An Independent Scientific Assessment of Well Stimulation in California

Volume I

Well Stimulation Technologies and their Past, Present, and Potential Future Use in California

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Executive Summary

In 2013, the California Legislature passed Senate Bill 4 (SB 4), setting the framework for regulation of well stimulation technologies in California, including hydraulic fracturing. SB 4 also requires the California Natural Resources Agency to conduct an independent scientific study of well stimulation technologies in California to assess current and potential future practices, including the likelihood that well stimulation technologies could enable extensive new petroleum production in the state, evaluate the impacts of well stimulation technologies and the gaps in data that preclude this understanding, identify risks associated with current practices, and identify alternative practices which might limit these risks.

The study is issued in three volumes. This document, Volume I, provides the factual basis describing well stimulation technologies, how and where operators deploy these technologies for oil and gas production in California, and where they might enable production in the future. Volume II discusses how well stimulation affects water, the atmosphere, seismic activity, wildlife and vegetation, traffic, light and noise levels; it will also explore human health hazards, and identify data gaps and alternative practices. Volume III presents case studies to assess environmental issues and qualitative risks for specific geographic regions. Volumes II and III will be released July 2015.

Well stimulation enhances oil and gas production by increasing the permeability of the reservoir rocks. The report discusses three types of well stimulation as defined in SB 4. Hydraulic fracturing uses a high-pressure fluid in a well to create fractures in the rock and then props the fractures open by injecting sand so they remain permeable after the high pressure ceases. Acid fracturing uses a high-pressure acidic fluid to fracture the rock and etch the walls of the fractures, so they remain permeable after they partly close following application of the high pressure. Matrix acidizing does not fracture the rock; instead, low-pressure acid is pumped into the well to dissolve some of the rock and increase the permeability. Acid fracturing and matrix acidizing are referred to collectively as acid stimulation.

This report addresses oil and gas production both on land and offshore in California. Figure ES-1 provides basic statistics about the volume of oil and gas production from California basins between 2002 and 2014. The figure also illustrates how much of the produced volume is associated with hydraulic fracturing. In Northern California, production of natural gas is rarely conducted with the help of well stimulation. In contrast, about 20% of the total oil production in the state is facilitated by hydraulic fracturing, with most of this occurring in the San Joaquin Basin.

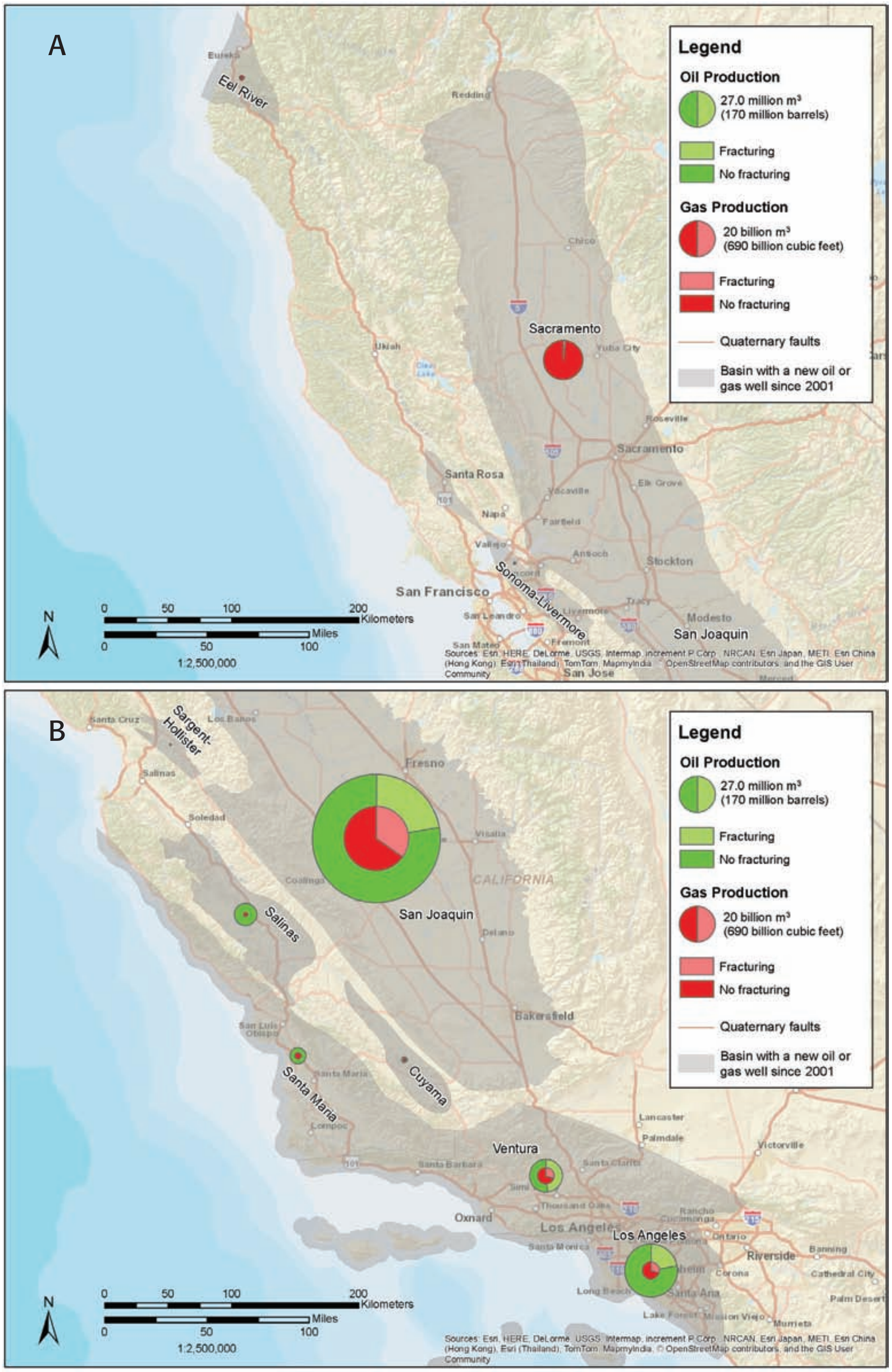

Figure ES-1. *Production of oil and gas with and without hydraulic fracturing in each basin in A) northern and B) southern California from 2002 through May 2014. The area of each circle is proportional to the production volume in each basin.*

Data Availability, Key Findings and Conclusions

- The following findings and conclusions are based on available information. Data on where, when, and how operators conduct well stimulation in the state were not collected thoroughly or consistently across the state prior to 2014. Data submittal on all operations across the state was required starting in 2014; however, the number of reported operations initially decreased as operators adjusted to the new regulations imposed by SB 4. We developed findings and conclusions based on a review of published literature and official and voluntary databases through June 2014. Much of the information prior to the start of mandatory reporting in January 2014 remains incomplete and unverified. We describe the limitations of the data throughout the report in order to transparently qualify the accuracy of the conclusions.

- Due to the timeline of this study relative to the institution of mandatory reporting on January 1, 2014, the analyses conducted in this report assess only six months of well stimulation data resulting from the implementation of SB 4. Even after the start of compulsory reporting, inconsistencies between datasets collected by various state and private institutions suggest that inaccuracies may persist. However, we cross-checked multiple independent data sets and found largely consistent results, indicating that we can have reasonable confidence in the quality and consistency of the data collected before and since mandatory reporting commenced. Comprehensive understanding of well stimulation in the state requires complete and accurate reporting regulations as specified by SB 4 and sufficient time for the number and type of operations to stabilize. In contrast to the well stimulation data, we consider the available information on the geology of developed petroleum resources in California and the potential for future use of well stimulation in similar reservoirs of the state to be of high quality.

- Recognizing these limitations in the data, the report conclusions should be taken as generally accurate, if not precise. The authors have reasonable confidence that additional data becoming available in the future might change some of the quantitative findings in the report, but would not fundamentally alter the report conclusions about well stimulation in California.

Hydraulic fracturing of onshore oil wells: Almost all hydraulic fracturing in California occurs in the San Joaquin Basin in wells that produce primarily oil. We expect this practice to continue as the main use of well stimulation in the state for the foreseeable future.

- Over the last decade, about one fifth of oil production in California came from wells that had been subject to hydraulic fracturing. In this time period, operators fractured about 125 to 175 wells of the approximately 300 wells installed per month in California. Available data indicate that hydraulic fracturing has been the main type of well stimulation. The number of hydraulic fracturing operations per month in California represents one-tenth of the number of hydraulic fracturing operations reported to FracFocus per month in the entire country in 2012 and 2013. As FracFocus is a voluntary database, the true number of hydraulic fracturing operations conducted in the country is likely higher than reported, and so the fraction of operations in California is probably lower. About 95% of reported hydraulic fractures in California were in the San Joaquin Valley, nearly all in four oil fields in Kern County (Chapter 3).

- Current hydraulic fracturing activities in California are different than in other states, and as such recent experiences with hydraulic fracturing in other states do not necessarily apply to current hydraulic fracturing in California. Available data suggest that present-day hydraulic fracturing practices in California are different from other states such as Texas and North Dakota, primarily because of differences in the geology of the petroleum reservoirs. Generally, current hydraulic fracturing in California tends to be performed in shallower wells that are vertical as opposed to horizontal; and requires much less water per well, but uses fluids with more concentrated chemicals than hydraulic fracturing in other states. For example, in California, a hydraulic fracturing operation consumes on average 530 cubic meters (m^3; 140,000 gallons, gal) of water per well, compared to about 16,000 m^3 (4.3 million gal) per well used in horizontal wells in the Eagle Ford Formation in Texas. Consequently, the practices and impacts of hydraulic fracturing in other states do not directly apply to current hydraulic fracturing in California (Chapter 3).

- The most likely scenario for future oil recovery using hydraulic fracturing is expanded production in and near existing oil fields in the San Joaquin Basin in a manner similar to the production practices of today. The vast majority of hydraulic fracturing in the state takes place in the San Joaquin Basin in reservoirs that depend on this technology for economic production. A significant amount of oil remains in these reservoirs. It is highly likely that continued production in these reservoirs will use hydraulic fracturing (Chapter 4).

- This study's review of the two oil resource projections from deep source rocks in the Monterey Formation developed by the United States Energy Information Administration (US EIA) concluded that both these estimates are highly uncertain. Recent reports from the US EIA have indicated there may be substantial oil resources in deeper source-rock reservoirs, especially in the Monterey Formation. The 2011 US EIA report suggested 2.4 billion m^3 (15 billion barrels) of recoverable oil in these source rocks, but a subsequent 2014 US EIA report using more restrictive assumptions reduced the estimate to 0.095 billion m^3 (0.6 billion barrels). There is little evidence to support either estimate. No reports of significant production from the Monterey or other source rocks have been identified to date in California. If innovations do someday allow recovery of oil from California's source rocks, the undertaking would likely require well stimulation technology. Future exploration of Monterey source rock could improve our understanding of the potential, challenges, costs, and rewards for production in these reservoirs (Chapter 4).

Stimulation of dry gas wells[1]: Almost all wells that produce primarily gas are located in Northern California. These dry (non-associated) gas wells are rarely stimulated, and we do not expect this to change in the near future.

- Operators rarely stimulate California dry (non-associated) gas wells. Approximately ten dry gas wells per month were installed on average from 2002 through 2011, of which about one was hydraulically fractured. We found no records of hydraulic fracturing of gas wells since 2011 and no records of acid stimulation in these wells. However, most of the gas production in the state is not from dry gas wells, but from wells that primarily produce oil. As such, about a fifth of the gas produced in the state is facilitated by hydraulic fracturing (Chapter 3).

- Geologic assessment indicates that significant unconventional natural gas resources on a basin-wide scale, such as the Marcellus or Barnett shales or in the Piceance basin, probably do not exist in California. Most of the remaining undiscovered non-associated natural gas in California is likely to be similar to reservoirs in production today that currently do not use well stimulation technology. The geologic conditions in California are unlikely to have created large basin-wide gas plays (Chapter 4).

- Operators hydraulically fracture gas storage wells. Hydraulic fracturing facilitates about a third of the subsurface storage of natural gas in the state. We expect this to continue given the importance of these facilities to balance urban natural gas demand from season to season. About two times a year on average, operators of gas storage facilities use hydraulic fracturing to enhance storage, mostly in one facility serving southern California (Aliso Canyon) (Chapter 3).

Hydraulic fracturing offshore: Hydraulic fracturing is used in a small proportion of offshore wells; we expect hydraulic fracturing to continue to play an incidental role in offshore production.

- The majority of offshore production takes place without hydraulic fracturing. Most of this limited hydraulic fracturing activity is conducted on man-made islands

1. Wells typically produce both oil and gas. The distinction between a dry gas well and an oil well is in the relative amount of oil and gas produced. Dry gas wells produce a large amount of gas compared to oil, sometimes called "non-associated" gas. Oil wells produce a small amount of gas relative to oil, known as "associated" gas.

close to the Los Angeles coastline; little activity is documented on platforms. Operations on close-to-shore, man-made islands resemble onshore oil production activities. Ninety percent of offshore fracturing operations in California waters occurred on man-made islands in the Wilmington field. On these islands, operators conduct about 1-2 hydraulic fracturing operations in the 4-9 wells installed per month. The only available survey of stimulation in federal waters records 22 fracturing stimulations conducted or planned from 1992 through 2013, compared to more than 200 wells installed during that period. All but one of these hydraulically fractured wells were in the Santa Barbara-Ventura Basin. About 10-40% of fracturing operations in wells in state waters and half of operations in federal waters were frac-packs[2] (Chapter 3).

- If expansion of oil production offshore is allowed in the future, production could occur without well stimulation technology. Billions of barrels of potential oil reserves exist off the California coast, but both federal and state laws and policies restrict expansion of production into new areas. Current production from offshore platforms uses some well stimulation to marginally improve productivity, but most production does not require well stimulation. New production, if ever permitted, would likely resemble existing production. The use of well stimulation technologies discussed in this report in the offshore environment would not affect production nearly as much as a change in current policies and regulations that now restrict new production offshore (Chapter 4).

Acid stimulation: Operators report the use of acid for well stimulation much less often than hydraulic fracturing. Of the known operations, most are matrix acidizing treatments conducted in oil wells in the San Joaquin Basin.

- Available data indicate that operators use acid stimulation about 10% as often as hydraulic fracturing in California. In contrast, operators commonly use acid treatments for well maintenance and remediation of damage caused by drilling. In California, the definition of acid stimulation varies from one regulatory agency to another, and the agencies have different record-keeping practices. This makes it difficult to assess the extent of acidizing in the state. Analysis of existing data suggests that acid is widely used for well maintenance in California, whereas about 15–25 acid operations in the approximately 300 wells installed per month in California are reported as stimulation. Nearly all reported cases of acid stimulation take place in the southwestern portion of the San Joaquin Basin. Although acid is commonly used for well maintenance and remediation, acid stimulation does not represent an important well stimulation technology in California compared to hydraulic fracturing (Chapter 3).

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2. As opposed to hydraulic fracturing intended to open permeable fracture pathways in unconventional reservoirs to enable oil or gas production, frac-packs are employed to deal with formation damage around a production well and/or sand production into the well. See Chapter 2 for more details.

- Acid stimulations in California reservoirs are not expected to lead to major future increases in oil and gas development in the state. In general, the geologic conditions in the state's oil reservoirs are not amenable to effective acid stimulation treatment. Acid stimulations can be effective in carbonate reservoirs, but these are rare in California. The underlying geology of California means that acid is not useful now or in the future for creating major increases in the permeability of the formation (Chapters 2 and 3).

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

APCCH	American Petrofina Central Core Hole
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
AU	Assessment Unit
barrels/min	Barrels per Minute
BBO	Billion Barrels of Oil
BCFG	Billion Cubic Feet of Gas
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
CCST	California Council on Science and Technology
cm	Centimeter
CO_2	Carbon Dioxide
cP	Centipoise
cp	Commonly Polyacrylamide
CT	Crystobalite-type
CVRWQCB	Central Valley Regional Water Quality Control Board
DOC	Department of Conservation
DOE	Department of Energy
DOGGR	Division of Oil, Gas, and Geothermal Resources
EDTA	Ethylenediaminetetraacetic Acid
EGMBE	Ethylene Glycol Monobutyl Ether
EOR	Enhanced Oil Recovery
EPS	Explosive Propellant Systems
EUR	Estimated Ultimate Recovery
ft	Feet/Foot
ft^3	Cubic Feet
g/cm^3	Grams per Cubic Centimeter
g/l	Grams per Liter
gal	Gallons
gal/ft	Gallons per Foot, (see also gpf)
GIS	Geographic Information System
GPa	Gigapascals
gpf	Gallons per Foot (see also gal/ft)
GTK	Growth-to-Known
HCl	Hydrochloric Acid
HF	Hydrofluoric Acid
HF/HCl	Hydrofluoric/Hydrochloric Acid

IB	Inner Borderland
ICoTA	Intervention & Coiled Tubing Association
in	Inches
km	Kilometers
km^2	Square Kilometers
LBNL	Lawrence Berkeley National Laboratory
LPG	Liquid Propane
m	Meters
m^2	Square Meters
m^3	Cubic Meters
m^3/s	Cubic Meters per Second
Ma	Million Years Ago
MAPDIR	Maximum Pressure Differential and Injection Rate
md	Millidarcies
mi^2	Square Miles
MMB	Million Barrels
MMBO	Million Barrels of Oil
MMBOE	Million Barrels of Oil Equivalent
MMS	Minerals Management Service
MPT	Mud Pulse Telemetry
MWD	Measurement While Drilling
NGL	Natural Gas Liquids
NH_4HF_2	Ammonium Bifluoride
NIFZ	Newport Inglewood Fault Zone
NORM	Naturally Occurring Radioactive Materials
NTA	Nitrilotriacetic Acid
NYSDEC	New York State Department of Environmental Conservation
OCS	Outer Continental Shelf
OOIP	Original Oil in Place
ppm	Parts per Million
psi	Pounds per Square Inch
PVFZ	Palos Verdes Fault Zone
PVP	Palos Verdes Peninsula
Remax	Maximum Potential Recovery Efficiency
SB 4	Senate Bill 4
SCAQMD	South Coast Air Quality Management District
scf	Standard Cubic Feet
scf/STB	Standard Cubic Feet of Gas per Stock Tank Barrel of Oil
SMFZ	Santa Monica Fault Zone
STB	Stock Tank Barrel
TCF	Trillion Cubic Feet
TOC	Total Organic Carbon
TSO	Tip Screenout

TVD	True Vertical Depth
US EIA	United States Energy Information Administration
USGS	United States Geological Survey
WFZ	Whittier Fault Zone
WST	Well Stimulation Technologies