 billion cu ft per day.

Burgos Basin

The Burgos basin is an onshore-offshore basin. Onshore it lies directly south of East Texas, terminating at the Rio Grande. Offshore it extends northeast in the deep ocean to the Mexican Ridges and to a part of the Perdido fold belt. It is bounded on the west by the Sabinas basin and by the Tamaulipas arch, and in south by the Tampico-Misantla basin. It has an area of 70,000 sq km. It is a major producer of natural gas, producing 22 percent of Mexico's total natural gas and 78 percent of its nonassociated gas.

The stratigraphic column in the Burgos basin above a Paleozoic basement of igneous, metamorphic, and volcano-clastic rocks consists of carbonates and marine evaporitic sequences of Mesozoic age, overlain by a thick sequence of Tertiary rocks.

The source rock is believed to be Tithonian in age. The reservoirs range from Upper Jurassic-Cretaceous to Eocene-Miocene. The Frio Marino formation of Upper Oligocene age is a substantial gas reservoir in the southern part of the Burgos basin.

While the nonassociated natural gas is found only in onshore fields, oil is found in addition to gas in offshore reservoirs. The continuation of the Perdido fold belt from the U.S. part of Gulf of Mexico to the Burgos basin holds the promise of gas of the Eocene age.

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Burgos exploration began in the 1920s, but production started only in 1945. The basin production is developed on 10,000 square miles, but that is only a small part of the extent of the basin.

About 85 percent of 1999 Burgos production came from the eight largest fields; the largest contributors were Culebra and Arcos. The other six fields are Arcabuz, Cuitlahuac, Merced, Monterrey, Pandura, and Reynosa. The Gas Technology Institute believes that Burgos basin output will climb from the 1999 rate of .97 billion cu ft per day to 2.3 billion cu ft per day in 2015. In 2010 the production was 1.6 billion cu ft per day.

The recent discovery of shale gas in the Burgos basin obtained by fracking the Eagleford shale holds great promise. In Texas, north of the border, all of the major national and international energy companies are investing in Eagleford shale plays. As this formation continues southward into Mexico, it deepens and thickens. No reserve estimates are available, but it is possible that this formation could yield large amounts of dry gas.

Tampico-Misantla, Chicontepec and Magiscatzin Basins

The coastal Tampico-Misantla Basin lies between the Sierra Madre Oriental fold and thrust belt to the west, the Burgos basin to the north, and the Veracruz basin to the south. It occupies an area of 50,000 sq km.

The Tampico Misantla basin has been the most prolific oil and gas producer with four important plays.

The most well known of these is associated with the so-called Golden Lane, located in the Tuxpan platform which is a Cretaceous carbonate ridge and is believed to consist of a series of reefs. One of the wells drilled on this platform, Cerro Azul No. 4, has been, as mentioned earlier, one of the most prolific oil wells ever drilled.

The second play is from the slope deposits on the Tamabra trend surrounding the platform. The Poza Rica “giant” oil field lies on this trend.

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The third play comes from the offshore San Andres formation, which consists of Upper Jurassic oolitic limestones.

The fourth and possibly most important play for the future is associated with the Chicoutopec field. The Paleogene Chicoutopec formation is deposited between the Sierra Madre Oriental and the Golden Lane platforms. The 2000 meter-thick formation consists of submarine fan turbidites derived from the Sierra Madre Oriental and contains alternating sequences of shale and thin, bedded limestones.

The source of oil is believed to be Tithonian. It varies in API gravity from 40 degrees in the north to 18 degrees in the south. The latter is classified as heavy oil. Even though these heavy oil deposits are believed to be some of the largest in the world, rivaling those of Saudi Arabia (according to some sources), the recovery rate has been extremely low; the deposits are candidates for extensive application of enhanced oil recovery (EOR) techniques. However, current EOR techniques are difficult to apply here because of the specific geologic situation. Development of new techniques and, consequently, increases in oil production will be slow, and is expected to take a number of years.

The Tampico-Misantla is a mature basin that has produced more than 2 billion barrels of oil—primarily from the Golden Lane (Tuxpan platform) sub-province, and more particularly from the Tamabra play—which accounts for approximately 68 percent of the basin's oil production. Secondary hydrocarbon production comes from onshore fields in the Chicoutopec and Magiscatzin sub-basins, and from the offshore San Andres/Lobina fields.

In 2008, oil production was 86,000 barrels per day (b/d). As of 2009, proven hydrocarbon reserves in the Tampico-Misantla basin amount to 1.1 billion barrels. If advanced EOR techniques are applied to the large amount of heavy oil in place, the reserves could increase several-fold.

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Veracruz Basin

The Veracruz foreland basin lies between two productive basins—the Tampico-Misantla basin to the north and the Saline-Comalcalco basin to the south. On the west it is bounded by the Laramide Sierra Zongolica fold thrust belt and in the east it continues into the Campeche-Sigsbee salt basin. It occupies an 18,000 sq km area.

The age of the rocks in the Veracruz basin range from the Jurassic to the Quaternary. Prominent source rocks that yield oil and gas are the marine carbonates of the Tithonian and Turonian age. Source rocks also exist from the Oligocene and Miocene. These are deltaic shales that generate mainly gas.

Reservoirs from the Mesozoic are mainly limestones and dolomites, while the Tertiary reservoirs consist of sandstones and conglomerates. Reservoirs from the Miocene are particularly important.

The Veracruz basin has been productive since 1953. From the 40 fields found, 26 are currently active and produce from the following two areas:

1. The buried structural front of the fold and thrust Sierra Madre Oriental belt, also known as Cordoba platform. It consists of Middle-Cretaceous limestone and produces oil and bitter, wet gas.
2. The Tertiary basin corresponds to a depocenter filled with conglomerates, sands, and clays deposited as a result of a lifting of the Sierra Madre Oriental and deformed by recent volcanic settlements, producing nonassociated gas.

Production in Veracruz basin reached its maximum in 2006 when it produced 0.861 billion cu ft of gas per day. It was considered to be the second-best gas-producing basin in the country in 2008. The proven reserves for this basin account for 5 percent of Mexico's total reserves. Gas production in 2010 was 0.84 billion cu ft per day. Hydrocarbon reserves were 0.2 billion barrels (oil equivalent).

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Sureste Basin (including Campeche-Sigsbee, Saline Comalcalco, Macuspana Basins and the Villahermosa Uplift)

The Sureste basin—which includes the Saline-Comalcalco basin, the Campeche-Sigsbee salt basin and the Villahermosa uplift—has been by far the most important Mexican hydrocarbon basin. It contains the very prolific (but now declining) Cantarell field as well as the neighboring Ku-Maloob-Zaap and Sihil fields.

During the early opening of the Gulf of Mexico from the Late Triassic to Early Jurassic, salt was deposited. Salt tectonics resulted in the formation of structural and stratigraphic traps in the Saline-Comalcalco and Campeche-Sigsbee areas.

The sedimentary column in the Sureste basin ranges from the Middle Jurassic to the Holocene. In the Campeche–Sigsbee area, the Oxfordian contains shallow marine clastics, evaporites, and shallow organic rich carbonates. The Lower Kimmeredgian contains shaley sediments, while the Upper Kimmeredgian contains oolitic carbonate banks.

The overlying Tithonian calcareous shale is considered the most important oil source rock in the Sureste basin. The Lower Cretaceous section in the Villahermosa area consists of carbonate-evaporitic deposits; the Campeche-Sigsbee area consists of dolomite and shaley lime stones. These rocks are also important petroleum producing rocks.

While source rocks occur throughout the stratigraphic column, the most important source rocks—in addition to the Tithonian mentioned above—are in the Oxfordian. Source rocks also occur in the Tertiary but they are limited to the Macuspana basin, which primarily produces nonassociated gas.

In the Campeche-Sigsbee area, Upper Cretaceous deposits are represented by dolomites, shaley limestones, and cherts. Dolomitized breccias constitute important reservoirs.

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The main productive basins (sometimes termed sub-basins) within the Sureste basin are:

1. Chiapas–Tabasco–Comalcalco basin (approximately coincident with the Villahermosa uplift in Figure 1)

The Mesozoic Chiapas-Tabasco province covers an area of 13,100 sq km, and corresponds to the central onshore part of the Sureste basin. A northward offshore extension of the basin is found in the Campeche-Sigsbee basin province. Total daily production of the province from different stratigraphic intervals is 576,000 b/d of mainly light oil, and 1.84 billion cu ft of gas from 57 fields (out of a total of 75 discoveries). El Complejo Bermudez and the Jujo-Tecominoacan fields are the most famous. The reserves amount to 1.7 billion barrels of oil equivalent.

2. Campeche-Sigsbee Basin

The reservoirs are in Oxfordian quartzose arenites of coastal dune origin, Late Jurassic Kimmeridgian oolitic limestones, Late Cretaceous to Early Paleocene carbonate breccias, associated calcarenitic turbidite facies of Paleocene-Eocene, and associated Mio-Pliocene siliciclastic turbidite facies.

The region is by far the most prolific petroleum province in Mexico and includes the super-giant Cantarell Field, which in 2003 alone produced 2.1 million b/d and .53 billion cu ft of gas per day, out of a total daily production of 2.4 million barrels of oil and 1.50 billion cu ft of gas for the entire province. In 2004, gas production was 1.03 billion cu ft per day and oil production was 1.68 million b/d. Total reserves amount to 11.37 billion barrels of oil equivalent.

3. Salina del Istmo Basin

The productive reservoirs in the Salina -del Istmo basin occur in three play types: Middle to Late Miocene turbidite sands, Late Miocene-Pliocene deltaic sands, and Plio-Pleistocene fluvial sands. All are associated with anticlinal traps produced by normal faults of extensional tectonic regime. The gas production is .054 billion cu ft per day and the oil production is 44,000 b/d.

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4. Macuspana Basin

The Macuspana sub-basin is located on the coastal plain of the Gulf of Mexico. Extending from the central part of the state of Tabasco to the extreme southwestern tip of the Campeche province, the sub-basin has an area of approximately 13,800 km sq, with one-sixth of its area offshore, and is a producer mainly of nonassociated, shallow gas (less than 3,000 m deep). The producing horizons are associated with fluvio-deltaic sandstones and shelf limestones of the Macuspana formation. Traps are both stratigraphic and structural, the latter being mainly roll-over anticlines associated with an extensional regime and resultant deformation. As yet no production comes from the offshore part of the sub-basin. Gas production is .23 billion cu ft per day; the oil production rate is 39,600 b/d, and reserves amount to .17 million barrels of oil equivalent.

IV. Important Fields

The most important Mexican oil fields are the Cantarell, Ku-Maloob-Zaap, and Sihil fields in the Campeche Sigsbee basin; the fields on the Golden Lane and in the vicinity of the Golden Lane in the Tampico-Misantla basin; and in the Chicontepec field in the Chicontepec basin. Noxal field in the Veracruz basin was, at one time, considered very promising.

By far the most famous Mexican field is the aging, super-giant Cantarell field. It was discovered in 1976 by a fisherman named Rudesindo Cantarell and named after him. Most giant fields on land (but not at sea) are discovered through the presence of seeps. Cantarell is the rare case in which the presence of seeps at sea (discovered by Cantarell) came first. Extensive geological and geophysical investigations came afterward. Cantarell owes its existence to a giant asteroid strike (occurring at the Cretaceous Tertiary boundary), which created the Chicxulub crater. The breccia resulting from the impact subsequently became dolomitized and fractured, and served as the reservoir rock. The source rocks are Tithonian calcareous shales. The oils range in API gravity from 10 degrees to 50 degrees. Oil with API below 20 is considered heavy oil. In addition to the Cretaceous reservoirs, production is also from the Kimmeridgian and Eocene, although the Cretaceous reservoirs are the most productive. Production in 1981 was 1.16 million b/d and fell to 1 million b/d in 1995 in Cantarell. An EOR project consisting of nitrogen injection increased

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production, which peaked at 2.1 million b/d in 2003. At that time the production rate was second only to the giant Ghawar field in Saudi Arabia. The production rate has declined drastically since 2003 and in 2009, the production rate was 770,000 b/d. It is continuing to decline but it is ultimately expected to stabilize at 400,000 b/d.

The Ku-Maloob-Zaap field is located immediately to the northwest of the Cantarell field. It was discovered in 1979 and has been the largest source of new production growth in recent years. Nitrogen was injected to boost production, and the production rate was 864,000 b/d in 2009. In August 2010, its production rate exceeded that of Cantarell. However, there are two problems associated with the Ku-Maloob-Zaap field: The oil produced is heavier than in the Cantarell field, and it appears that oil quality and production may be falling as water and salt seep into the reservoir.

The Sihil field was discovered lying under the Cantarell field. While the current production rates are small, it is estimated that the reserves amount to more than 1 billion barrels.

Important production comes from fields lying offshore the state of Tabasco. These fields lie in the Reforma-Comalcalco and Litoral de Tabasco basins, shown in Figure 2 (corresponding to parts of the Salina-Comalcalco basin and the Villahermosa uplift in Figure 1). Production, although less than in previous years, is now stabilizing at about 500,000 b/d.

The Tampico-Misantla basin, the Golden Lane (Tuxpan platform) sub-province, and more particularly the adjacent Tamabra play have in the past been very prolific. Cerro Azul No. 4 on the Golden Lane and the Poza Rica giant on the Tambral play are well known. But the production in this area has gone down substantially.

Development of the Chicontepec field has been a major goal of Pemex. In 2006, President Vicente Fox announced that Pemex would invest US\$47.5 billion over 20 years to develop fields in Chicontepec basin. The development costs to date have exceeded US\$11 billion. While this field is expected to hold very large reserves (more than 15 billion barrels by some estimates), they are in interbedded layers of tight limestone and shale. Besides, most of the reserves are

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heavy oil. As a result, recovery rates have been very low, possibly as low as 6 to 8 percent. The target for September 2009 was 100,000 b/d. The actual recovery was slightly less than 30,000 b/d.

Noxal is a deep underwater oil field in the offshore part of Veracruz basin. The field lies 4,000 m below the sea bottom, which is itself 930 m below sea surface, about 100 km off the coast of Veracruz state. Its discovery in 2006 was hailed with great fanfare and it was estimated then that the reserves in this field would amount to 10 billion barrels of crude oil. Further drilling, however, revealed a much more modest natural gas find of 245 billion cu ft and production from a test well was only nine million cu ft per day.

V. Summary and Future Prospects

Leaving aside the requirement for future investment, the possibility of recovery of hydrocarbons in the future will depend on the geological situation in the producing basins; the history of production in these basins; and the development and application of new technology. Let us see how these factors apply to the Mexican basins.

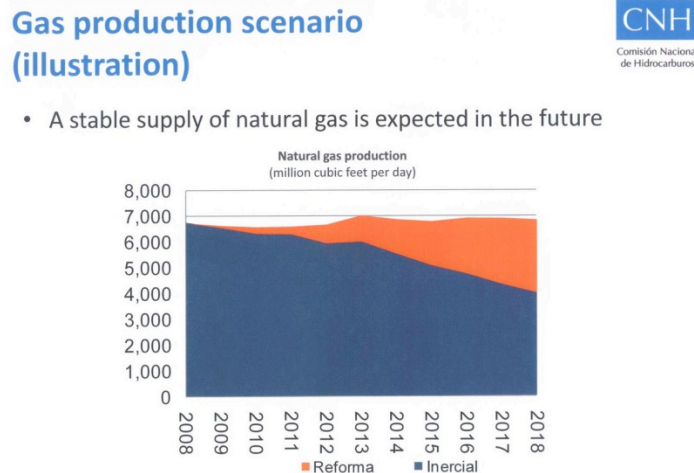
Shortly after the opening of the Gulf of Mexico, Early Mesozoic shales—most prominently Tithonian and Kimmeredgian in age, and rich in organic matter—were deposited in the entire area occupied by all of the Mexican producing basins. It is this organic matter that was later converted to oil and gas.

During the Cretaceous and Eocene, the Laramide orogeny took place in Mexico (actually, this orogeny continues north into North America), where it created a fold and thrust mountain belt, the Sierra Madre Oriental (see Figure 2). Adjacent to this belt lies a deep valley—the foredeep also created by the orogeny—which accumulated enormously thick layers of sediments. The deep burial and elevated temperatures converted the organic matter in the foredeeps to oil. This oil then migrated upward into reservoirs of Cretaceous and Tertiary age in the Sabinas, Chicontepec, and western parts of the Burgos and Veracruz basins. However, over-maturation resulted in the production of gas (indicated in yellow in Figure 2) in all of these basins, with the

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exception of the Chicontepec. No oil was generated—and if any was generated, it has escaped—and the gas is known as nonassociated gas. As far as the future is concerned, there is no reason to expect that oil will be discovered in this area. The gas supply from these and other basins in Mexico is expected to diminish moderately in the future (see Figure 3).

Figure 3. Estimated Future Gas Production Rates



Source: Estrada (2010)

The Chicontepec basin is different. In the Chicontepec basin, both oil and gas are produced. The API gravity of the oil in the Chicontepec basin is generally lower than 20 degrees, that is, it is heavy oil. The genesis of heavy oil is interesting. During the upward migration of oil, it meets groundwater containing bacteria. These bacteria like to feed on oil, but they prefer the lighter hydrocarbons, leaving the heavier hydrocarbons, which then constitute a residue of heavy oil. The heavy and viscous oil cannot migrate up and escape. It stays buried in the ground and can exist as a large deposit. The Chicontepec basin indeed holds a large amount of “oil in place.” Some estimates place it at 15 billion barrels, which would exceed Mexico’s present reserves. Pemex is rightly focusing new efforts to extract this oil. But there are problems.

In order to produce heavy oil, a favored method is to inject steam into the reservoir through an injection well, which makes the oil lighter and less viscous, and then pump it out through producing wells. Another method is the steam assisted gravity drainage (SAGD) method. SAGD

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technology requires the drilling of two parallel horizontal wells through the oil-bearing formation. Into the upper well, steam is injected creating a high-temperature steam chamber. The increased heat loosens the thick crude oil, causing it to flow downward in the reservoir to the second horizontal well. The second well is located parallel to and below the steam injection well. The heated, thinner oil is then pumped to the surface via the second horizontal, or production, well.

Both methods ideally require the reservoir to consist of a single thick formation. However, that is not the case with the Chicontepec, where the reservoir consists of a succession of thin shales and carbonates. Existing steam injection methods are hard to apply. Newer technology is required to raise the recovery rate above the present 6 to 8 percent.

Heavy oils also often contain relatively large amounts of sulphur and metals such as vanadium, nickel, and copper, which are most undesirable from a refiner's point of view and they require "upgrading" before they can be subjected to normal refining processes.

Thus Chicontepec may in the future be an important source of oil, but very large investments coupled with technological advances would be needed to unlock and utilize this large resource.

The Tampico-Misantla coastal basin has been a very important basin in the past. The fields on the carbonate reefs of the Golden Lane and on the adjacent slopes have been very important in the past and were once the largest sources of oil in Mexico. At the present time, the output from these fields is small and plays a relatively minor role in the overall picture in Mexico. This basin is not expected to be a prolific producer in the future in the onshore and near-offshore areas, which have been explored.

Farther south, the onshore part of the Veracruz basin also lies on a foredeep basin. Reservoirs of Cretaceous and the Tertiary ages exist. Miocene sandstones reservoirs are most prominent. Both oil and gas are produced. Next to the Burgos basin, the Veracruz basin is the largest producer of natural gas in Mexico and contains 5 percent of the total reserves. I expect the production of gas to continue at near-present levels. The oil in Veracruz basin is also heavy oil and the situation may in some ways be similar to the Chicontepec basin, but there does not seem to be much

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activity to explore and produce heavy oil in this basin. This basin also had some activity in the deep offshore. At one time, the Noxal field in the Veracruz basin was considered to hold high promise. However, subsequent findings did not fulfill that promise.

The Sureste basin, with its various sub-basins, has been the most prolific oil and gas producer in Mexico. Although the source rocks in the basin are basically similar to the source rocks in the foredeep basins, the geological evolution of this basin has been quite different. It has not been subjected to an orogeny similar to the Sierra Madre Oriental. Major structural as well as stratigraphic traps are related to salt tectonics. Except in Macuspana basin, the gas is associated with produced oils that range in gravity from very light to heavy. While there are some important Tertiary reservoirs, the most important are Mesozoic carbonates.

Table 1 gives the present rates of production and estimated reserves of all the Mexican basins. The information in this table comes from various sources with various dates. The table is left incomplete where data were unavailable or unreliable. But it should serve to give a general picture of production rates and proven reserves. So-called P2 and P3 reserves are not included. (Note that the production rates for a number of basins are grouped with the Sureste basin).

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Table 1. Basins in Mexico

Basin	Production	Fields	Active Fields	Wells	Gas Production Rate (Million cubic feet per day)	Oil Production Rate (thousand barrels per day)	Proven Hydrocarbon Reserves (billion barrels)	Main Projects and Fields
Burgos	Gas	221	179	2771	1600	NA	0.4	Burgos, Lamprea, Delta del Bravo
Sabinas	Gas	23	18		1350	NA	?	Monclova-Buena Suerte, Lampasco, Merced
Tampico-Misantla	Oil				NA	86		Aceite Terciario del Golfo, Poza Rica, Lankahuasa, Cazones, Sardina
Chicontepec		75	57	5421	70	41	1.1	
Veracruz	Oil-Gas	40	26	190	840	5	0.2	Cuenca de Veracruz, Papaloapan B
Sureste	Oil				> 3210	>2327	12.6	Cantarell, Ku-Maloob-Zaap, Crudo Ligero Marino, Antonio J. Bermúdez, Delta del Grijalva, Jujo Tecominoacán, Akal, Nohoch, Kutz, Chuc, Sihil
<i>Salina del Istmo</i>		<i>52</i>	<i>28</i>		<i>35</i>	<i>44</i>		
<i>Comalcalco-Chiapas-Tabasco</i>		<i>75</i>	<i>57</i>		<i>1835</i>	<i>576</i>		
<i>Macuspana</i>		<i>36</i>	<i>13</i>	<i>210</i>	<i>310</i>	<i>33</i>		
<i>Sonda de Campeche</i>		<i>24</i>	<i>18</i>		<i>1030</i>	<i>1680</i>		
<i>Cantarell</i>	<i>Oil</i>		<i>10</i>	<i>98</i>	<i>596</i>	<i>558</i>		
<i>Ku-Maloob-Zaap</i>	<i>Oil</i>			<i>164</i>	<i>282</i>	<i>839</i>		
Deep Gulf of Mexico	Oil-Gas		4		NA	NA	0.1	Lakach, Golfo de México B, Golfo de México Sur, Área Perdido
Total					~6000 cf/d	~2500 b/d	~14	


Sources: Baker Institute estimates based on the Sistema de Información de Energía (2011), Pemex Exploración y producción (2009), and other sources found in the reference list

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As far as the future is concerned, illustrations from a report by Mexico’s National Hydrocarbons Commission (Comision Nacional de Hidrocarburos) are particularly instructive. Table 2 from this report shows that production in the mature fields is declining, and Figure 4 predicts that the decline will be substantial.

Table 2. Many Fields Are in Decline

Mexican E&P Outlook



Comisión Nacional
de Hidrocarburos

Mature fields

Status of oil and associated gas fields**

Size*	Declining	Plateau	Development	Total
Supergiant	1	0	0	1
Giant	5	2	0	7
Big	44	8	3	55
Medium	32	7	7	46
Small	62	16	36	114
Total	144	33	46	223

*Size: Supergiant original 2P reserves > 5,000 MMBPCE; Giant > 1,500 MMBPCE; Big > 250 MMBPCE; medium > 80 MMBPCE.
** Status: Declining if production is less than 85% of the max; plateau if production reached its peak but hasn't declined more than 85% of the peak.

México has 223 oil and associated gas fields with production and reserves, from which 177 are already declining or will be in the next 2 years. From the 46 fields in development, 29 are Chicontepec fields.

Source: Estrada (2010)

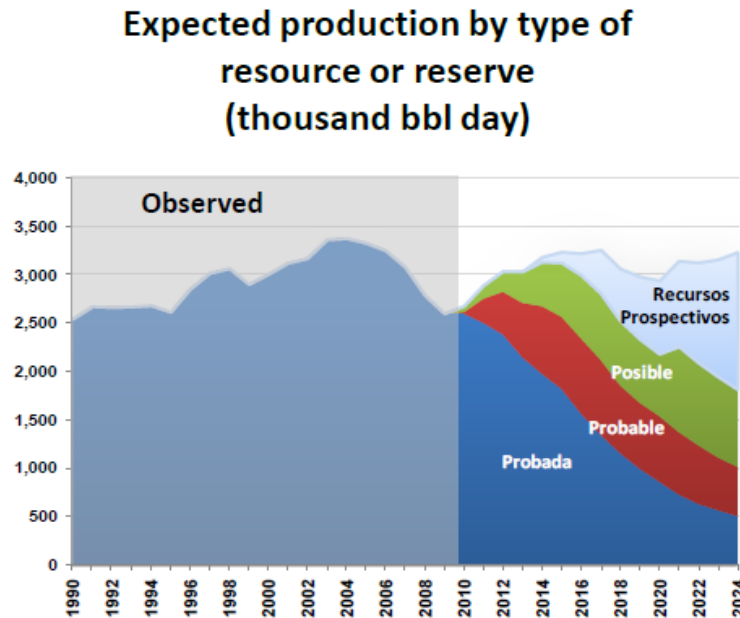
As to the question of where future reserves will come from, I have discussed above the issues with regard to Chicontepec (high technology and the problems of dealing with heavy oil). Because of the specific nature of its geology, conventional EOR techniques may not work. Incrementally advancing new EOR techniques, as well as the need to upgrade heavy oil so that it can be refined in existing refineries, will take time. Substantial increases in production will take several years.

Other, but much less explored, possibilities lie in the deep ocean parts of the basins. These are the offshore parts of basins in Figure 1 equivalent to “the deep Gulf of Mexico” in Figure 2. The Perdido belt and the Mexican Ridges in the Burgos basin would be obvious exploration targets, as would other deep sea areas. Most productive exploration would have to be subsalt. Subsalt

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exploration in the U.S. part of the Gulf of Mexico has required high technology and huge investments.

Figure 4. Estimated Future Oil Production Rates



Source: Estrada (2010)

To explore for possible reservoirs below the salt, advanced seismic methods are employed. The necessity for employing advanced methods can be seen from an optical analogy. To see structures below the salt seismically is comparable to looking through a very cloudy piece of glass to resolve objects that might lie below the glass. To “see” below the salt seismically, it is customary to carry out three-dimensional seismic surveys and then process the acquired data using state of the art techniques, such as “pre-stack depth migration.” Apparently, Pemex is carrying out such surveys. One of the ongoing three-dimensional seismic surveys occupies about 10,000 sq km and extends from shallow water to deep water. There appears to be plans to further extend the survey. If drilling is carried out now and reservoirs are confirmed by drilling, it will still take three to five years for the production to come on line. In areas where no geophysical surveys have been carried out but new surveys are planned, production may not be possible for five to 10 years. (BP’s giant subsalt Thunderhorse field took 10 years from start to production).

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The cost of drilling is substantial. If it takes 100 days to drill a subsalt well at US\$500,000 per day, the cost of each well is US\$50 million. There is, of course, no certainty that the well will be productive. For that reason, development costs are often shared between several companies and Pemex may want to change its policies to be able to do so.

As to the question of whether outside technical help will accelerate efforts to find and produce more oil, the answer is probably no. Most geophysical exploration and drilling is carried out by contractors in any case, and Pemex can hire these contractors. Data interpretation and critical drilling decisions would have to be made by Pemex. The scientists and managers at Pemex are certainly capable of making those decisions.

Mexico is on the horns of a dilemma. Present production is coming principally from the Sureste basin, which also has the largest proven reserves. Although new finds of giant fields cannot be ruled out in the Sureste basin, further exploration in this already heavily explored basin may not prove very fruitful in terms of finding major new reserves. Clearly, developing new technology to extract more heavy oil in the Chicoutopec basin and carrying out subsalt exploration in the deep sea would seem to be the primary keys to obtaining more reserves. In order to explore new areas and to develop new technology, it is essential to make large investments. But as with all exploration in previously unexplored areas, and with efforts to develop new technology, the results of these endeavors are unpredictable and the risks are great. In any event, even under the most favorable conditions, finding new fields or substantially increasing production from existing fields will, at minimum, take several years.

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