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# The Future of California's Oil Supply

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## Abstract

Once an oil exporter, California now depends on imports for more than 60% of its oil supply. This paper examines the oil production outlook for each of California's major oil sources, including California itself. Oil production trends, published geological and engineering reports, and proposed developments in California's supply area are reviewed to define supply trends, especially for the medium-to-heavy, sour crudes that are processed in California's refineries. Refinery upgrading capacity is already highly developed in California, thus it is assumed that a competitive advantage in heavy, sour crudes will continue, although refining heavy oil releases more carbon dioxide.

About a quarter of California's imports are from Alaska, the rest from foreign sources including Saudi Arabia, Ecuador and Iraq. Before foreign sources became so important, California's refining industry processed California's own crudes and Alaska's North Slope crude.  Like those crudes, oil from northern Saudi Arabia, southeast Iraq, and Ecuador is also sour and medium to heavy, ranging from 16 to 35° API and from 2 to more than 3% sulfur by weight. By far the most important sour crude development in California's supply area is Saudi Arabia's 900,000 BOPD Manifa project, originally slated for completion in 2011 but now facing delays. Manifa contains oil that ranges from 26 to 31° API and from 2.8 to 3.7% sulfur. Over the longer term, Alaska will continue to play an important supply role if the Chuckchi and Beaufort Seas live up to expectations.

Middle East production is not increasing, yet oil cargoes from the Middle East have to pass growing Asian markets to reach California. Alaska and Mexico also supply oil to the Pacific Basin, but are facing production declines. The effect of rising Asian demand on Pacific Basin oil markets is already visible, with significant amounts of oil coming to California from Atlantic Basin sources such as Angola, Brazil, and Argentina.

The US West Coast pipeline system is separate from the integrated East Coast, Gulf Coast and Midwest system, so energy security issues for the West Coast may differ from those of the country as a whole. There are policy options that could affect California's oil supply security, including increased oil development in Alaska or offshore California, development of additional oil pipeline outlets on Canada's Pacific Coast or substituting natural gas for oil if possible. All of these policy options are currently the subject of political debate.

## Historical Oil Production Trends in California's Supply Area

Historical oil production trends are of interest because, unlike reserve estimates, they are readily verifiable factual information. Another issue with published reserve data is the quality of the supporting information; Alberta produces a detailed annual reserves report, while Saudi Arabia and Iraq publish only national aggregate figures. All of the oil production volumes reported in this section are from the Oil and Gas Journal or the Alaska Division of Oil and Gas and do not include natural gas plant liquids.

Iraq's oil production peaked in 1979 at 3.43 million BOPD. In 2007 it was 2.09 million BOPD, but production levels had been affected by internal instability and were higher in 2008.

Saudi Arabia's oil production peaked in 1981 at 9.64 million BOPD. The Saudis have consistently claimed a productive capacity substantially greater than this, but have not produced as much since, even in times of high oil prices. In 2007 Saudi oil production was 8.63 million BOPD.

California's own oil production peaked in 1985 at 1.1 million BOPD. By 2006 it had declined to 685,000 BOPD. California's heavy oil fields have been intensively developed and production from them is expected to decline further.

Alaska's oil production peaked in 1988 at 2.14 million BOPD; in 2007 it was 756,000 BOPD. Alaska's oil production is dominated by the Prudhoe Bay Field, which is at an advanced stage of decline, but substantial exploration potential remains, both onshore and offshore.

Oil production in Mexico peaked in 2004 at 3.38 million BOPD; in 2007 it produced 3.08 million BOPD. Mexico's oil production is expected to continue to decline because of the increasing maturity of the offshore oil fields in the Gulf of Campeche.

Ecuador's oil production was 535,000 BOPD in 2006, but in 2007 it was only 499,000 BOPD. One year of declining production may be a result of many factors, and is not necessarily indicative of near-term supply problems.

The oil production levels of Angola, Brazil, and Canada are currently at all-time highs due to increased heavy oil development in Canada, and to deep offshore discoveries in Brazil and Angola. These 'ABC' countries are likely to play an increasing role in California's oil supply.

## California's Oil Production

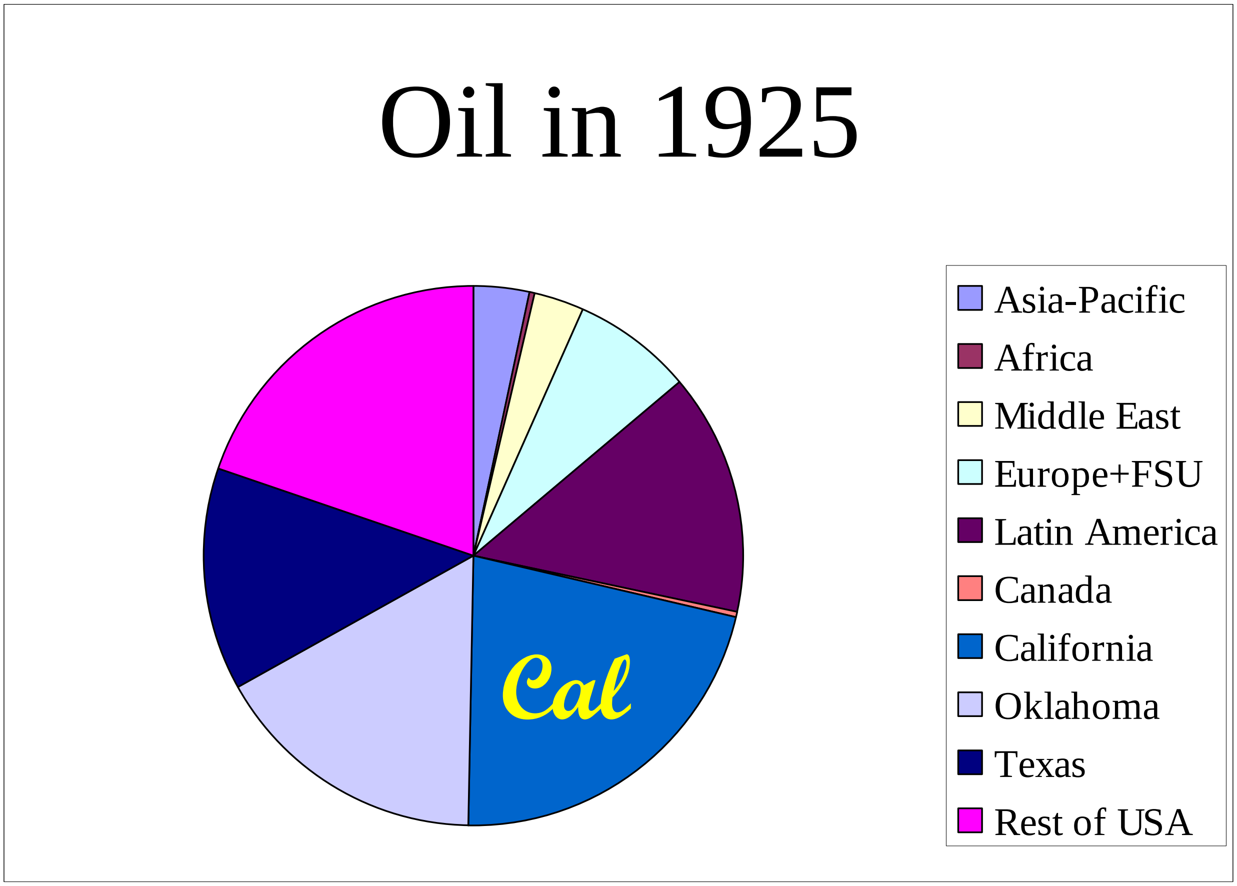
Although California's oil production did not peak until 1985, its importance in the world of oil was greatest around 1925, when California accounted for more than 22% of world oil production (American Petroleum Institute, 1993) This was the peak of development of the Los Angeles Basin oil fields, but before the discovery of the East Texas Field or the development of the Permian Basin. Figure 1 shows the relative importance of different oil-producing regions in 1925.

Because of California's history as an oil producing and exporting province, its refining industry was originally built to process local crudes. Table 1 shows the API gravity and sulfur content of two of the most important California crude streams.

Table 1: California Oil Properties (Guerard, 1984)

| Field | Kern River | Wilmington |
|---|---|---|
| API Gravity | 12.6° | 19.4° |
| Sulfur Content | 1.19% | 1.59% |
| Viscosity@100°F | 6,000 cp | 470 cp |

Figure 1: World Oil Production in 1925




Total: 2,926,000 BOPD

California's produced 683,000 BOPD in 2006. Of this production, 409,000 BOPD was heavy oil, and 113,000 BOPD of the total was produced offshore (California Division of Oil, Gas, & Geothermal Resources, 2006).

California's Heavy Oil Production is dominated by four large, steam-enhanced oil production projects in Kern County. These are the Midway-Sunset, Kern River and Cymric Fields, and the Tulare Sand in South Belridge Field. These four projects accounted for about 69% of California's heavy oil production in 2006. All of these are declining except for Cymric, which has had its life extended by the development of a deeper reservoir, the Etchegoin. The recent production history of these four projects is shown in Figure 2. Note that the values shown in the figure for South Belridge are for the Tulare sand only and do not include the light oil production from the Belridge Diatomite. Although the production of large amounts of incremental heavy oil from these reservoirs is a great technical accomplishment, that same success now makes further production declines inevitable because about half of the OOIP has already been produced.

Other known heavy oil and tar sand deposits in California have not been developed because the oil is too viscous. The largest of these, the Foxen Tar Sand in the Santa Maria Basin, is estimated to have 2 billion barrels of OOIP while other known tar sands at Oxnard, Arroyo Grande and Paris Valley have less than 1 billion barrels of OOIP in aggregate (Hallmark, 1982). This compares to estimated OOIP of 6.2 billion barrels for the Midway-Sunset Field and 4.1 billion barrels for the Kern River Field (Roadifer, 1986). The conclusion is that these undeveloped oil accumulations are smaller than existing major projects and are not likely to arrest onshore production declines. The greatest potential for increasing California's oil production probably lies offshore.

Figure 2 (California Division of Oil, Gas, & Geothermal Resources, 1994 through 2006)

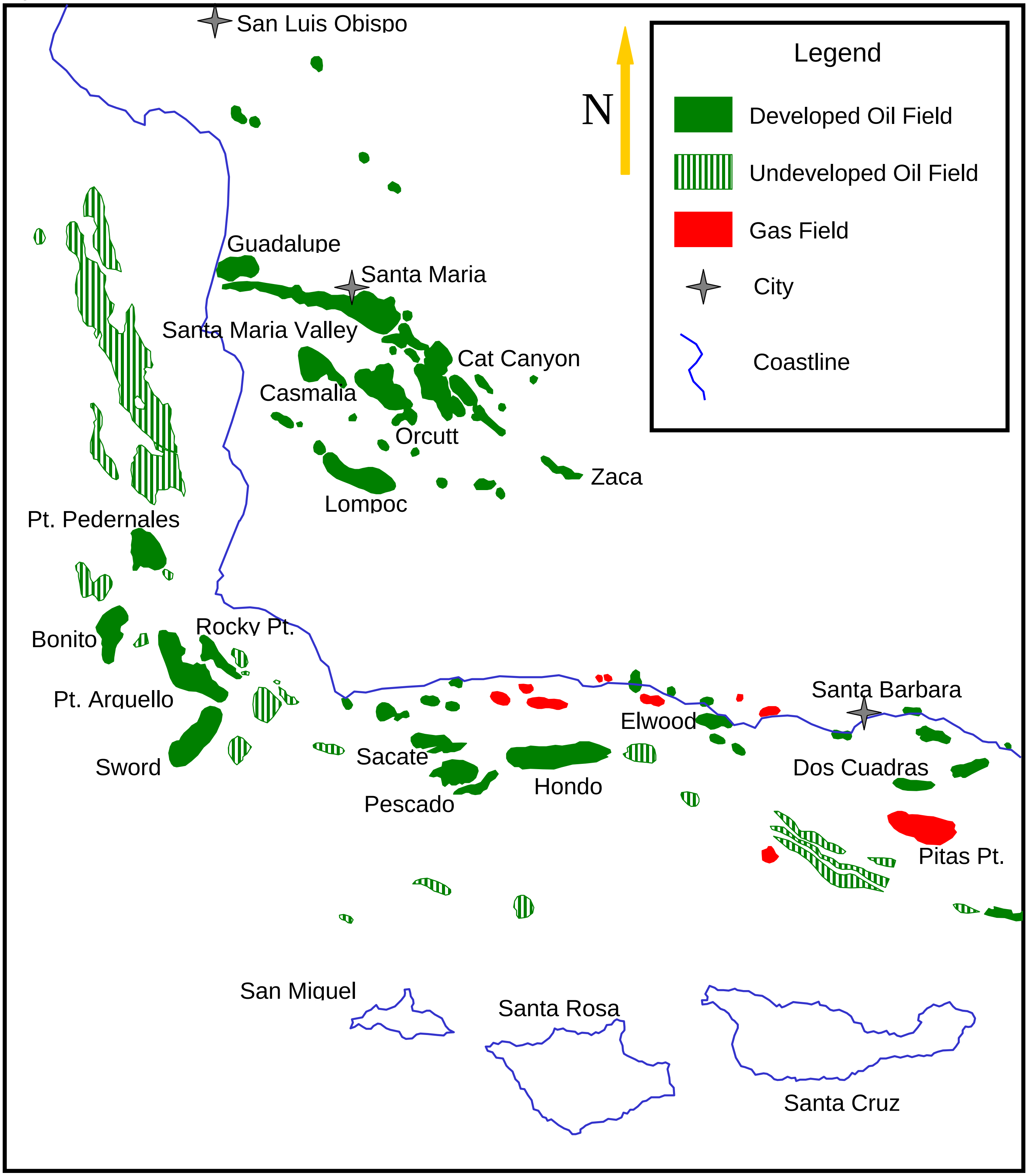
## Offshore California

One of the few areas in the world that has large, undeveloped oil reserves is offshore California.
Offshore oil production from wooden piers began at Summerland around 1890. There were concerns about the impact of offshore drilling even early in its history, so a compromise was reached in which all of the state offshore royalties were dedicated for many years to the Department of Beaches and Parks.

A major oil spill in 1969 strengthened opposition to offshore drilling and today there is in practice a ban on new platform installations. This has not prevented all new field developments; Bonito and Sword are recent extended-reach developments from existing platforms. Large heavy oil fields north of Point Sal are far from existing infrastructure and remain undeveloped. Figure 3 shows developed and undeveloped oil fields around Santa Barbara County. The offshore field outlines in the figure are from MMS and the onshore field outlines are from the California Division of Oil and Gas. Although only a small part of the California Coastline is shown in the figure, it includes most of the known offshore oil reserves of the state. These were estimated at 303 million barrels of remaining proved reserves, 1.166 billion barrels of remaining unproved reserves, and 149 million barrels of known resources on expired leases at yearend 2003 (Syms. and Voskanian, 2007).

In addition to these known fields, there is considerable exploration potential offshore California. That potential is greatest offshore Southern California, but is also significant offshore Central and Northern California. At a $46 per barrel price assumption, the undiscovered economically recoverable oil resources offshore Southern, Central and Northern California are estimated at 3.9, 1.9 and 1.5 billion barrels respectively (MMS, 2006). This 7.3 billion barrel total rises to 8.6 billion barrels in the $80 per barrel case. Resources of this magnitude could represent a significant addition to California’s oil supply.

Figure 3: Oil Fields of the Santa Barabara Channel and Santa Maria Basin, California




## Alaska

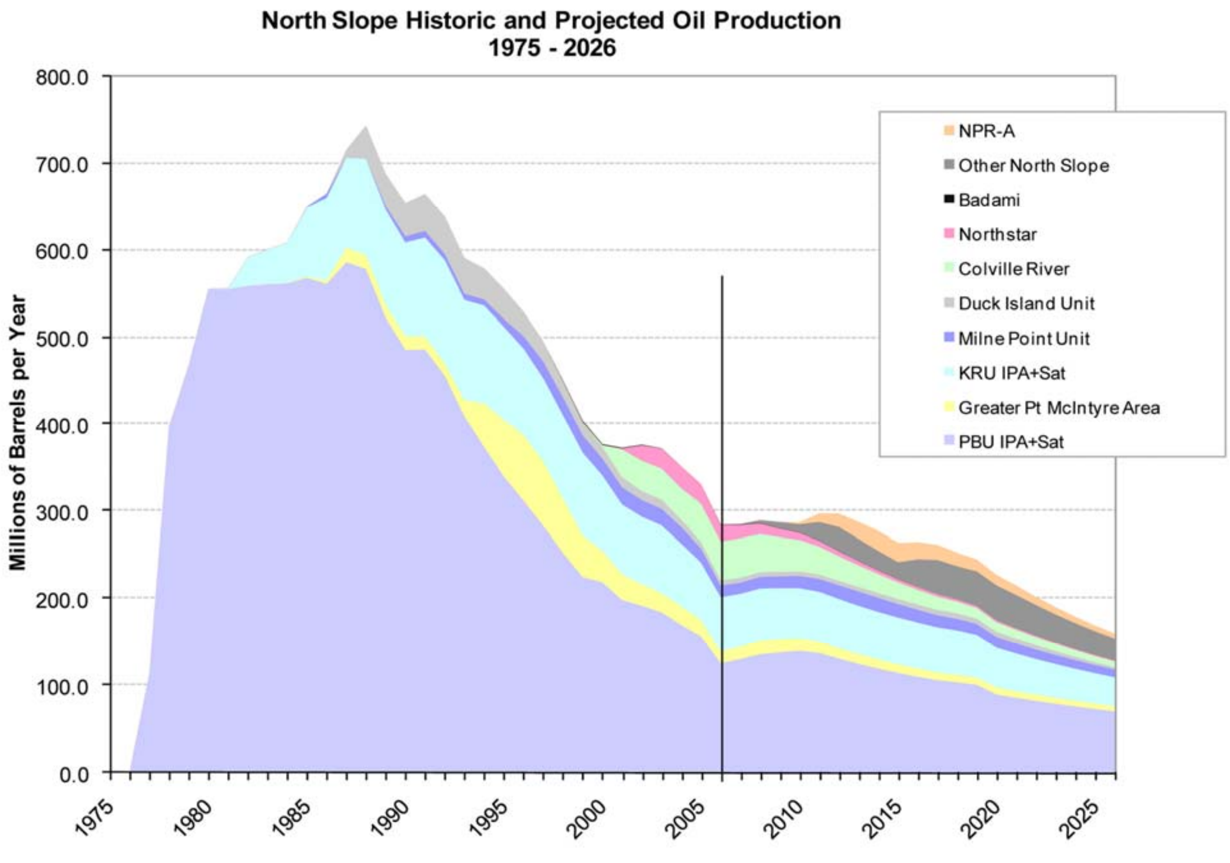
Alaska's oil production is currently about a third of its 1988 peak. Alaska is a very high cost area, so low oil prices discouraged development from 1986 until about 2005. In addition, the Trans-Alaska Pipeline partners benefit from the substantial tariff, which gives them a competitive advantage. Figure 4 shows the history and projections for North Slope oil production. This figure is based on remaining reserves in existing fields. The important observation is that existing and proposed Alaskan developments are not likely to provide a major increase in

Alaskan oil supply; major new developments would be needed.

Much of the discussion of oil development on Alaska's North Slope centers on the coastal plain of the Arctic National Wildlife Refuge. The area in question is only a very small part of the North Slope, and an important structure within it was tested by an exploratory well in 1986 – 1987. The well was drilled on a native inholding in the 1002 area. The results of this well and several others were not used by the USGS in its assessment of ANWR potential for confidentiality reasons.

The Chukchi and Beaufort Seas have large oil potential, as evidenced by the number of tracts receiving bids in recent federal lease sales. Chukchi Sea lease sale 193 in 2008 received $2.66 billion in winning bids on 488 blocks (MMS, 2008). In the Beaufort Sea, 2007 lease sale 202 received $42 million in winning bids on 92 blocks (MMS, 2007) and 2005 lease sale 195 received $47 million in winning bids on 121 blocks (MMS, 2005). These tracts could contain sufficient resources to offset the projected declines shown in Figure 4. The undiscovered economically recoverable oil resources in federal waters offshore Alaska are estimated at 8.35 billion barrels at a $46 per barrel price assumption, and 21.5 billion barrels in the $80 per barrel case (MMS, 2006). Note that the offshore Alaska resource estimates are more sensitive to oil prices than those offshore California.

Figure 4 (Alaska Division of Oil and Gas, 2008)



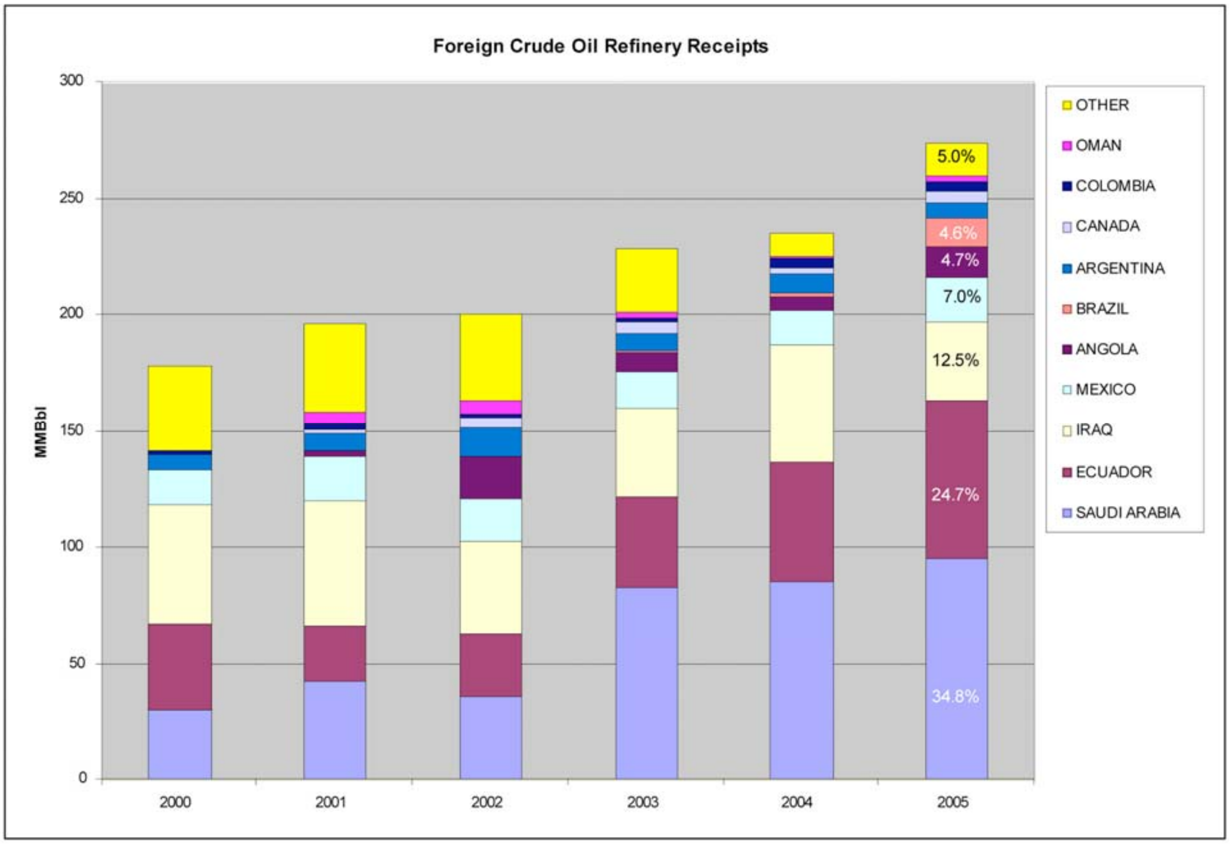

Source: Alaska Division of Oil and Gas (2008)

**Foreign Sources of Oil to California**

Figure 5 shows the countries of origin for California's foreign crude receipts from 2000 through 2005[7]. Note the dominance of Saudi Arabia, Ecuador and Iraq, with Mexico coming in a distant fourth in oil supply to California. Another important development is the appearance of Angola, Brazil and Canada as significant suppliers in 2005.

California's oil sources are the main suppliers of heavy, sour crudes to the Pacific Basin. For this reason, California competes directly with other Pacific Rim consumers that have the ability to process these heavier oils.

Figure 5 (California Energy Commission, 2007)




**Saudi Arabia and Iraq**

Most Saudi production comes from older onshore fields, but the Arab Medium and Heavy grades used by California refineries are primarily produced offshore northernmost Saudi Arabia. The oil fields of southeast Iraq, Kuwait and northernmost Saudi Arabia produce primarily from sandstone reservoirs of Cretaceous age. These fields are characterized by multiple pay zones and strong natural water drives. Cretaceous carbonate reservoirs and shallow heavy oil are also present.

Table 2: Safaniya Field Reservoir Parameters[1]

| Reservoir | Safaniya | Khafji |
|---|---|---|
| Net Thickness (ft) | 136 | 137 |
| Oil Gravity | 27 | 27 |
| Viscosity (cp) | 6.4 | 4.55 |
| Sulfur Content | 2.93 % | 2.84 % |
| Porosity | 26 % | 25 % |
| Permeability (md) | 5700 | 6250 |

[1]Saudi Aramco, *Oil Reservoirs, Table of Basic Data*, Year-End 1980

The Safaniya Field was discovered in 1951 and is the world's largest offshore oil field. Production of Arab Heavy crude comes from two major sands, the Safaniya and the Khafji. Peak historical production was about 1.8 million BOPD in 1981. Table 2 above shows that these reservoirs combine excellent permeability with low oil viscosity at reservoir conditions so this is a conventional production operation even though we call the oil Arab Heavy.

The Zuluf Field was discovered in 1965. Production of Arab Medium crude comes from the Khafji sand. Production capacity was increased to 1.1 million BOPD in 1993.

The northern Saudi oil fields are becoming mature, but Qatif and Abu Safah of the southern Saudi fields were expanded in 2004 and produce Arab Medium. There is also a proposed 900,000 BOPD heavy oil development of the Manifa Field, but it has recently been delayed from its completion date of yearend 2011 (Saudi Aramco cancels Manifa Contract, 2008). Manifa lies between the northern and southern producing areas and produces Arab Heavy from carbonate reservoirs of Cretaceous age. Table 3 gives parameters of the three most important reservoirs in Manifa Field.

The southern Saudi fields produce mostly Arab Light from carbonate reservoirs of Jurassic age. These reservoirs do not have natural water drives and are waterflooded for that reason. Horizontal drilling is now used extensively in Saudi oil projects.

Table 3: Manifa Field Reservoir Parameters[2]

| Reservoir | U. Ratawi | L. Ratawi | Manifa |
|---|---|---|---|
| Net Thickness (ft) | 50 | 188 | 71 |
| Oil Gravity | 31 | 26 | 29 |
| Viscosity (cp) | 2.6 | 4.4 | 2.8 |
| Sulfur Content | 2.77 % | 3.66 % | 2.97 % |
| Porosity | 17 % | 22 % | 20 % |
| Permeability (md) | 50 | 600 | 300 |

About 80% of Iraq's oil production comes from the southeast. Northern Iraq's oil production is exported to the Mediterranean via Turkey and does not supply California. Further Iraq development depends on political stability and investment levels, which are difficult to predict at this time. Project Kuwait, which is a redevelopment of the fields in northern Kuwait, has been repeatedly delayed. For these reasons, future production levels are difficult to predict.

**Latin America and West Africa**

Ecuador was the source of a quarter of California's foreign imports in 2005. Nearly all of Ecuador's oil production comes from the Oriente Basin, which is located east of the Andes. Unlike the Middle East, where production is dominated by a small number of very large fields, oil production in Ecuador comes from numerous fields. Although Ecuador's production was less in 2007 than in 2006, several additional heavy oil fields could be developed including Pungarayacu, which is estimated to contain between 4.5 and 7 billion barrels of oil in place (Ecuador's Giant Pungarayacu to See Heavy Oil Appraisal, 2008).

Mexico has been a significant supplier to California in the past, but is facing major production declines (Watkins, 2008). Mexico's oil production has been dominated by the Cantarrell Complex that came onstream in 1980, and further production gains were achieved with nitrogen injection, but now the field is in decline.

Brazil supplies some oil to California and production is increasing due to deep-water developments. Perhaps the most exciting current development in oil supply anywhere is the series of recent discoveries in the presalt

[2] Saudi Aramco, *Oil Reservoirs, Table of Basic Data,* Year-End 1980

sediments of the Santos Basin. If recent government estimates of 50 to 80 billion barrels of oil prove accurate, this will have a major effect on the world oil trade and is likely to greatly increase the volume of oil shipped from the Atlantic to the Pacific Basin.

Argentina, Venezuela and Angola also supply some oil to California. It is not anticipated that Agentina's oil exports will grow significantly in the near future. Venezuela has huge heavy oil reserves. It is not currently a major supplier of oil to California, but eventual development of these resources could change that. Angola is now a supplier to California, its oil production is increasing and it has joined OPEC.

**Canada as a Supplier to California**

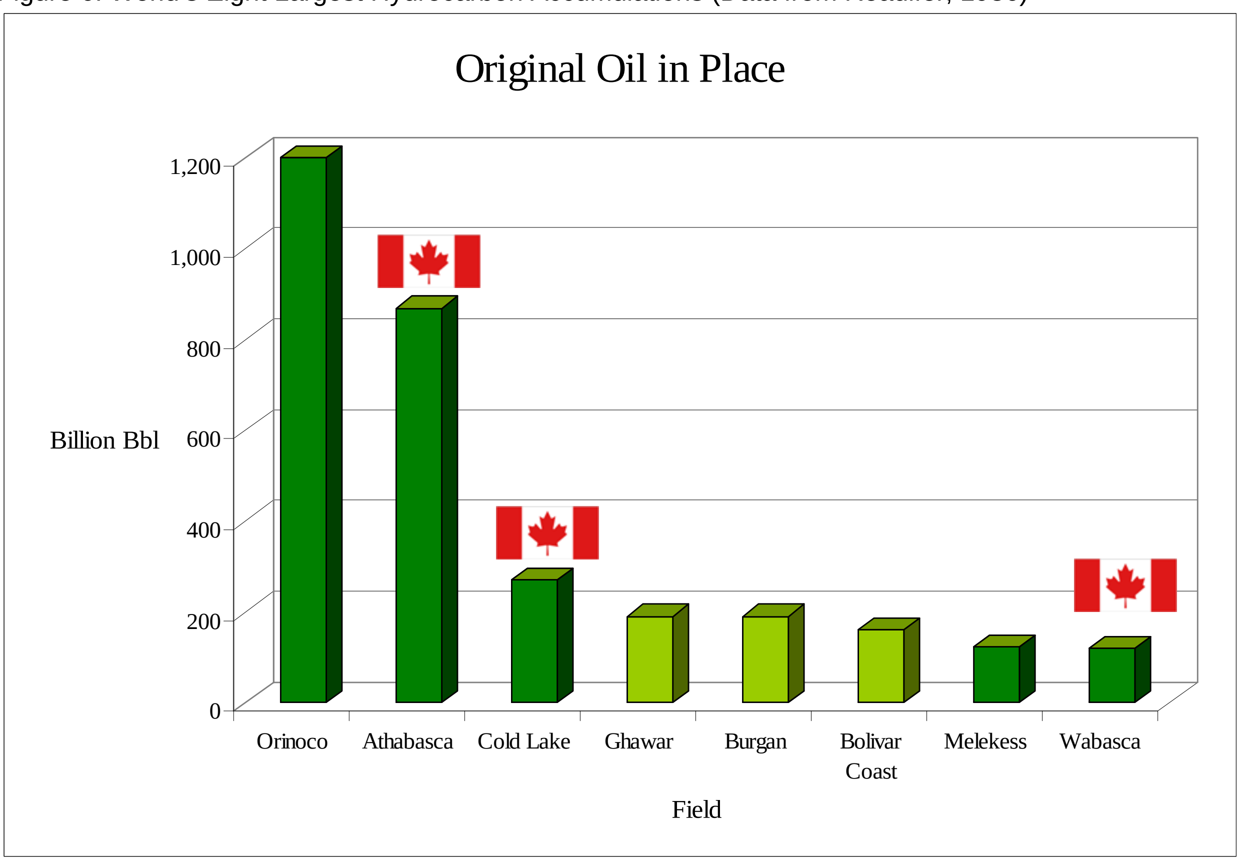
The heavy oil resources of Venezuela and Canada are the World's largest hydrocarbon accumulations. Figure 6 shows the world's eight largest hydrocarbon accumulations by oil in place. The source for this information dates to 1987, but such tabulations are difficult to find.

The economics of oil sands production recently became highly favorable and development is proceeding much more rapidly in Canada than in Venezuela. Canada has become the largest supplier of oil to the US and Canadian heavy oil dominates Midwest supply now. The Canadian Association of Petroleum Producers claims that production from the oil sands in Alberta will be 3.3 to 4.0 million BOPD in 2020.

Pipelines from the oil sands to Kitimat or Prince Rupert on the Pacific Coast have been proposed, and could supply California. There is an existing pipeline to Burnaby in British Columbia that has recently been expanded to 200,000 BOPD.

Oil sands production is more carbon-intensive than conventional oil. This carbon comes primarily from two processes; steam generation for bitumen extraction and production of hydrogen for refinery upgrading processes.

Figure 6: World's Eight Largest Hydrocarbon Accumulations (Data from Roadifer, 1986)

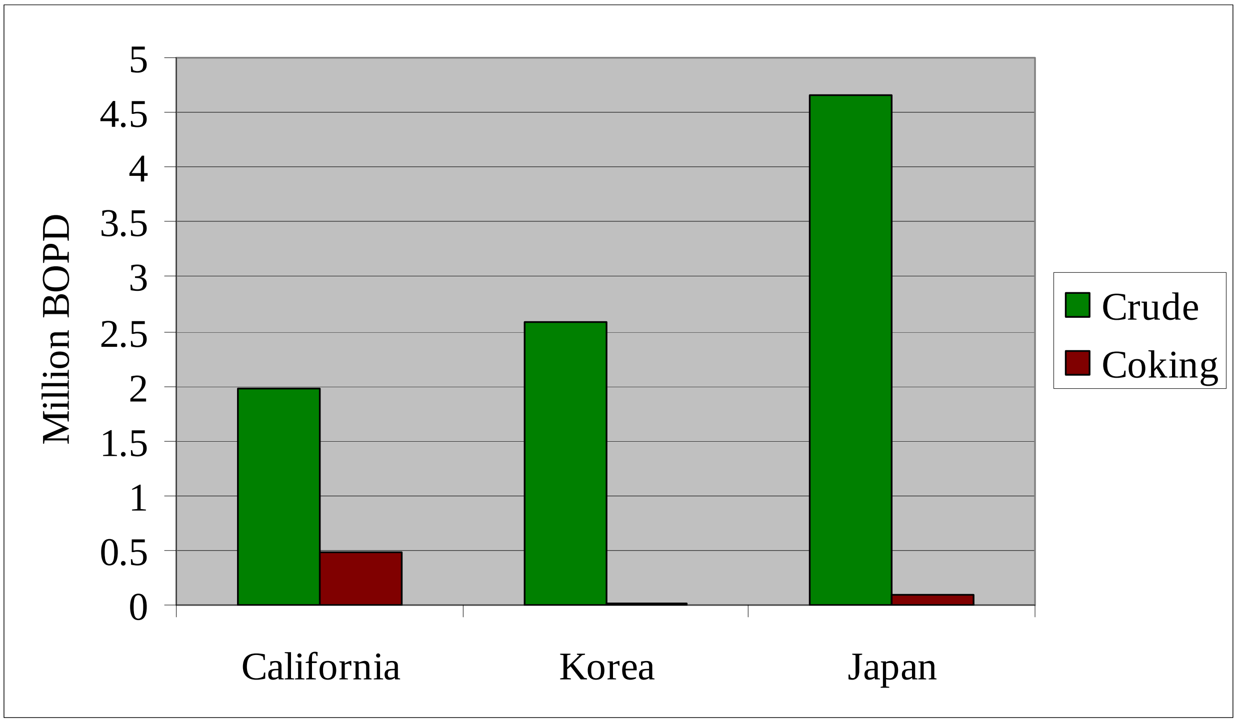



**California's Refining Capacity**

California refineries have evolved from processing California oil to processing a mix of California crudes, Alaska North Slope, Arab Heavy, and Ecuador Oriente, among others. Because of this history, California refineries are designed to process heavy oil.

Refineries designed to process heavy crude typically have three stages; distillation, cracking and coking. The ratio of coking capacity to crude distillation capacity gives an approximation of the extent to which a region's refineries have been designed to process heavy crude. Figure 7 shows that coking capacity in California is 25% of primary crude distillation capacity, as compared to 2.0% in Japan and 0.7% in Korea. This illustrates that enormous investments have already been made in heavy oil refining capacity in California.

Figure 7: Crude Distillation versus Coking Capacity for Major Pacific Oil Markets (Data from Nakamura, 2007)




**Energy Security Considerations and the Low Carbon Fuel Standard**

Concerns about energy security in California mostly revolve around oil. Because the waterborne crude market is global, regional oil price differentials are a function of freight rates if the market is in equilibrium. The problem is that oil supply disruptions are not equilibrium situations almost by definition. During disruptions energy security is an issue. The time required for markets to reach equilibrium is the time required to rearrange marine supply chains, which is to say that long supply lines decrease security. Diversification of oil supply sources increases security because it is unlikely that that multiple sources would be disrupted at the same time. Substitution increases energy security as long as the supply of the substitute is independent of the supply of oil.

Concerns about climate change have led California to propose a low-carbon fuel standard. The goal is to reduce carbon equivalent emissions per unit of fuel energy by 10 percent by 2020 (Farrell and Sperling, 2007). The problem with this approach is that it does not address the actual problem, which is total emissions, while working against California's competitive strength in the refining of heavy oil.

**Fuel Substitution Possibilities**

Oil is used primarily for transportation fuel in California. Alternative vehicle fuels include natural gas, propane, biofuels and electricity.

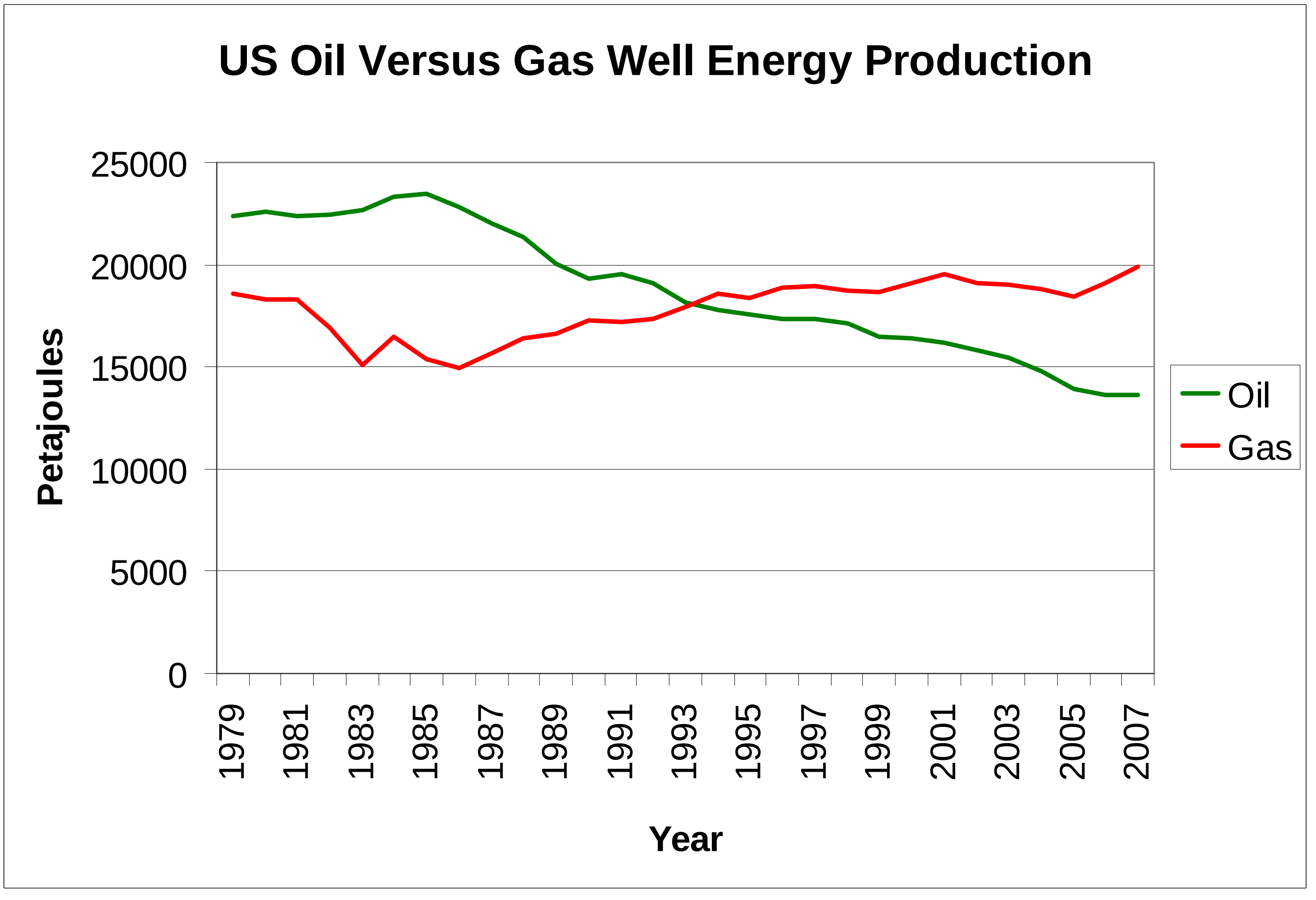
Natural gas is the least environmentally damaging transportation fuel, but storage is more difficult than for liquid hydrocarbon fuels. California's natural gas currently comes from the U.S. and Canada. Natural gas has several desireable aspects; it is cheaper than oil, large new resources have been found in the U.S. lower-48, and Alaska also has very large volumes of undeveloped natural gas. Natural gas vehicles also do not have the toxic aromatic compounds that are a problem with gasoline and Diesel fumes.

Since 1977, the Energy Information Administration has published figures for associated and non-associated gas production. Figure 8 is an approximate comparison between the energy yielded from oil wells and that from gas wells over time in the United States. Oil production was converted at 5.95 GJ per barrel, marketed dry gas at 1025 btu per cubic foot and gas liquids at 4.525 GJ per barrel, which is the value for propane. In order to adjust for the fact that a significant proportion of gas comes from oil wells, the energy curves labeled Oil and Gas in Figure 9 were calculated by the following approach:

$$Oil = energy(oil) + energy(assocgas) + energy(NGL) \times \left( \frac{volume(assocgas)}{volume(gas)} \right)$$

$$Gas = energy(nonassocgas) + energy(NGL) \times \left( \frac{volume(nonassocgas)}{volume(gas)} \right)$$

Figure 8: US Oil and Gas in Energy Units (Data source DOE/EIA)




Propane, biofuels and electric cars raise more difficult questions. Propane supplies are limited and it is an essential feedstock for the petrochemical industry. With biofuels, once again supplies are limited and biofuels compete with the food supply for land and fertilizer. Electricity comes from a variety of sources in California and it can be considered secure because nearly all of these sources are domestic. Electric cars are politically popular, but have an energy storage problem which limits their range. This is the reason that an earlier attempt to mandate electric cars in California was not successful. For the purposes of this paper, electric cars will not be considered current technology.

Of the currently available alternatives, natural gas appears to have the greatest potential for replacing a portion of California's oil usage in the transportation sector. Thailand, a nation which faces a similar choice between locallyproduced gas and Pacific Basin oil markets, has embarked on a program to increase the number of natural gas vehicles on its roads from 122,375 in 2008 to 332,000 in 2012. Their goal is to replace 20% of oil imports by then (Petroleum Authority of Thailand, 2008).

## Conclusions

1. California is increasingly dependent on the Middle East and Ecuador. This means the state is affected by factors outside of local control, such as the Manifa Field delay in Saudi Arabia. An additional concern about these areas is that reserves are reported without supporting information, leaving future supplies uncertain.
2. California's refining industry is built for heavy, sour crudes. This capability represents an enormous cumulative investment in a technology that gives us an energy security advantage.
3. Canada is the most promising oil source for California in the long term. It has very large reserves of the heavy oils that California's refining industry is built for. Canada's reporting of reserves is highly transparent, removing uncertainty over the magnitude of its resources.
4. Environmental concerns restrict oil development offshore California. Another environmental regulation, the low-carbon fuel standard, reduces California's energy security by discouraging oil from Canada and onshore California.
5. Substitution of compressed natural gas for liquid fuels in a portion of the vehicle fleet improves security.

## Acknowledgments

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