AB 1632 ASSESSMENT OF CALIFORNIA'S OPERATING NUCLEAR PLANTS

APPENDICES

FINAL CONSULTANT REPORT

Prepared For:
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Appendices

APPENDIX A: FEDERAL WASTE DISPOSAL EFFORTS

It has been more than 20 years since Congress identified Yucca Mountain as the site for a potential repository. The U.S. Department of Energy (DOE) only recently submitted a license application for the repository. The regulatory review of DOE's license application is expected to take years to complete, and final approval of the application is not a foregone conclusion. In light of this delay, options for spent fuel reprocessing and interim waste storage are also being considered. This appendix outlines the status of high-level waste disposal and spent fuel reprocessing initiatives.

Status of Yucca Mountain

The Nuclear Waste Policy Act of 1982, as amended, imposed a January 31, 1998, deadline for the opening of a federal nuclear waste repository at Yucca Mountain. As described in *Nuclear Power in California: 2007 Status Report*, the Yucca Mountain project has been plagued by a series of delays and mismanagement, and today, more than 10 years after the statutory deadline, the opening date for the repository remains at least 10 years away.[1]

DOE, which is managing the Yucca Mountain project, submitted a repository license application to the U.S. Nuclear Regulatory Commission (NRC) on June 3, 2008.[2] If the license application is approved, DOE will be authorized to construct a repository for spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nevada. Submission of the license application represents a major milestone for DOE. However, the project still faces serious difficulties. Consequently, DOE has abandoned its previously announced "best achievable" goal of having the repository open by 2017 and has not yet set a new date for opening the repository.[3]

Following is a summary of recent licensing developments, legislative actions, legal developments, and possible management changes being explored for the Yucca Mountain project. For background on the project and a discussion of developments prior to mid-2007, see *Nuclear Power in California: 2007 Status Report*.[4]

Licensing Developments

The NRC is responsible for reviewing the Yucca Mountain license application. There are two steps to the review process: an acceptance review and a technical review. The purpose of the

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[1] MRW & Associates, Inc. *Nuclear Power in California: 2007 Status Report.* Prepared for the 2007 Integrated Energy Policy Report. CEC-100-2007-005. October 2007, Chapter 3.

[2] U.S. Department of Energy. "DOE Marks Milestone in Submitting Yucca Mountain License Application," June 3, 2008. Accessed: June 19, 2008. http://www.ocrwm.doe.gov/info_library/newsroom/documents/060308_la_pr.pdf.

[3] Tetreault, Steve, Stephens Washington Bureau. "Lack of money spells uncertainty for Yucca nuke dump, DOE says." February 19, 2008. Accessed: April 21, 2008. http://www.lvrj.com/news/15760627.html.

[4] MRW & Associates, Inc. *Nuclear Power in California: 2007 Status Report,* Chapter 3.

acceptance review is to determine if the application is suitable for performing a detailed technical review. If the application passes the acceptance review, the NRC will have three years to complete the technical review and public hearings process and to determine whether or not to issue the license.[5] If necessary, the NRC may ask Congress for a one-year extension.

DOE prepared the Yucca Mountain license application based on the U.S. Environmental Protection Agency's (EPA) draft radiation protection standards because the final standards have not yet been released. The NRC does not require final EPA standards in order to complete the application acceptance review and begin the subsequent license review. However, final EPA standards will be required before the license review can be completed.[6]

DOE was required to make electronically available all documentary material relevant to the licensing proceeding at least six months prior to submitting the license application.[7] In October 2007 DOE certified its collection of over 3.5 million documents for the NRC's public database of license related documents.[8]

In October 2007, DOE released several Draft Environmental Impact Statements (EIS) related to Yucca Mountain. The Draft Repository Supplemental EIS considers the potential environmental impacts of changes that have been made in the repository design and operational plans since the completion of the original Yucca Mountain Final EIS in February of 2002. The Draft Nevada Rail Corridor Supplemental EIS considers potential environmental impacts of spent fuel transport along the proposed Mina rail corridor. The Draft Rail Alignment EIS considers potential impacts of the construction and operation of a railroad in Nevada. DOE held eight public hearings for interested parties to comment on the draft documents. The 90-day comment period ended in January 2008 (see "Comments of California State Agencies on Draft Environmental Impact Statements").[9]

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5 U.S. Nuclear Regulatory Commission. "Fact Sheet on Yucca Mountain." Accessed: June 19, 2008. <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-yucca-license-review.html>

6 If the final EPA standards differ from the proposed standards, the NRC will revise its proposed rule to match these standards. The NRC can do this during the license review process. Weber, Michael. "Examination of the Licensing Process for the Yucca Mountain Repository," October 31, 2007. Accessed: June 19, 2008 <http://epw.senate.gov/ >.

7 10 CFR 2.1003

8 U.S. Department of Energy. "U.S. Department of Energy Certifies Its Document Collection for Yucca Mountain License Application." Press Release. October 19, 2007. Accessed: April 21, 2008. <http://www.ocrwm.doe.gov/info_library/newsroom/ documents/ LSN_Press_Release_V_10-19-07.pdf>.

9 U.S. Department of Energy. "About OCRWM, Budget and Funding." Accessed: April 23, 2008. <http://www.ocrwm.doe.gov/about/budget/index.shtml>.

Comments of California State Agencies on Draft Environmental Impact Statements

In comments to DOE, Commissioner James Boyd of the California Energy Commission stated that the Yucca Mountain environmental analyses were incomplete since route-specific transportation analyses and evaluations of potential groundwater impacts in California had not been completed. In addition, Boyd noted that DOE had provided insufficient information to characterize potential impacts from waste shipments and repository operations and to make a decision on the suitability of the Yucca Mountain site.

The California Attorney General and Department of Fish and Game also submitted comments. Attorney General Brown stressed that DOE had not analyzed the risk of terrorism or the economic consequences of sabotage or transportation accidents created by the transportation routes under consideration. The California Department of Fish and Game raised concerns about groundwater impacts, particularly in the Amargosa River and Death Valley regions.

Sources: Public comments of Commissioner James D. Boyd, California Energy Commission, January 10, 2008. "The State of California's Comments on the U.S. Department of Energy (DOE) Draft Environmental Impact Statements Related to a Proposed Geologic Repository at Yucca Mountain, Nevada"; Public comments of Attorney General Edmund G. Brown, Jr., California Department of Justice, January 10, 2008. "Comments on U.S. Department of Energy's National Environmental Policy Act Documents for the Yucca Mountain Repository"; and Public Comments of Denyse Racine, Senior Environmental Scientist, California Department of Fish and Game, January 17, 2008. "Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada"

Legislative Developments

Legislative proposals in support of Yucca Mountain that were introduced in 2006 have languished in Congressional committees.[10] One new proposal that was introduced in January 2008 has also not moved forward. This bill, which would authorize DOE to make non-nuclear infrastructure upgrades at Yucca Mountain prior to NRC licensing, remains in the Committee on Environment and Public Works.[11]

Some legislators are turning to other waste management solutions. A statement of the Senate Energy and Natural Resources Committee notes that while most of the committee members support constructing new nuclear power plants, they differ over options for waste disposal. Some support a continued focused effort to develop Yucca Mountain while others support reprocessing or other approaches to storage. According to Committee spokesman Bill Wicker,

[10] H.R. 5360/S. 2589 and S. 3962

[11] Nuclear Waste Policy Amendments Act of 2008. (S. 2551, Sen. Inhofe, U.S. Senate, Jan 24, 2008).

this reflects a change: "On Senate Energy, there has always been a broad, general consensus on nuclear waste, a consensus that this year no longer exists."[12]

Senator Domenici, the author of a 2006 bill that would have provided DOE with additional operational and budgetary support for Yucca Mountain, introduced a bill in June 2008 (S. 3215) that supports reprocessing technologies instead.[13] According to Domenici, Yucca Mountain is not needed since spent fuel could be reprocessed, and the reprocessing waste could be stored in underground locations such as the New Mexico salt formations.[14] Domenici's focus on alternatives to Yucca Mountain reflects his sense that "[we] have been working at (Yucca Mountain) for 15 to 16 years, and we are nowhere."[15, 16]

Congress awarded DOE just $386.4 million of the $494.5 million requested for the FY 2008 Yucca Mountain budget, even after the House of Representatives voted to award DOE the full budget request.[17] DOE announced that it would lay off 500 workers as a result of this budget cut, further slowing down work on the repository. DOE also emphasized that these delays are expensive: a three-year delay in opening Yucca Mountain would increase Nuclear Waste Fund-related legal liabilities from $7 billion (in 2017) to $11 billion (in 2020).[18] DOE will be liable for costs associated with keeping spent fuel at reactor sites because DOE failed to fulfill its contractual obligation with nuclear power plant operators to take possession of the spent nuclear fuel by 1998.

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[12] Knapik, Mike. "US Senate committee now divided over nuclear waste policy." February 27, 2008. Accessed: April 28, 2008. <http://www.nucwatch.com/platts/2008 /platts080229.txt>.

[13] S. 3215, Strengthening Management of Advanced Recycling Technologies Act of 2008, Introduced in the U.S. Senate, June 26, 2008.

[14] Tetreault, Steve, Stephens Washington Bureau. "Plan seeks temporary sites for nuclear waste storage." April 24, 2008. Accessed: April 24, 2008. < http://www.lvrj.com/ news/18101754.html>.

[15] Tetreault, Steve, April 24, 2008.

[16] A report of the Union of Concerned Scientists echoed this frustration over the Yucca Mountain process, asserting that "it is critical to identify and overcome technical and political barriers to licensing a permanent repository, and the DOE should identify and begin to characterize potential sites for a permanent repository other than Yucca Mountain." Gronlund, Lisbeth, David Lochbaum, Edwin Lyman, Union of Concerned Scientists. "Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges." December 2007, page 1.

[17] U.S. Department of Energy. "U.S. Department of Energy Issues National Environmental Policy Act Documents for Public Comment." Press Release. October 4, 2007. Accessed: April 21, 2008. <http://www.ocrwm.doe.gov/info_library/newsroom/ documents/Press_Release_EIS_10-05-07_Final.pdf>.

[18] Wald, Matthew L. "As Nuclear Waste Languishes, Expense to U.S. Rises." *New York Times*, February 17, 2008.

In June 2008 the House of Representatives Committee on Appropriation once again recommended approval of DOE's full nuclear waste disposal budget request.[19] However, the Senate has not yet voted on the FY 2009 appropriations bill so actual funding levels may be lower than the requested $494.7 million.

Legal Challenges

Over the past decade, the State of Nevada has launched numerous challenges against the Yucca Mountain repository. In October 2007 and April 2008, the NRC determined that it could not take action on two outstanding petitions until DOE files its license application.[20] The first petition was a request to limit the amount of nuclear waste that could be stored above ground while awaiting underground disposal at the Yucca Mountain site.[21] The second was a request that Sandia National Laboratories, a major contractor at the nuclear waste site, be suspended from the project and investigated for putting schedule over safety.[22]

During this same period, the State issued two new challenges:

- Attorneys for the State of Nevada petitioned in October 2007 to invalidate DOE's document collection certification. According to the petition, key documents about the nuclear waste project have not been posted on the NRC's Licensing Support Network and "millions" of e-mails and irrelevant documents were put on the database to confuse reviewers.[23]
- In April 2008, the State of Nevada asked the NRC to reject DOE's plan to rely on metal alloy shields for groundwater contamination protection that would not be installed for at least 100 years. In a letter to NRC Chairman Dale Klein, Bob Loux, chief of the Nevada

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19 U.S. House of Representatives, Committee on Appropriations. "Summary: 2009 Energy and Water Appropriations, Full Committee Markup." June 2008. Accessed: July 7, 2008. <http://appropriations.house.gov/pdf/EWFY09FCSummary06-08.pdf>.

20 Tetreault, Steve, Stephens Washington Bureau. "NRC puts complaint about Yucca on hold; Officials say it's too soon to judge request for probe." October 30, 2007. Accessed: April 21, 2008. <http://www.lvrj.com/news/11882731.html>.

21 State of Nevada. "Petition for Rulemaking to Amend Part 63 to Clarify The Limits on Spent Fuel Storage at The Yucca Mountain Site." Petition to U.S. Nuclear Regulatory Commission. December 22, 2006. Accessed: April 23, 2008. <http://www.state.nv.us/nucwaste/news2006/pdf/nvag061222 petition.pdf>.

22 State of Nevada. "Petition for an Independent Investigation and Suspension of Sandia National Laboratories from Further Work On the Yucca Mountain Project." Petition to U.S. Nuclear Regulatory Commission. October 16, 2006. Accessed: April 23, 2008. <http://www.state.nv.us/nucwaste/news2007 /pdf/nvag071016nrc_petition.pdf>.

23 U.S. Nuclear Regulatory Commission. "Motion to Strike DOE's October 19, 2007 LSN Recertification and to Suspect Certification Obligations of Others Until DOE Validly Recertifies." Docket No. PAPO-00, ASLBP No. 04-829-01 PAPO, October 29, 2007. Accessed: April 23, 2008. <http://www.state.nv.us/nucwaste/news2007/ pdf/efm071029nrc.pdf>.

> State Nuclear Projects Agency, called the idea of "robots installing expensive and heavy drip shields made of rare metals highly speculative."[24] Loux noted that the robots have yet to be invented and that there is no guarantee that the large quantities of titanium and palladium that will be needed will be available in 100 years.

The NRC had not responded to these petitions as of June 2008.

Potential Management Changes

DOE has proposed to reorganize U.S. nuclear waste management work under a government-owned public corporation or federal authority.[25] The corporation would have responsibility for Yucca Mountain, reprocessing initiatives, and any future efforts to collect and store high-level waste on an interim basis until the Yucca Mountain repository is opened. According to the proposal, the corporation would be given access to the Nuclear Waste Fund. This would free the corporation from the annual congressional appropriations process and provide it with budgetary certainty. However, congressional action could be required both to enable the Nuclear Waste Fund to be used for activities other than waste disposal and to free the corporation from congressional budgetary control.

DOE also says it may seek bids for a contract to manage the Yucca Mountain program after the contract for current manager Bechtel SAIC Co. expires at the end of March 2009. DOE holds two one-year options to extend the Bechtel contract, but DOE is investigating other alternatives.[26]

Status of Reprocessing Initiative

In early 2006 DOE initiated the Global Nuclear Energy Partnership (GNEP), a program to establish a proliferation-resistant nuclear fuel cycle based on a newly established domestic reprocessing capability.[27] As discussed in *Nuclear Power in California: 2007 Status Report*, there is substantial opposition to the program from prominent scientists and public interest groups, in

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[24] Loux, Robert. "NRC Should Not Accept DOE's Yucca Mountain Application if it Relies on thousands of Titanium 'Drip Shields' it Almost Certainly Will Never Install." Letter from Robert Loux, Executive Director, Nevada Agency for Nuclear Projects to U.S. Nuclear Regulatory Commission Chairman Dale E. Klein. April 15, 2008.

[25] *Power News*. "DOE proposing Federal Corporation for Nuclear Waste." Accessed: April 21, 2008. <http://web.hermesemessenger2.com/tfg/public/Update_Links.asp?EmailAddress=&ScheduleID=1066&IssueID=274&FileName=http://web.hermesemessenger2.com/tfg/public/newsletters/present/ISSUE274/article757.html&ArticleID=757>.

[26] *Associated Press*. "Energy Department Seeks bids on Yucca Mountain Management Job." February 12, 2008. Accessed: April 21, 2008. <http://www.kolotv.com/home/headlines/15548027.html>.

[27] The long-term global fuel supply aspects of this program are not relevant to California at this stage and are not discussed here.

large part due to the high cost of the program and potential proliferation risks.[28] U.S. Energy Secretary Samuel Bodman was scheduled to make a decision in June 2008 on whether to move forward with GNEP and, if so, which technologies to pursue.[29] However, as of early July, this decision has not yet been announced.

In anticipation of Secretary Bodman's decision, DOE has been building partnerships with industry and has continued to develop plans for GNEP research and development facilities. DOE has also been responding to critiques of GNEP by reframing the program to focus on research and development rather than on activities that would support near-term commercialization of advanced reprocessing technologies. It is unclear at this time whether this represents a substantive program shift.

In late 2007 the National Academies released a review of DOE's nuclear energy research and development programs, including GNEP. The authors expressed concern that the GNEP schedule would require decisions to be made on whether to go forward with GNEP and on which technologies to pursue before sufficient technical and economic analyses had been conducted and subjected to peer review. The report concluded that GNEP should not go forward as proposed and that it should be replaced by a less aggressive research program (see "Recommendations of the National Academies").[30]

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[28] In a December 2007 report, the Union of Concerned Scientists added their voice to the debate. The report concluded that the proposed GNEP program would offer no waste disposal benefits and would increase the risks of nuclear proliferation and terrorism. Gronlund, et al. December 2007: 1. See also, *Nuclear Power in California: 2007 Status Report*, Chapter 4.

[29] U.S. Department of Energy. "Global Nuclear Energy Partnership Strategic Plan." GNEP-167312, Rev. 0, January, 2007. Accessed: April 24, 2008. <http://www.gnep.energy.gov/pdfs/gnepStrategicPlan January2007.pdf>.

[30] National Research Council, Committee on Review of DOE's Nuclear Energy Research and Development Program. "Review of DOE's Nuclear Energy Research and Development Program." ISBN: 978-0-309-11124-9, pp. 5-6. Accessed: April 24, 2008. <http://www.nap.edu/nap-cgi/execsumm.cgi?record_id=11998>.

Recommendations of the National Academies

- DOE should defer the decision on whether to move forward with GNEP. DOE should commission an independent peer review of the state of knowledge as a prerequisite to any decision on future research programs.
- DOE should compare both the technical and financial risks of a reprocessing program with the potential benefits. Such an analysis should undergo an independent, intensive peer review.
- DOE should develop and publish detailed technical and economic analyses to explain and describe the reprocessing technologies under consideration as well as a range of alternatives. An independent peer review group should review these analyses. DOE should pursue the development of multiple processes until a fully fact-based comparison can be made and a decision taken on which process or processes could be carried to engineering scale.
- DOE should bring together other appropriate divisions of DOE and other federal agencies, representatives from industry and academia, and representatives from other nations well before any decisions are made on the technology.

Source: Committee on Review of DOE's Nuclear Energy Research and Development Program, National Research Council, ISBN: 978-0-309-11124-9 . "Review of DOE's Nuclear Energy Research and Development Program" (Source: http://www.nap.edu/nap-cgi/execsumm.cgi?record_id=11998 accessed 4/24/08)

The Government Accountability Office (GAO) conducted a review of DOE's plans for GNEP and released a report in April 2008 noting similar problems. GAO found that DOE's plan to build engineering-scale facilities could meet the GNEP objectives if the advanced technologies are successfully developed and commercialized. Nonetheless, this plan has two shortcomings. First, the lack of industry participation could reduce the prospects for eventual commercialization of the technologies. Second, DOE's plan to build the reprocessing plant before conducting research and development that would help determine the plant's design requirements unnecessarily increases the risk that the spent fuel will be separated in a form that cannot be recycled.[31]

Congress echoed these critiques in the FY 2008 budget authorization, which granted DOE just $181 million of the $395 million request for GNEP. The Appropriations Act made it clear that the funds were to be spent on research and development efforts and that "no funds are provided for facility construction for technology demonstration or commercialization."[32]

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[31] U.S. Government Accountability Office. "Global Nuclear Energy Partnership: DOE Should Reassess Its Approach to Designing and Building Spent Nuclear Fuel Recycling Facilities." April 2008.

[32] U.S. Congress. "Consolidated Appropriations Act, 2008 – Division C – Energy and Water Development and Related Agencies Appropriations Act, 2008 (H.R. 2764, PL 110-161)." January 30, 2008. (House Appropriations Committee Print) pp. 568, 604. Accessed: April 25, 2008.

DOE has responded to these critiques by reframing GNEP to focus on research and development and on building an engineering-scale advanced fuel cycle facility. DOE has announced that it no longer intends to site and develop a commercial-scale recycling center and fast reactor at the present time.[33] The FY 2009 budget request appears to reflect this change: of the $301.5 million requested, over $230 million is for research and development activities, with smaller amounts for conceptual studies of GNEP facilities. DOE requested no funding for technology development.[34] Yet, the House Appropriations Committee appears unconvinced: the committee approved a FY 2009 Energy and Water appropriations bill in June 2008 that would cut all funding for the GNEP program due to concerns that it "undermines our Nation's nuclear non-proliferation policy."[35]

In fact, DOE is continuing to pursue advanced reprocessing technologies, and there is no indication that DOE's time frame has been changed. In recent months, DOE has made two sets of awards totaling $34.3 million to four industry teams to develop plans for a commercial-scale recycling center and fast reactor and has contracted with Tennessee Valley Authority to evaluate the desirability of an integrated intermediate-scale advanced fuel cycle demonstration project.[36] The industry teams have completed conceptual design studies, technology development roadmaps, and business plans, and they are now working on detailed studies (see "GNEP Technological Challenges"). Their studies plan for reprocessing start dates between 2018 and 2028 and fast reactor deployment between 2018 and 2025.[37] These dates are in line with DOE's goal to commercialize an advanced reprocessing system in the mid-to-late 2020s.[38]

<http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_ cong_house_committee _prints&docid=f:39564c.xxx.wais>.

33 U.S. Department of Energy. "Programmatic Environmental Impact Statement Update." Accessed: April 25, 2008. <http://www.gnep.energy.gov/peis/gneppeis.html>.

34 U.S. Department of Energy. "FY 2009 Congressional Budget Request." Page 663. Accessed: April 25, 2008. <http://www.ne.doe.gov/budget/budgetpdfs/fy09Vol_3_NE.pdf>.

35 U.S. House of Representatives, Committee on Appropriations. "Summary: 2009 Energy and Water Appropriations, Full Committee Markup." June 2008.

36 U.S. Department of Energy. "Department of Energy Awards More Than $16 Million for GNEP Technology Development Plans." Press Release. October 1, 2007. Accessed: April 24, 2008. <http://www.doe.gov/news/5535.htm>; U.S. Department of Energy. "DOE Awards $18.3 Million to Nuclear Industry Consortia for GNEP Studies." Press Release. March 28, 2008. Accessed: April 21, 2008. <http://www.doe.gov/news/6100.htm>; Tennessee Valley Authority. "Memorandum of Understanding between the Tennessee Valley Authority and the U.S. Department of Energy for Advanced Fuel Cycle Demonstration Support." April 18, 2008, page 1. Accessed: April 24, 2008. <http://www.ne.doe.gov/pdfFiles/TVADOE_ AFCDMOU0408.pdf>.

37 Centre for International Governance Innovation. "GNEP Watch: Development in the Global Nuclear Energy Partnership." Issue 5 (March 2008): page 4. Accessed: April 25, 2008. <http://www.cigionline.org>.

38 U.S. Department of Energy, "Spent Nuclear Fuel Recycling Program Plan." May 2006, page 16. Accessed: April 28, 2008. <http://www.gnep.energy.gov/pdfs/snfRecycling ProgramPlanMay2006.pdf>.

Senator Domenici, a strong supporter of reprocessing, introduced a bill in June 2008 (S.3215) that would further encourage the near-term commercialization of reprocessing. The bill would require DOE to offer to enter into one or more agreements with private entities to complete the design of one or two reprocessing technologies. It would also require DOE to share with private entities the cost of obtaining construction and operating licenses for up to two reprocessing facilities.[39]

As discussed above, DOE has proposed that a new government-owned corporation be created to oversee all nuclear waste management issues, including GNEP. This change, if effected, would provide DOE with budget certainty and with more independence in identifying priorities and directing the course of GNEP.

Status of Centralized Storage Initiatives

Federal interim waste storage proposals have not progressed in the past year. As discussed in *Nuclear Power in California: 2007 Status Report*, these proposals have been met by protest from state leaders and from DOE.[40]

Private Fuel Storage, LLC, a private consortium of utilities attempting to construct an interim fuel storage facility on the Goshute Reservation in Utah, filed a complaint against the U.S. Department of Interior's decisions to reject the proposed lease of tribal land and to disapprove of the use of public lands for an intermodal transfer facility.[41] As of June 2008, no opinion had been issued in this case.

With significant uncertainty remaining as to when—and even if—the Yucca Mountain repository will open, the nuclear industry has mounted a campaign to court communities that might be willing to host interim spent fuel storage sites. According to NEI's senior director for state and local government affairs, talks are moving forward with two or three communities.[42] No agreements have yet been announced.

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[39] S. 3215, "Strengthening Management of Advanced Recycling Technologies Act of 2008," Introduced in Senate, June 26, 2008.

[40] MRW & Associates. *Nuclear Power in California: 2007 Status Report*, pages 63-66.

[41] Private Fuel Storage, LLC. "Skull Valley Band of Goshute Indians and Private Fuel Storage Seek Reversal of Interior Department Rulings." July 17, 2007. Accessed: April 28, 2008. <http://www.privatefuelstorage .com/whatsnew/whatsnew.html>.

[42] Tetreault, Steve, Stephens Washington Bureau. "NEI courts volunteers for interim storage." February 27, 2008. Accessed: April 21, 2008. <http://www.pahrumpvalley times.com/2008/Feb-27-Wed-2008/news/19960495.html>.

GNEP Technological Challenges

At a November 2007 hearing of the Senate Committee on Energy & Natural Resources, Dr. Terry Wallace of Los Alamos National Lab and Dr. Neal Todreas of the Massachusetts Institute of Technology both spoke to the challenges that will need to be overcome in order to achieve GNEP's technological goals. The key challenges that they identified are 1) the development of separations technologies, transmutation fuels, a source of fast neutrons to test the fuels, and a fast reactor; 2) the development of tools to predict the long-term behavior of new waste forms in the repository; and 3) the development of strong material safeguards.

Three separations technologies are being considered: UREX+, COEX, and NUEX. UREX+ separates spent fuel into uranium, fission products, and transuranics (or simply neptunium plus plutonium). It is being developed by DOE at the national labs. COEX separates spent fuel into a uranium-plutonium mix (sometimes with neptunium), a pure uranium stream, and a mix of other minor actinides and fission products. It is being developed by AREVA and the French Atomic Energy Commission. NUEX separates spent fuel into uranium, fission products, and transuranics. It is being developed by EnergySolutions, Inc. AREVA and EnergySolutions were among the four industry teams to receive DOE funding to develop conceptual design studies for GNEP facilities.

UREX+ 1a, which is the current version of UREX+, has been demonstrated relatively successfully at the bench scale, but only over short times and with fresh solvents. As long-term process chemistry has not yet been demonstrated and scale up has not yet been initiated, bench scale development is expected to continue until roughly 2012. The status of COEX and NUEX has not been directly addressed, but Dennis Spurgeon of DOE and Senator Domenici implied that one or both of these technologies is close to commercial development.

Transmutation fuels are at an earlier stage of development than separations technologies. Three steps will be required before transmutation fuels are commercially ready: fuel development, fuel testing, and fuel refinement. Los Alamos is developing a source of fast neutrons, which will be required for fuel testing.

Sources: U.S. Senate Committee on Energy and Natural Resources, Hearing To Receive Testimony on the Global Nuclear Energy Partnership, November 14, 2007. http://energy.senate.gov; "Global Nuclear Energy Partnership" Briefing Paper #117, Uranium Information Centre, October 2007, <http://www.uic.com.au/nip117.htm>; and "Spent Fuel Reprocessing Options: Melding Advanced & Current Technology," Presentation of Alan Dobson, EnergySolutions at the GNR2 Conference, June 13, 2007, <http://www.gnr2.org/html/2007/6-29.pdf>

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Research and Development Program. <http://www.nap.edu/nap-cgi/execsumm.cgi?record_id=11998>.

Nuclear Waste Policy Act of 1982, as amended in 1987. Subtitle E, Section 160.

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Tetreault, Steve, Stephens Washington Bureau. “NRC puts complaint about Yucca on hold; Officials say it’s too soon to judge request for probe.” October 30, 2007. <http://www.lvrj.com/news/11882731.html>.

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Appendix B: Generation Alternatives Source Material

This appendix describes the source material for the summary information provided in Chapter 9 on the resource potential, cost, environmental impacts, and local impacts of several generation technologies. It also provides additional discussion of some of these impacts. It is not intended as a comprehensive review and comparison of all life cycle impacts of generation technologies. Please refer to Chapter 9 for further discussion of these technologies.

The information in this appendix relates to existing nuclear plants and to new power plants that could be built in California. These include gas-fired power plants and renewable power plants. California law does not allow the siting of new nuclear plants or the building of new coal plants in the state.

Resource Potential

Resource potential in this context refers to the amount of power that could theoretically be derived from a particular resource type. It is discussed in terms of technical potential and economic potential. The technical potential refers to the amount of power that is theoretically attainable after accounting for basic physical, environmental, regulatory, and geographic constraints of the resource. The economic potential is that portion of the technical potential that is cost-effective to develop in the near term.

This section summarizes recent estimates of the technical and economic potentials of generation resources in California. Additional resource potential in neighboring states is not considered.

Nuclear and Gas-Fired Power Plants

The concepts of economic and technical potential are generally used with regard to renewable energy are not directly applicable to nuclear and gas-fired power.[43] In addition, they are relevant only to the consideration of new plants. As mentioned above, new nuclear plants are not considered in this report.

Wind-Powered Plants

California's wind resources are extensive and geographically diverse. More than 4,000 km^2 of land in California is characterized by high quality, Class 4 or higher winds.[44, 45] California

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[43] The limiting factors for gas-fired power development are transmission access, availability of natural gas transportation, gas supply and storage, and, in certain locations, air quality restrictions. These are not fundamental restrictions in the same way that a lack of wind fundamentally restricts the ability to develop wind power.

[44] Black & Veatch. "Renewable Energy Transmission Initiative (RETI) Phase 1A, Draft Report." March 2008.

[45] Wind power classes are based on wind power density levels (measured in watts per meter squared). Typically, wind sites with a wind power class of four or larger are preferred for utility-scale wind projects.

currently has 2,438 MW of wind power generation,[46] 95 percent of which is in the Altamont, Tehachapi, and San Gorgonio passes.[47] The greatest potential for new wind resource development is in San Bernardino, Imperial, and Kern counties.[48] In addition, large offshore turbines are being developed.[49]

In 2006 the National Renewable Energy Laboratory (NREL) estimated a technical potential of over 21,000 MW of high quality wind capacity in California (see Table 1).[50] The Energy Commission's 2007 Intermittency Analysis Project estimated a total technical potential of 22,782 MW.[51]

Table 1: California Wind Technical Potential by Wind Power Class[52]

Wind Class	**Technical Potential (MW)**
Class 4	11,955
Class 5	4,843
Class 6	3,021
Class 7	1,281
Total	**21,100**

In 2005, the Energy Commission and consultant Davis Power evaluated the economic potential for wind power in California by 2017 at 4,831 MW and 15,658 GWh.[53] For this evaluation, they considered grid benefits, location of resource relative to transmission interconnects,

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46 American Wind Energy Association. "U.S. Wind Energy Projects – California." January 2008. Accessed: March 11, 2008. < http://www.awea.org/projects/>.

47 California Energy Commission. "Overview of Wind Energy in California." February 2008. Accessed: March 10, 2008. <http://www.energy.ca.gov/wind/overview.html>.

48 As of February 2008, Kern and San Bernardino counties accounted for 69 percent of wind capacity in the CAISO generation queue.

49 Yen-Nakafuji, D. "California Wind Resources." April 2005. Accessed: March 7, 2008. <http://www.energy.ca.gov/2005publications/CEC-500-2005-071/CEC-500-2005-071-D.PDF>.

50 Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

51 Brower, M., and AWS Truewind, LLC. 2007. "Intermittency Analysis Project: Characterizing New Wind Resources in California." California Energy Commission, PIER Renewable Energy Technologies. CEC-500-2007-014.

52 Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

53 California Energy Commission. "Strategic Value Analysis: Economics of Wind Energy in California." June 2005.

transmission line and substation upgrade requirements, and the need for additional transmission infrastructure investment.

Solar Thermal Plants

Solar thermal technologies typically involve heating a working fluid to generate electric power. There are three primary solar thermal plant technologies: parabolic troughs, power towers, and parabolic dish-engines. California currently has 354 MW of parabolic trough solar capacity from the Mojave Desert Solar Energy Generating Systems (SEGS), which is the largest collection of parabolic systems in the world.[54] Currently, there are no power towers or parabolic dish-engines in operation in California; however, Stirling Engine Systems has negotiated power purchase agreements with San Diego Gas and Electric and Southern California Edison for 800 to 1,750 MW of dish-engine capacity.[55]

The technical potential for solar thermal generation is limited to areas with adequate sunlight (i.e., an annual average direct normal solar radiation of 6 kWh per m^2 per day) and a relatively flat slope of less than one percent. Forests, bodies of water, roads, and cities are not included in the set of technically feasible land.

The Energy Commission estimated in 2005 that the technical potential for solar thermal energy in California is 2,717,545 GWh and 1,061,361 MW.[56] Sixteen counties in California have technically feasible land for solar thermal development. Among them, San Bernardino and Imperial counties have the greatest technical potential, estimated at 381,159 MW and 220,244 MW, respectively.[57]

NREL employed a Geographic Information System screening approach to identify economically viable solar thermal resource areas. NREL used the technical potential criteria listed above but further restricted the resource areas to locations with an average annual direct normal solar radiation of 6.75 kWh per m^2 per day. NREL found 6,728 mi^2 of “economically favorable” land for solar energy development, which translates into an economic potential of 1,900,786 GWh of energy and 803,647 MW of capacity.[58] Applying more stringent standards requiring a minimum contiguous area of five square kilometers, Black & Veatch estimated a total economic potential of 443,799 MW (see Table 2).[59]

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[54] California Energy Commission. “California Solar Resources.” April 2005.

[55] Black & Veatch. “RETI Phase 1A, Draft Report.” March 2008.

[56] California Energy Commission. “California Solar Resources.” April 2005: 19.

[57] California Energy Commission. “California Solar Resources.” April 2005.

[58] National Renewable Energy Laboratory (NREL). “Concentrating Solar Power.” Presentation of Mark Mehos to the Committee on Regional Electric Power. April 8, 2008, page 14. Accessed: May 9, 2008. <http://www.westgov.org/wieb/meetings/crepcsprg2008/briefing/ present/m_mehos.pdf>.

[59] Black & Veatch. “RETI Phase 1A, Draft Report.” March 2008: 6-34 - 6-36.

Table 2: California Solar Thermal Economic Potential by Solar Power Class[60]

Region	Capacity by Solar Power Class					Total Capacity
	1	2	3	4	5	
Owens Valley	1,592	2,688	14,585	18,510	3,469	40,844
Kern County	-	2,154	6,145	17,073	21,135	46,507
Los Angeles Area	2,259	7,390	17,226	7,269	-	34,145
San Diego	-	3,904	480	-	-	4,384
Mohave and Imperial	-	72,226	158,082	59,181	28,430	317,920
Total	**3,852**	**88,363**	**196,519**	**102,033**	**53,034**	**443,799**

Solar Photovolataic Plants

California contains enormous tracts of land that are technically suitable for solar photovoltaic (PV) development. In 2005 the Energy Commission assessed California's solar PV potential by assuming that PV panels with a capacity factor of 10 percent could be installed everywhere except on bodies of water, environmentally sensitive areas, agricultural lands, and areas with north-facing slopes greater than 5 percent. The Energy Commission found that the technical potential for PV in California is 17 million MW.[61] This estimate does not differentiate stand alone PV plant potential from rooftop PV potential. For economic reasons, only rooftop systems are expected to be installed in the near-term. The Energy Commission estimated that the technical potential of rooftop PV systems alone is greater than 38,000 MW for near-term residential applications and exceeds 37,000 MW for near-term commercial systems.[62] Over 6,500 MW of utility-scale PV projects were listed in the CAISO Controlled Generation Queue as of March 2008.[63]

[60] Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

[61] California Energy Commission. "California Solar Resources." April 2005: 8.

[62] California Energy Commission. "California Solar Resources." April 2005: 9.

[63] California Independent System Operator (California ISO). "The California ISO Controlled Grid Generation Queue, March 21, 2008." Accessed: March 25, 2008. <http://www.caiso.com/14e9/14e9ddda1ebf0.pdf>.

Geothermal Plants

California leads the nation in terms of installed geothermal capacity with 1,884 MW.[64] California's geothermal resources are spread across the state. About 53 percent of installed capacity comes from the Geysers Geothermal Field in Lake and Sonoma counties, 28 percent comes from Imperial County, and 16 percent comes from Coso Hot Springs in Inyo County.

In 2004, GeothermEx, Inc. evaluated the technical potential of California's geothermal resources based on the quality of the resource, geographic location, source temperature, and evidence of a discrete resource. They used statistical methods to forecast minimum, maximum, and most-likely generation capacities based on the heat levels of certain resource areas and found that an additional 2,862 MW of geothermal generating capacity are most likely available for development, mainly in Imperial County, the Geysers Geothermal Field, and Medicine Lake.[65]

Of the available technical capacity, GeothermEx estimated that 1,700 MW could be developed for at most $2,400 per kW.[66] Black & Veatch estimated that 2,375 MW of incremental geothermal potential would be developed in California through 2018.[67]

Biomass Plants

Biomass-fired generation in California is concentrated in agricultural, forest, industrial, and municipal areas with steady flows of wood waste. Los Angeles, San Diego, and Orange Counties have the highest gross biomass potential within California.[68] Other potentially attractive options include wood-fired facilities in northern California and agricultural residue centers in the Central Valley.

The California Biomass Collective estimates that the gross annual stock of biomass is more than 83 million bone dry tons, with 45 percent of that amount from forestry, 27 percent from agriculture, and 28 percent from municipal waste.[69] The technical potential is significantly smaller at 31 million bone dry tons /year, since this figure takes into account an ecosystem limitation associated with biomass procurement and the 5 million bone dry tons /year consumed by existing biomass power facilities. The California Biomass Collective estimates that

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64 Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

65 GeothermEx, Inc. "New Geothermal Site Identification and Qualification." Prepared for Public Interest Energy Research (PIER) Program, California Energy Commission. April 2004.

66 Ibid.

67 Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

68 California Biomass Collaborative. "Biomass Resource Assessment in California." PIER. California Energy Commission. April 2005.

69 California Biomass Collaborative. "California Biomass and Biofuels Production Potential."December 2007.

California's technical biomass potential could generate 34,582 GWh or 4,650 MW of power using current technologies.[70]

Table 3: 2007 California Biomass Potential (Million bone dry tons /year)[71]

Sector	Gross Potential	Technical Potential
Agriculture	21	6.9
Forestry	27	11.8
Municipal	35	7.2
Total	**83**	**26**

Estimates of California's gross biomass potential provided by NREL differ substantially from those provided by the California Biomass Collective. NREL estimated that roughly 12 million bone dry tons of incremental biomass are available each year, resulting in 2,000 MW of potential capacity.[72] Black & Veatch noted that the California Biomass Collective relied on local production and disposal data whereas NREL relied on national databases. As such, the technical potential suggested by California Biomass Collective may be more reliable.

Demand-Side Resources

Demand-side resources are mechanisms that reduce or defer the demand for electricity. This section presents research on the technical potentials in California of two types of demand-side resources: energy efficiency and demand response.

Energy Efficiency

In 2006, Itron forecasted the technical, economic, and market potential for energy efficiency savings from the three California investor-owned utilities (see Table 4). In the context of this study, economic potential refers to the savings that would be achieved if all feasible cost-effective energy efficiency measures were undertaken. Market potential is the subset of economic potential that could be achieved from certain scenarios based on market conditions, program design, and three different incentive levels: 1) a continuation of incentives at the 2004 level ("current market potential"); 2) increased incentive level that includes full incremental measure costs ('full market potential"); and 3) incentive levels set to the average of the full incremental costs and current incentive levels ("average market potential").

70 GeothermEx, Inc."New Geothermal Site Identification and Qualification." April 2004.

71 California Biomass Collaborative. "California Biomass and Biofuels Production Potential." December 2007.

72 Black & Veatch. "RETI Phase 1A, Draft Report." March 2008.

Table 4: Annual Energy Efficiency Savings Potential by 2016[73]

	Technical Potential	Economic Potential	Full Market Potential	Average Market Potential	Current Market Potential
Energy (GWh)	63,184	53,150	23,974	20,065	16,226
Peak (MW)	15,483	11,151	4,887	3,772	2,594

In 2007 the Energy Commission evaluated the savings from five possible energy efficiency savings targets: 1) current goals for investor-owned utilities and feasible targets for publicly owned utilities ("current goals"); 2) 80 percent of economic potential for all utilities ("80 percent of economic potential"); 3) 100 percent of cost-effective economic potential for all utilities ("100 percent of economic potential"); 4) 10 percent reduction in consumption in 2016 ("10 percent reduction in 2016"); and 100 percent of technical potential ("technical potential").[74] The savings from each scenario are shown in Table 5.

Table 5: Annual Energy Efficiency Savings Potential by 2016[75]

	Technical Potential	100% of Economic Potential	80% of Economic Potential	10% Reduction in 2016	Current Goals
Energy (GWh)	53,000	39,000	32,000	28,000	19,000
Peak (MW)	12,200	6,600	5,300	6,800	3,900

The American Center for an Energy Efficient Economy calculated the energy efficiency potential in California at 18 percent of energy usage,[76] which would have been 54,000 GWh in 2007.[77] This figure includes only technologies that are currently ready for wide-spread penetration and is limited to equipment needing replacement over a ten year period.

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73 Itron, Inc. "California Energy Efficiency Potential Study, Volume 1." Submitted to Pacific Gas & Electric. May 2006.

74 California Energy Commission. "2007 Integrated Energy Policy Report." Pages 84-85.

75 California Energy Commission. "2007 Integrated Energy Policy Report." Pages 84-85.

76 American Center for an Energy Efficient Economy (ACEEE). "ACEEE Summer Study on Energy Efficiency in Buildings." August 2004. The savings are counted over a 10 year period from 2003 to 2013.

77 California Energy Commission. "2007 Net System Power Report." April 2008, page 5.

Combined Heat and Power

Combined heat and power (CHP, or cogeneration) is the simultaneous production of electricity and heat from a single fuel source. Typical installations involve either 1) the recovery of waste heat from a gas turbine or engine for use in industrial processes, or 2) the use of excess steam from a steam boiler to generate electricity.[78] Both types of installations use what would otherwise be a waste product as an energy source. As a result, the original fuel source produces more energy (in the form of heat and electricity) than it would in a system where heating and electricity were managed independently.

The potential for additional CHP in California is significant. In a 2005 study, the Electric Power Research Institute (EPRI) reported that there is a technical potential of 30,000 MW of additional CHP, including 14,000 MW additional potential from existing facilities, 6,000 MW from expected new facilities through 2020, 4,000 MW of combined cooling heating and power (CCHP) projects, and 6,000 MW of export market potential.[79] EPRI estimated a base case for market penetration of 2,000 MW through 2020, increasing to 7,000 MW in a high deployment case. The high deployment case includes existing incentives, facilitation of the power export market, new incentive payments for transmission and distribution support and greenhouse gas reductions, the rapid development and deployment of advance technologies, and an improvement in customer acceptance of CHP.[80]

Demand Response

Demand response refers to technologies and incentive programs that reduce power consumption during peak periods, either by shifting consumption to off-peak periods or by reducing overall consumption. In 2007 the Energy Commission estimated the potential for demand response savings in California as ranging from a technical potential of 15,360 MW to a market potential of 3,072 MW (see Table 6). The Energy Commission forecast in January 2008 that investor-owned utility demand response programs would exceed the 3,072 MW market potential and achieve peak savings of 4,243 MW in 2008.[81]

A 2007 study completed by Lawrence Berkeley National Laboratory estimated a market potential for large commercial and industrial demand response programs of up to three percent

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[78] U.S. Environmental Protection Agency. "Combined Heat and Power Partnership." June 5, 2008. Accessed: September 4, 2008. < http://www.epa.gov/chp/basic/index.html>.

[79] Electric Power Research Institute. "Assessment of California CHP Market and Policy Options for Increased Penetrataion." Cosponsored by the California Energy Commission Public Interest Energy Research Program (PIER). July 2005, page ix.

[80] Electric Power Research Institute. "Assessment of California CHP Market and Policy Options for Increased Penetrataion." Cosponsored by the California Energy Commission Public Interest Energy Research Program (PIER). July 2005, page ix.

[81] Hungerford, David. "2008 Summer Outlook." Presentation. January 16, 2008. <http://www.energy.ca.gov/2008_summer_outlook/documents/2008-01-16_workshop/presentations/ Hungerford_David.PDF>.

of total large customer peak demand.[82] The rate freeze stipulated by Assembly Bill 1X currently bars 70 percent of residential energy consumption from price-responsive demand response.[83] The Brattle Group estimated that voluntary dynamic pricing demand response could have reduced demand in California by as much as 1,500 to 2,000 MW in 2007.[84]

Table 6: California's Technical, Economic, and Market Potential for Demand Response[85]

Demand Impacts	Definition	Peak Savings[86]	Peak Savings[87] (MW)
Technical Potential	Outcome if all customers use the best available technology	25 percent	15,360
Economic Potential	Outcome if all customers used cost-effective technologies	12 percent	7,373
Market Potential	Outcome if a cost-effective combination of technologies is adopted at an assumed level of penetration	5 Percent	3,072

Interconnection/Reliability Issues

This section reviews interconnection and reliability issues associated with generation alternatives, such as the need for new transmission infrastructure and the reliability impacts of intermittent output.

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[82] The study defines demand response market potential as "the amount of demand response – measured as short term load reductions in response to high prices or incentive payment offerings – that policymakers can expect to achieve by offering a particular set of demand response options to customers in a particular market or market segment under expected market or operating conditions." Goldman, C., N. Hopper, et al. "Estimating Demand Response Potential among Large Commercial and Industrial Customers: A Scoping Study." Lawrence Berkley National Laboratory. January 2007.

[83] Assembly Bill 1X. (Keeley, Chapter 4, Statues of 2001).

[84] The Brattle Group. "The State of Demand Response in California." September 2007.

[85] California Energy Commission. "2007 Integrated Energy Policy Report." December 2007: 95.

[86] Weighted average across all customer classes.

[87] Based on Staff's 2008 forecast for statewide coincident peak demand forecast (61,439 MW).

Nuclear Power Plants

Because of their size and location relative to major load centers, Diablo Canyon and SONGS contribute reliability and resource adequacy benefits to the grid.[88] SONGS also provides grid reliability benefits because of its location between the Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E) service territories. According to the CAISO, significant transmission and reactive power support would be needed if SONGS were to shut down. Similar support would not be required following a shutdown of Diablo Canyon. However, if Diablo Canyon were to shut down, California's north to south and south to north power transfer capability would be reduced and transmission upgrades could be necessary to maintain transfer capability at current levels.[89]

Nuclear plant reliability and transmission issues associated with a major power disruption are addressed in Chapter 6. Interconnection is not a concern for operating power plants.

Gas-Fired Power Plants

Gas-fired power plants present few reliability or interconnection issues. The reliance on natural gas is the largest reliability concern. However, natural gas supply disruptions are uncommon, and natural gas storage supplies can be used during temporary disruptions.

Wind-Powered Plants

Relatively little investment has been made in new transmission in the U.S. over the past 15 to 20 years, and in recent years it has become clear that lack of transmission access and investment are major barriers to wind development. New transmission facilities are particularly important for wind resource development because of wind's locational dependence and distance from load centers. In addition, there is a mismatch between the short lead times for developing wind projects and the lengthier time often needed to develop new transmission lines. Furthermore, wind's relatively low capacity factor can lead to underutilization of new transmission lines that are intended to serve only wind farms.[90]

Interconnecting wind generation involves both physical and institutional challenges. Unlike conventional sources of energy, harnessing energy from wind requires transmission facilities that interconnect multiple generators, often in remote areas. Wind generation also tends to be added in relatively small increments, and one wind resource area may include several developers across non-adjoining sections of land.

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[88] California Energy Commission. "2007 Environmental Performance Report of California's Electrical Generation System." January 2008.

[89] MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." Prepared for the 2007 Integrated Energy Policy Report. October 2007.

[90] Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006." May 2007, page 20.

The intermittency of wind also presents a challenge since fluctuations in wind generation require compensating adjustments from other generating resources (or demand side resources) to ensure system reliability and to prevent over-generation.[91] These challenges can be addressed, at least partially, through the geographic dispersion of wind farms, which moderates the extremes of wind generation, and through reliable forecasting of wind generation output.[92] The CAISO indicates that integrating the wind power that is expected as a result of the state's 20 percent renewable portfolio standard (RPS) is operationally feasible if certain changes to operating procedures are made.[93] Several European countries have already successfully integrated large amounts of wind generation into their electrical grids. For example, 18.5 percent of Denmark's energy was generated by wind in 2005,[94] and Germany integrated more than 20,000 MW of wind by 2006.[95]

Solar Thermal Plants

Solar thermal plants depend on sunshine to generate electricity; unexpected cloud cover can quickly reduce power output. To maintain constant output, solar thermal plants may be hybridized with fossil fuels systems. In addition, solar thermal trough technologies can be adapted to enable thermal energy storage. With backup fossil power or storage capabilities, solar thermal plants can provide dispatchable power and operational flexibility in spite of the intermittency of the sunshine.

Figure 1 characterizes the generation profile of a solar thermal facility with thermal storage capabilities. As shown in the figure, storage enables solar thermal systems to meet peak demands that occur in the evening hours when the sun is no longer well-positioned for direct generation. Storage also reduces the need for generation reserves to "firm-up" the intermittent solar power generation. Current solar trough storage technologies have capacities of up to twelve hours.[96]

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[91] Over-generation is most likely to occur if both hydroelectric and wind generation are operating at maximum capacity during very light load conditions. In response, the CAISO may have to reduce generation levels of baseload resources. Better storage solutions for pumped hydro and improved coordination with the State Water Project could also be used to increase load during light load conditions. Porter, K. and Intermittency Analysis Team. "Intermittency Analysis Project: Review of International Experience Integrating Variable Renewable Energy Generation, Appendix A: Denmark." April 2007.

[92] California Energy Commission. "2007 Integrated Energy Policy Report." December 2007.

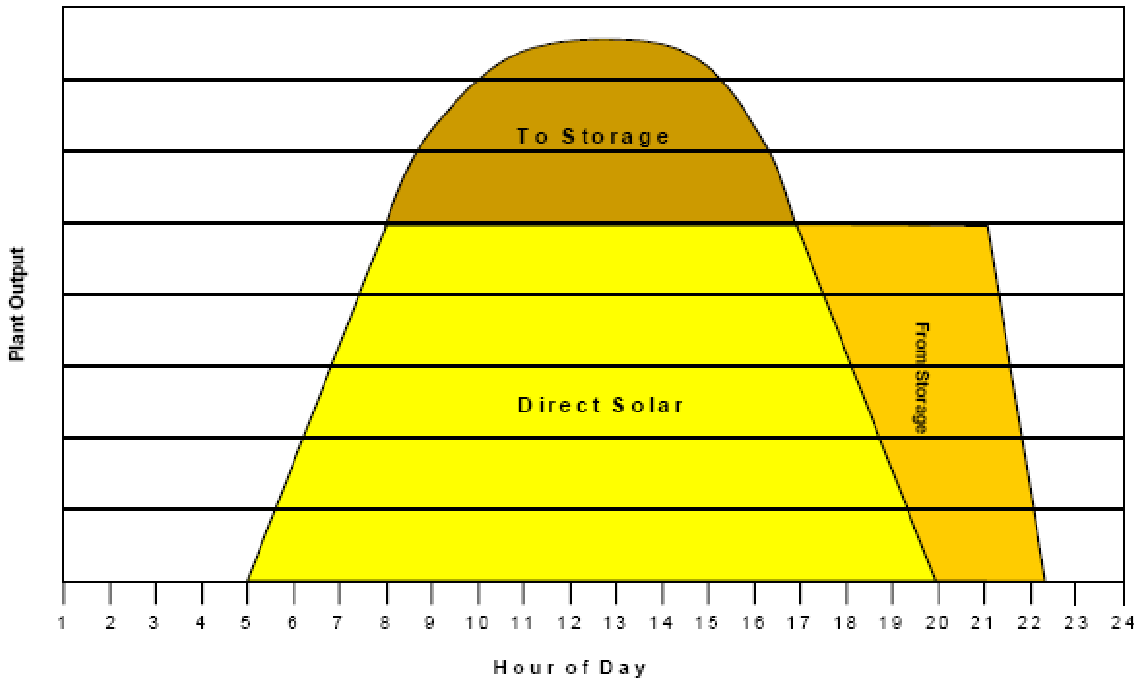
[93] California ISO. "Integration of Renewable Resources." November 2007.

[94] Porter, K. and Intermittency Analysis Team, April 2007.

[95] California Energy Commission. "PIER Research Development & Demonstration Program." April 2007.

[96] Black & Veatch. "Arizona Renewable Energy Assessment." Prepared for Arizona Public Service Company, Salt River Project and Tucson Electric Power Corporation. September 2007.

Figure 1: Conceptual California Solar CSP Generation Scenario with Storage[97]



Solar PV Plants

Interconnection and reliability issues for utility-scale PV plants are similar to solar thermal plants. (Storage for PV plants would be in the form of batteries, not thermal storage.) Small-scale PV applications typically do not pose interconnection or reliability concerns.

Geothermal Plants

Interconnecting geothermal resources into the transmission system involves many of the same challenges as interconnecting wind resources: geothermal generation tends to be added in relatively small amounts; generation must be collected from multiple sources in remote areas; and a single geothermal resource area may be characterized by multiple developers across segmented parcels of land. Consequently, developer coordination plays an important role in geothermal interconnection.

Most geothermal power plants are operated as base load generation resources with reliable output levels. However, reliability issues can arise due to output fluctuations or reservoir decline. Output fluctuations occur due to changes in ambient temperature, with higher ambient temperatures reducing ouput.[98] These seasonal changes in temperature can generally be easily

[97] Black & Veatch. "Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California." Prepard for NREL. April 2006.

[98] In general, geothermal production is more efficient when the difference between the primary heat source temperature and the ambient temperature is large.

accommodated. Reservoir decline poses a more serious problem. Since 1988, the maximum capacity of the Geysers Geothermal Field has declined from 1,866 MW to its current level of roughly 1,000 MW due to heavy steam withdrawal and overproduction.

Biomass Plants

Biomass power plants do not require unique interconnection considerations. The economics of fuel availability, supply, and transportation dictate the location of biomass power facilities, and these facilities are usually located near transmission or distribution interconnection points. Biomass plants also do not pose reliability concerns.[99]

Demand-Side Resources

Interconnection and reliability issues associated with demand-side resources vary according to the policy or technology considered. Codes and standards that increase energy efficiency have no associated interconnection or reliability issues. Demand response programs also do not require additional physical interconnection; however, in some circumstances they could negatively impact reliability. Reliability impacts could arise if customers fail to curtail power use as expected, or if demand response programs result in a sharp reduction of load over a short period. Utilities are generally able to manage or forestall these impacts. For example, they can install utility-controlled thermostats that stagger the impact of reduced air conditioning demand on the system. These thermostats ensure that demand is reduced as expected and that the reduction is staggered so that it does not imbalance the transmission system.

Cost of Alternative Generation Sources

An important factor in the assessment of generation alternatives is the cost to construct and operate a power plant. Depending on the technology, costs may be dominated by capital costs or by fuel costs. To compare the costs of different technologies, it is thus useful to consider the levelized cost, which is a measure of total costs (i.e., capital costs, financing costs, and ongoing operating costs) per unit of energy output. This section presents a review of recent studies regarding the levelized costs of *existing* nuclear plants and *new* gas-fired and renewable plants.

Nuclear Power Plants

Nuclear power plants are capital intensive plants with relatively low operating costs. In evaluating the cost of nuclear power it is therefore important to distinguish between operating costs, which do not account for construction costs, and levelized costs, which do. It is also important to distinguish between currently operating plants, whose construction costs have generally been depreciated, and new plants, whose construction costs must be paid for as part of the cost of power.

[99] California ISO. "Integration of Renewable Resources." November 2007.

Another consideration in evaluating the cost of nuclear power is the likely change in costs over time. In particular, rising nuclear fuel prices, labor shortages, and changing security requirements could increase the cost of nuclear power. These are discussed in Chapter 10.

Nationally, levelized costs for most currently operating nuclear power plants range from approximately $30 - $80 per MWh. California's operating nuclear power plants have a lifetime levelized cost of electricity close to the upper end of this range.[100]

Gas-Fired Power Plants

Natural gas power plants are relatively cheap to build, but the levelized costs associated with natural gas power depend on the price of natural gas. Currently, California relies on imports from other states and Canada for most of its natural gas. The cost of this gas has risen sharply in the last decade. Liquefied natural gas imports could offer an alternative source for the fuel in the future. This additional supply option could bring prices down; alternatively, increased demand worldwide and a falling dollar could push prices up further.[101] Natural gas power plants also face an uncertain economic future as a result of potential greenhouse gas regulations.

A recent Congressional Budget Office report highlighted this uncertainty. The report found that if natural gas fuel prices were to double from their average since the year 2000, the expected levelized cost of natural gas power could reach $97 per MWh. If, however, fuel costs were to drop by 50% from this average, the levelized cost could fall to $36 per MWh.[102]

There are two main categories of natural gas power plants: simple cycle combustion turbines and combined-cycle cogeneration plants. Combined cycle plants take advantage of waste heat in order to burn natural gas more efficiently than simple cycle plants. They are used as baseload or intermediate-load plants, while simple cycle plants are used primarily for quick-start peaking. Simple cycle plants are cheaper to build than combined cycle plants in absolute terms. However, the Energy Commission found in a 2007 study that the larger size of combined cycle plants yields economies of scale during construction that enables the otherwise more complex technology to have an installed cost per kW below that of a small simple cycle peaker plant (see Table 7).[103] This finding remains controversial.

Combined cycle plants are cheaper on a levelized basis than simple cycle plants primarily because they have higher load factors. As shown in the levelized cost comparison in Table 7, the

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[100] MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007: 140.

[101] Liquefied natural gas is transported via ship, not pipeline. This frees natural gas from geographic constraints and makes it available to the global market.

[102] U.S. Congressional Budget Office. "Nuclear Power's Role in Generating Electricity." May 2008, page 13.

[103] California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007, pages 7, 18.

simple cycle plants are much more expensive because the capital costs must be recovered over fewer hours of operation.

Table 7: Natural Gas Power Plant Costs, Existing and New ($ 2007)[104]

	New Advanced Combined Cycle, 800 MW	New Small Simple Cycle, 50 MW
Overnight Cost, $/kW	$766	$974
All-In Cost, $/kW	$763 - $834	$846 - $1,053
Levelized Cost, $/MWh	$81 - $96	$352 - $647
Percent of Levelized Cost from Fuel	59%-75%	12%-24%

Wind-Powered Plants

Average wind power prices have fallen from $62 per MWh (2007$) in 1999 to $37 per MWh (2007$) in 2006 (see Figure 2).[105] More recently, however, prices have increased. The weakness of the dollar, rising materials costs, a shortage of turbines and other components, and a concerted movement towards increased manufacturer profitability are the primary reasons for this increase. Among projects built in 2006, reported installed costs ranged from $1,150 per kW to $2,240 per kW, with an average cost of $1,480 per kW—up $220 per kW (18%) from 2005.[106]

Wind price trends are shown in Figure 2 and Figure 3 below. Cost estimates provided by Black and Veatch, the Energy Commission, and the American Solar Energy Society (ASES) are shown in Table 8 below.

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104 California Energy Commission. December 2007: 7, 10, 18.

105 These prices come from the Lawrence Berkeley National Lab database and are reduced by the receipt of any available state and federal incentives, and by the value that might be received through the separate sale of renewable energy certificates. As a result, these prices do not represent wind energy generation costs. Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006." May 2007, page 10.

106 Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. May 2007: 15.

Figure 2: U.S. Wind Power Price, 1999-2006, $/MWh (2006$)[107]

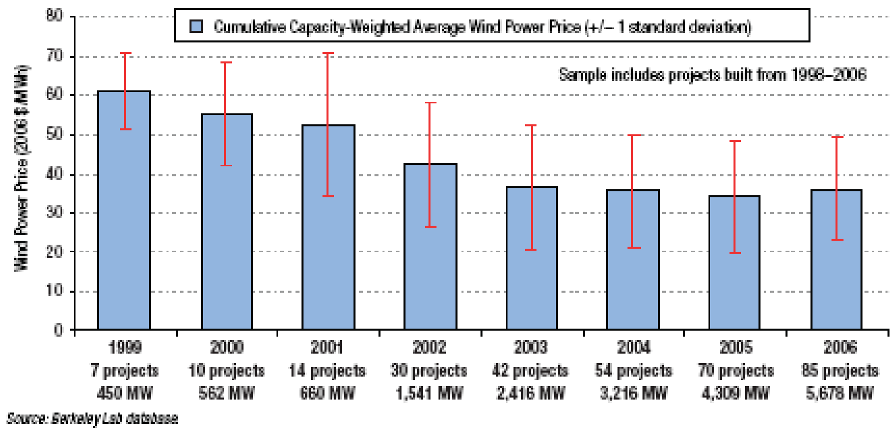
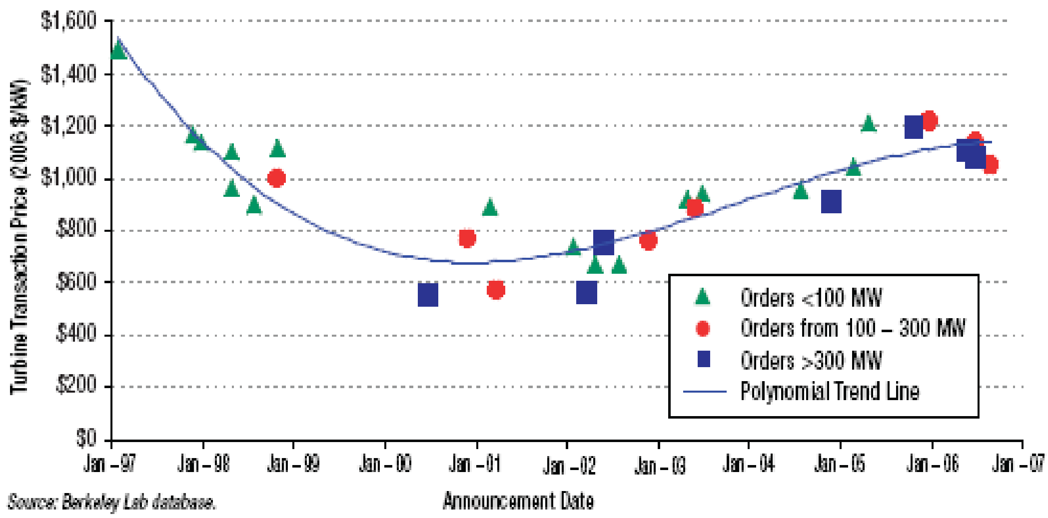


Figure 3: U.S. Wind Turbine Price 2003 – 2006 $/kW (2006$)[108]



[107] Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. May 2007: 10.

[108] Wiser, Ryan and Mark Bolinger, Lawrence Berkeley National Laboratory, U.S. Department of Energy. May 2007: 16.

Table 8: Cost of Wind Power (Class 4-6)[109]

	Black & Veatch		Energy Commission	ASES
Characteristic	Onshore	Offshore	Class 5	Class 4-6
All-In Cost, $/kW	$1,900 - $2,400	$5,000 - $6,000	$1,972 -$2,000	$1,580*
Levelized Cost, $/MWh	$59 - $128	$142 - $232	$61 - $84	$49 - $66

* Deduced from Energy Commission assumptions

Solar Thermal Plants

Current estimates of the cost of concentrating solar power range from $110 per MWh to $519 per MWh. The U.S. Department of Energy's Concentrating Solar Power Subprogram funds technology development with the aim of reducing the cost of a trough plant to $82 per MWh by 2011 and $27-$46 per MWh by 2020 (2007$).[110] The Western Governors' Association expects technology development, volume production, and scale-up in plant or project size to decrease costs to $52-$73 per MWh for a 2,000-4,000 MW plant in 2015.[111] Table 9 below provides a summary of solar thermal cost estimates from the Western Governors' Association, Black & Veatch, and the Energy Commission.

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109 Black & Veatch. "RETI Phase 1A: Draft Report." March 2008: 5-34; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7, 18; Milligan, Michael. "Tackling Climate Change in the U.S.: Potential Carbon Emissions Reductions from Wind by 2030." January 2007: 107.

110 This is a small program. The Subprogram budget appropriation for 2007 was $7.6 million out of a total of $124 million for the Solar Energy Technologies Program. U.S. Department of Energy, Solar Energy Technology Program. "About the Program: Budget." Accessed: May 8, 2008. <http://www1.eere.energy.gov/solar/budget.html>.

111 Western Governors' Association. "Clean and Diversified Energy Initiative Solar Task Force Report." January 2006: 15-16.

Table 9: Concentrating Solar Power Levelized Cost Estimates, $/Mwh (2007$)[112]

Western Governors' Association	Black & Veatch	Energy Commission
$110 - $120	$137 - $176	$199 - $519[113]

Solar PV Plants

The cost to purchase and install PV panels is approximately $6,000 - $9,000 per kW, with 45 to 50 percent of this cost for the PV modules and 50 to 55 percent for the inverter and installation. Table 10 below provides a summary of PV cost estimates from the University of California Energy Institute (UCEI), the Energy Commission, and Black& Veatch.

Table 10: Solar Photovoltaic Cost Estimates (2007$)[114]

	UCEI	Energy Commission	Black & Veatch
System Size	10 kW	1 MW	20 MW
All-In Cost, $/kW	$8,000	$9,632 - $9,672	$6,500 - $7,500
Levelized Cost, $/MWh	$337 - $565	$469 - $705	$201 - $276

At current prices, PV is not cost competitive with other renewable technologies. The California Solar Initiative and the proposed federal Solar America Initiative aim to reduce these costs by creating a competitive market that spurs technological and process improvements. The Solar America Initiative focuses on bringing down the cost of PV technology through grants to agencies and industry players for research and development as well as market transformation purposes.[115] The program's goal is to reduce the cost of residential electricity from solar PV to around $130 to $180 per MWh by 2011 and $80 to $100 per MWh by 2020 (see Table 11 and Table 12). Costs for commercial scale (10 to 100 kW) and utility scale (1 MW or greater) PV are

112Western Governors' Association. January 2006: 16; Black & Veatch. "RETI Phase 1A: Draft Report." March 2008: 1-7; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7.

113 The lower end of the range is for parabolic troughs and the upper end is for Stirling dishes.

114 Borenstein, Severin. "The Market Value and Cost of Solar Photovoltaic Electricity." University of California Energy Institute. January 2008, table 4; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7; Black & Veatch. "RETI Phase 1A: Draft Report." March 2008: 1-7.

115 U.S. Department of Energy, Solar Energy Technology Program. "Solar America Initiative: Funding Opportunities." Accessed: May 9, 2008. <http://www1.eere.energy.gov/solar/solar_america/funding_opportunities.html>.

expected to be lower. The expected price reduction should come from module cost reductions, module efficiency improvements, economies-of-scale for aggregated and larger PV markets, and improved system designs.[116]

Table 11: Solar America Initiative Solar Photovoltaic Levelized Cost Targets, $/MWh[117]

	2005 Benchmark	2011 Target	2020 Target
Utility-Scale	$130 - $220	$100 - $150	$50 - $70
Commercial-Scale	$160 - $220	$90 - $120	$60 - $80
Residential-Scale	$230 - $320	$130 - $180	$80 - $100

Table 12: Solar America Initiative Solar Photovoltaic 2020 Installed Price Targets, $/kW[118]

Utility-Scale	$1,500 - $2,250
Commercial-Scale	$2,000 - $2,750
Residential-Scale	$2,250 - $3,000

Southern California Edison submitted an application to the California Public Utilities Commission in March 2008 seeking authority to implement a program that aims to build up to 250 MW of solar PV on large commercial rooftops capable of accommodating one to two MW systems. Southern California Edison aims to reduce the cost of solar PV to $3,500 per kW by deploying approximately 50 MW each year. The utility claims that economies of scale and technology and efficiency advancements will enable the major cost reduction.[119] This price target is in-line with the 2011 cost targets for the Solar America Initiative.

116 Denholm, Paul et al. "Tackling Climate Change in the U.S.: Potential Carbon Emissions Reductions from Solar Photovoltaics by 2030." January 2007: 96.

117 U.S. Department of Energy. "Solar Energy Technologies Multi Year Program Plan 2007 – 2011." January 2006, page 17. <http://www1.eere.energy.gov/solar/pdfs/set_myp_2007-2011_proof_1.pdf>.; US Department of Energy. January 2006: 33.

118 U.S. Department of Energy. January 2006: 33.

119 California Public Utilities Commission. "Application of Southern California Edison Company for Authority to Implement and Recover in Rates the Cost of its Proposed Solar Photovoltaic Program." California Public Utilities Commission Proceeding A.08-03-015. March 27, 2008. <http://www.cpuc.ca.gov/EFILE/A/80609.pdf>.

Geothermal Plants

The western states in the U.S. and southern Canada share a capacity of almost 13,000 MW of geothermal energy that can be developed on specific sites within a reasonable timeframe. The Western Governors' Association Geothermal Task Force estimates that 5,600 MW of this capacity is viable for commercial development by 2015 at levelized costs of roughly $55-$82 per MWh, with the remaining capacity viable for development at levelized costs of up to $200 per MWh. These cost estimates assume commercial project financing conditions and the extension of a production tax credit.[120] They are similar to estimates released by Black & Veatch and the Energy Commission in 2007 (see Table 13).

Table 13: Geothermal Levelized Cost Estimates, $/MWh (2007$)[121]

Western Governors' Association	Black & Veatch	Energy Commission
$55 - $82	$54 - $107	$65 - $76

Biomass Plants

A major challenge to biomass power is that dispersed feedstock and high transportation costs generally preclude plants from being built larger than 50 MW. By comparison, coal power plants rely on the same fundamental power conversion technology but can have much higher unit capacities, exceeding 1,000 MW. As a result of this larger capacity, modern coal plants are able to obtain higher efficiency at lower cost. One of the most economical methods to burn biomass is to cofire it with coal in existing plants. Through cofiring, biomass benefits from this higher efficiency and has a more competitive cost than a stand-alone, direct-fired biomass plant.[122] Due to potential differences in the price of coal and the price of biomass, the incremental cost of cofiring biomass in an existing coal plant can be as little as -$1 per MWh.[123]

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120 Without a production tax credit, levelized costs would be $23/MWh higher. Western Governors' Association. "Clean and Diversified Energy Initiative: Geothermal Task Force Report." January, 2006, page 9.

121 Western Governors' Association. January 2006: 9; Black & Veatch. "RETI Phase 1A: Draft Report." March 2008: 5-36; California Energy Commission. "Comparative Costs of California Central Station Electric Generation Technologies." December 2007: 7.

122 Black & Veatch. March 2008: 5-6.

123 Black & Veatch. March 2008: 5-9.

Table 14: Biomass Power Plant Costs (2007$)[124]

	Energy Commission	Black & Veatch (Solid Biomass)	Black & Veatch (Cofired Biomass)[125]
All-In Cost, $/kW	$2,263 - $5,925	$3,000 - $5,000	$300 - $500
Levelized Cost, $/MWh	$51 - $144	$67 - $150	-$1 - $22

Demand-Side Resources

Many different technologies, regulations, and measures are considered demand-side resources, each with a different cost. State policy prioritizes implementing cost-effective energy efficiency and demand response programs to meet electricity demand before building new generation resources.[126] Cost-effectiveness is defined in comparison to the market price of electricity. For example, if the cost of subsidizing more efficient light bulbs or appliances is deemed lower than the cost (including capital costs) of the electricity that would have been necessary without the efficiency advancement, then the energy efficiency measure is considered economical. Thus, the incremental cost of new demand-side resource measures that are implemented in California are on par with the market cost of electricity.

In order to determine the economic potential for energy efficiency, the CPUC uses the total resource cost test to compare cost estimates of energy efficiency resources to cost estimates of generation resources, such as building and operating new power plants.[127] This test takes into account the fact that many energy efficiency measures involve initial capital purchases and years of cost savings. It compares the incremental costs of each efficiency measure to the savings delivered by the measure to produce estimates of energy savings per unit of additional cost.[128]

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[124] California Energy Commission. December 2007: 7, 18; Black & Veatch. March 2008: 5-5, 5-9.

[125] Figures for cofired biomass reflect the incremental cost of cofiring biomass at an existing coal plant.

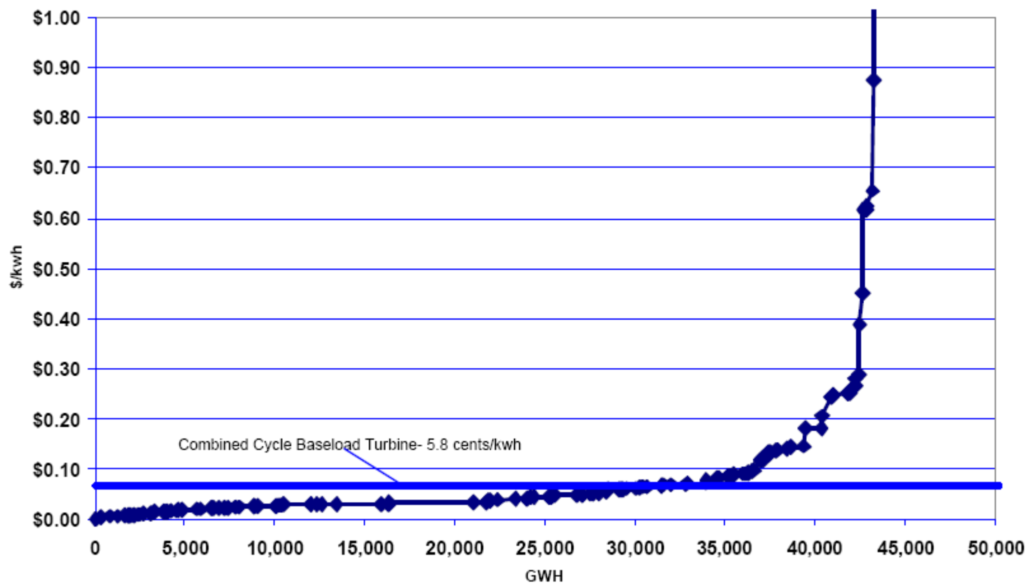
[126] California Energy Commission and California Public Utilities Commission. "Energy Action Plan II." September 21, 2005, page 2. <http://www.energy.ca.gov/energy_action_plan/2005-09-21_EAP2_FINAL.PDF>.

[127] Total resource cost ratios greater than or equal to one are generally considered to be cost-effective. However, total resource cost ratios do not include program administration costs associated with individual measures. Itron, Inc. "Assistance in Updating the Energy Efficiency Savings Goals for 2012 and Beyond, Task A4.1 Final Report: Scenario Analysis to Support Updates to the CPUC Savings Goals." March 24, 2007. Page 13.

[128] Itron, Inc, March 24, 2007: 13.

A 2002 study by XENERGY for the Energy Foundation evaluated the California energy efficiency supply curve (see Figure 4).[129] The study found that it would be cost-effective to pursue savings of 29,300 GWh per year if the levelized market power cost was 5.8 cents per kWh. The study also found that cost rose steeply to save more than 35,000 GWh a year, costing more than $1.00 per kWh to save 45,000 GWh a year. In general, the cost of incremental savings will increase as the most cost effective measures are completed and will decrease with improved technology and lower technology costs.

Figure 4: Energy Efficiency Supply Curve (GWh)[130]



Environmental Impacts

Different generation alternatives have widely varying impacts on the environment. This section presents an overview of several common impacts, such as greenhouse gas (GHG) emissions and land use, as well as resource-specific impacts.

Greenhouse Gas and Other Emissions

Greenhouse gas emissions related to electric power generation are a great concern for the State of California. All power sources emit greenhouse gases during plant construction. Nuclear

[129] Rufo, M. and Coito, F. "*California's Secret Energy Surplus: The Potential for Energy Efficiency*." Prepared by XENERGY Inc. for the Energy Foundation and Hewlett Foundation. October 2002. Cited in California Energy Commission's "Proposed Energy Savings Goals For Energy Efficiency Programs In California." October 7, 2003, page 8. <http://www.energy.ca.gov/reports/2003-11-05_100-03-021F.PDF>.

[130] California Energy Commission. "Proposed Energy Savings Goals For Energy Efficiency Programs In California." October 7, 2003: 8.

plants additionally emit greenhouse gases during fuel production and enrichment, and gas-fired plants additionally emit greenhouse gases during combustion. This section presents a summary of recent literature on the level of life cycle GHG emissions from each of the generation alternatives.

Nuclear Power Plants

Operation of nuclear power plants does not require combustion of fossil fuels and therefore emits very few GHGs or other pollutants. The major sources of GHG emissions for the nuclear power life cycle are uranium enrichment, plant maintenance, and plant construction.[131]

Estimates of life cycle GHG emissions vary widely depending on the assumptions used in the assessment and the region in which the assessment is conducted. Assumptions regarding the percentage of enrichment that is done via centrifuge technology, the fuel source for energy inputs, and the reactor lifetime contribute to the widest variation in GHG estimates.[132] Also, emissions from decommissioning and from disposing of high-level waste are difficult to estimate and may be considered speculative because there is limited experience with these components of the nuclear life cycle.

Estimates of GHG emissions from nuclear power generation range from 5 grams carbon dioxide (CO_2)-equivalent per kilowatt-hour (kWh) to 140 grams CO_2-equivalent per kWh.[133, 134] An analysis by Fthenakis and Kim provides a likely range of life cycle GHG emissions of 25-55 grams CO_2-equivalent per kWh.[135] Life cycle GHG emissions for nuclear power plants are discussed further in *Nuclear Power in California: 2007 Status Report.*[136]

Gas-Fired Power Plants

The emissions of most concern from the natural gas power production life cycle are CO_2 and nitrogen oxides (NO_x).[137] Additionally, methane can be emitted when natural gas is not burned completely or if leaks occur, and nitrogen deposition into plant and animal communities adapted to nitrogen-poor conditions can result in direct toxicity and/or facilitate the

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131 MRW & Associates, Inc. "Nuclear Power in California: Status Report." Prepared for the 2005 Integrated Energy Policy Report. March 2006.

132 MRW & Associates, Inc. "Nuclear Power in California: Status Report." March 2006.

133 AEA Technology Environment. "Environmental Product Declaration of Electricity from Torness

Nuclear Power Station." Technical Report prepared for British Energy. May 2005.

134 Storm and Smith. "Nuclear Power and Global Warming." October 2006.

135 MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007.

136 MRW & Associates, Inc. "Nuclear Power in California: 2007 Status Report." October 2007.

137 Northwest Power Planning Council. "Natural Gas Combined-cycle Gas Turbine Power Plants." August 2002. Accessed: March 27, 2008. <http://www.westgov.org/wieb/electric/Transmission%20 Protocol/SSG-WI/pnw_5pp_02.pdf>.

establishment of non-native plants that would not have otherwise been able to survive in a nitrogen-limited environment.[138]

A modern natural gas-fired power plant emits approximately 469-499 g CO_2 per kWh, with 81 percent from direct fuel combustion and much of the remaining from the fuel cycle (i.e., exploration, production, storage, and processing of natural gas).[139] Some more efficient plants may be capable of emitting only 400 g CO_2 per kWh.[140]

Natural gas plants often require air emission offsets in order to operate without impacting air quality. Offsets are in scarce supply in many areas of California, and the use of offsets for power plants has been controversial. The National Resources Defense Council (NRDC) and others recently filed suit against the South Coast Air Quality Management District regarding this issue.[141]

Wind-Powered Plants

Wind-powered plants do not emit GHGs or criteria pollutants during generation. Raw material inputs and the manufacture of all turbine components account for approximately 70 percent of the CO_2 and SO_x life cycle emissions and 50% of the NO_x life cycle emissions (see Figure 5).[142]

GHG emissions from wind-powered plants vary considerably, from about 10-150 grams of CO_2 per kWh depending on the wind quality, turbine lifespan, and CO_2 intensity of the steel.[143] The median U.S. life cycle emissions rate is in the vicinity of 45 grams of CO_2 per kWh, while California's median is higher at approximately 65 grams of CO_2 per kWh.[144]

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138 California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

139 Meier, Paul. "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis." August 2002; Spath, Pamela and Margaret Mann. "Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System". *NREL/TP-57027715*, National Renewable Energy Lab. September 2000, page 29. Accessed: December 6, 2006. <http://www.nrel.gov/docs/fy00osti/27715.pdf>.

140 Gagnon, Luc, Camille Belanger, and Yohji Uchiyama. "Life-cycle assessment of electricity generation options: The status of research in year 2001." Energy Policy 30. (2000), page 1271.

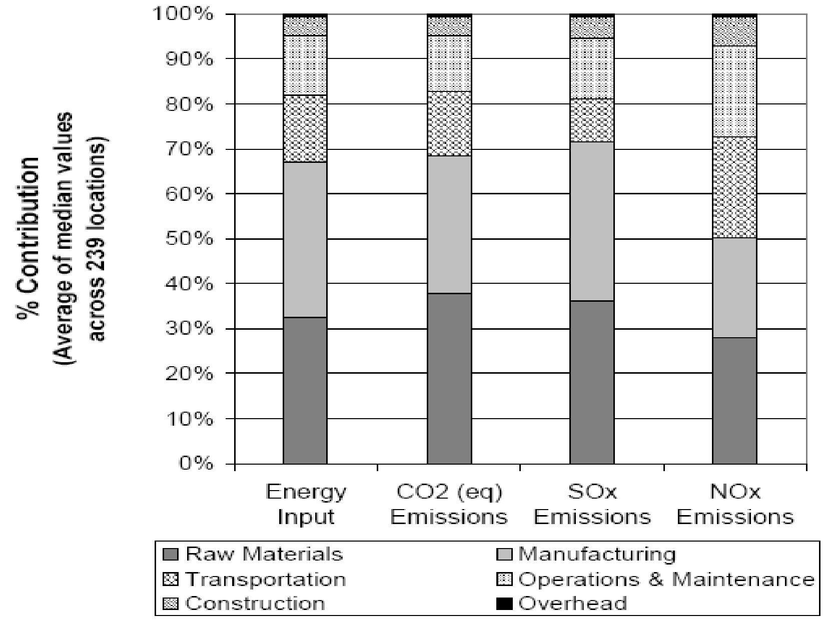
141 National Resources Defense Council (NRDC). "Notice of Intent to Initiate Citizen Suit Action under Section 304 of the Clean Air Act." April 2008.

142 Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." Defense Technical Information Center, March 2003, Appendix H. Accessed: March 24, 2008. <http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA415268&Location=U2&doc=GetTRDoc.pdf>.

143 Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." March 2003.; Gagnon, et al. "Life-cycle assessment of electricity generation options: The status of research in year 2001." (2002): 1271.

144 Liberman, E. "A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation." March 2003.

Figure 5: Lifecycle emissions of wind generation[145]



Solar Thermal Plants

There is limited life cycle data on the GHG emissions from solar thermal plants. Emissions from non-hybrid plants are primarily from the manufacturing and installing of solar thermal components.[146] Cooling tower drift from solar thermal systems can also contribute slightly to air pollution, although dry cooling presents a possible solution.

Direct GHG emissions from solar thermal plants vary depending on whether the plant has natural-gas backup capability (hybrid system). The proposed Carrizo solar facility is an example of a non-hybrid facility. GHG emissions for this facility were estimated in the project application to be at most 1.46 metric tons per year, primarily from the operation of a diesel firewater pump engine (assumed to operate 26 hours per year).[147] Hybrid solar/gas facilities such as the proposed Ivanpah project emit relatively higher amounts of GHGs, due to the partial use of fossil fuels. For this project, less than five percent of the total energy will come from fossil fuels, with 95 percent or more from solar. The direct annual emissions of GHGs from

145 Liberman, E. “A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation.” March 2003.

146 Emissions from hybrid systems are primarily from natural gas combustion. Emissions from natural gas combustion are discussed above.

147 URS Corporation. “Application for Certification for the Carrizo Energy Solar Farm, Volume 1.” October 2007.

the proposed Ivanpah SEGS were estimated in the project application to be 25,626 metric tons/year.[148]

Solar PV Plants

GHG emissions from solar PV systems arise primarily from production of the PV panel. Fthenakis and Kim calculated the lifecycle emissions of CO_2, methane, NO_x, and chlorofluorocarbons from solar systems as 22-49 grams of CO_2-eq per kWh.[149] Alsema and de Wild-Scholten calculated CO_2 emissions at 30-45 grams per kWh.[150]

Geothermal Plants

Geothermal fluids contain noncondensable gases. These include greenhouse gases (CO_2, methane, NO_x, and hydrogen), sulfur dioxide, hydrogen sufide, and ammonia. In binary plants, the geothermal fluid stays in a closed loop, and does not make contact with the atmosphere. However, in dry steam and flash steam plants, noncondensable gases are vented to the atmosphere. Emissions estimates for flash steam, binary and flash/binary, as well as dry steam geothermal plants are provided in Table 15. The level of emissions during construction and decommissioning are similar to that during operations.

Table 15: Emission Estimates for Geothermal Power Plants[151]

Type of Plant	Nitrogen Oxides (g/kWh)	Sulfur Dioxide (g/kWh)	Carbon Dioxide (g/kWh)	Particulate Matter (g/kWh)
Flash steam	0	.16	27	0
Binary and flash/binary	0	0	0	negligible
Dry steam	.0005	.0001	40	negligible

148 CH2M Hill Companies Ltd (CH2M Hill). "Application for Certification for the Ivanpah SEGS, Volume 1." August 2007.

149 Fthenakis, V.M. and H.C. Kim. "Greenhouse-gas Emissions from Solar Electric and Nuclear Power: A Life-cycle Study." Accepted for publication in Energy Policy. 2006. Accessed: February 28, 2008. <http://www.clca.columbia.edu/papers/Greenhouse_Gas_Emissions_Solar_ Nuclear_Energy_Policy-inPress.pdf>.

150 Alsema, E.A and M.J. de Wild-Scholten. "Environmental Impacts of Crystalline Silicon Photovoltaic Module Production." 13th CIRP International Conference on Life Cycle Engineering. May 31-June 2, 2006. Accessed: February 28, 2008. <http://www.nrel.gov/pv/ thin_film/docs/lce2006.pdf>.

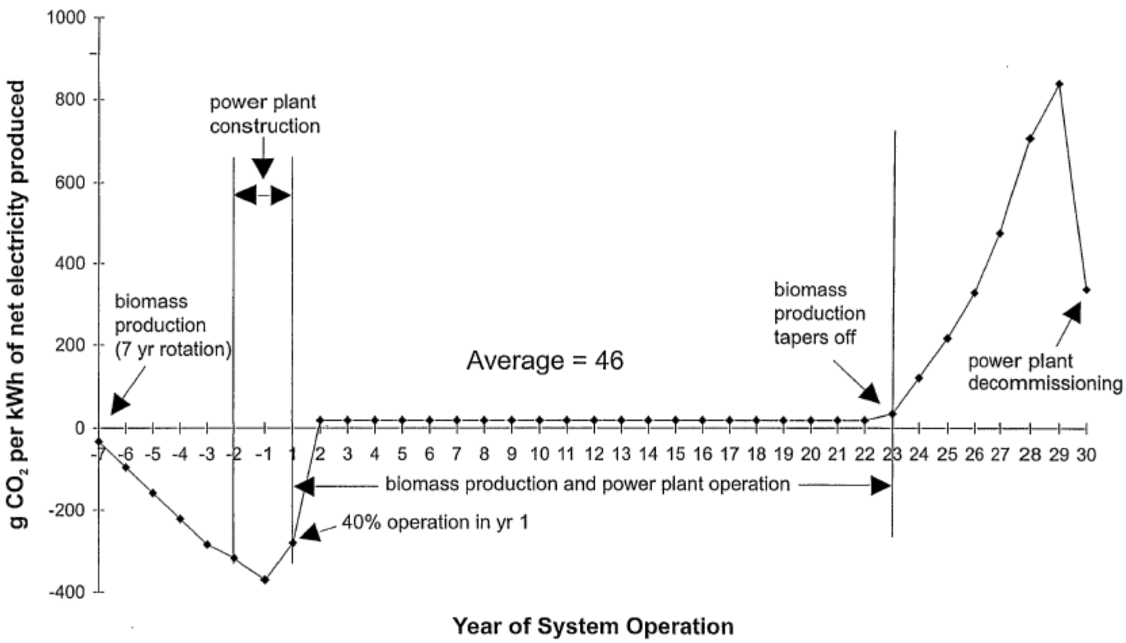
151 Kagel, A., D. Bates, and K. Gawell. "A Guide to Geothermal Energy and the Environment." Geothermal Energy Association. Washington, D.C. April 2007. Accessed: February 13, 2008. <www.geo-energy.org/publications/ reports/Environmental%20Guide.pdf>.

Hydrogen sulfide (not a greenhouse gas, but of particular health concern) can be removed from the vent stream by scrubbing or conversion to elemental sulfur. While not an issue during normal plant operations, the odor can be a nuisance even at very low concentrations during drilling and plant start up.

Biomass Plants

Biomass life cycle GHG emissions arise from the burning of biomass, feedstock transportation, plant construction, and ecosystem conversion or land-use changes. Some of these emissions are offset by the carbon dioxide absorbed during the growth process. Mann and Spath calculated net life cycle emissions of 46 g CO_2 per kWh (see Figure 6).[152] Gagnon et al. estimated that the typical biomass plant in the northeastern region of North America emits 118 g CO_2 per kWh.[153]

Figure 6: Net annual carbon dioxide emissions over the life of the system.[154]



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[152] Mann, M. and P. Spath. "Life Cycle Assessment of a Biomass Gasification Combined-Cycle System." NREL. December 1997, pages 46-50. Accessed: July 13, 2008. <
http://www.nrel.gov/biomass/process_analysis.html>.

[153] Gagnon, et al. "Life-cycle assessment of electricity generation options: The status of research in year 2001." (2002): 1271.

[154] Gagnon, et al. "Life-cycle assessment of electricity generation options: The status of research in year 2001." (2002).

Demand-Side Resources

Energy efficiency and demand-side resources in California encompass a myriad of different programs, measures, and standards. The environmental impact of each individual program will vary depending on the technologies involved and whether manufacturing or incremental construction is required. For example, some demand response programs require the use of additional metering devices, which must be manufactured, installed, and ultimately disposed of. Compact-fluorescent light bulbs contain mercury. Even building standards could have environmental impacts from incremental construction activities. However, the level of environmental impact caused by demand-side resources is generally small compared to impacts from fossil fuel generation or even renewable sources of energy. The Energy Commission noted that "[combined] heat and power, in particular, offers low levels of greenhouse gas emissions for electricity generation, taking advantage of fuel that is already being used for other purposes."[155]

Land Use

To assess the land use impacts from generation alternatives, the amount of land required and the intensity and duration of the land use must all be considered. This section presents an overview of the direct land use impacts from nuclear, gas-fired, and renewable generation alternatives.

Nuclear Power Plants

Nuclear power plants require approximately 0.75 acres per MW for generation.[156] This figure, however, does not include indirect land use requirements such as fuel production and waste storage. These indirect impacts may be 200 times as large as the generation-only footprint.[157] In addition, land impacts would be much greater in the unlikely event of a radiation release from the plant.

Gas-Fired Power Plants

As is the case with nuclear power plants, gas-fired power plants have a relatively low average generation land use profile of 1.65 acres per MW.[158] This figure does not include the indirect impacts related to fuel exploration and production.

Wind-Powered Plants

Wind farms occupy a relatively large area, approximately 5.4 acres per MW.[159] However, only a small portion of that land is required for electricity generation. The footprint of an individual

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155 California Energy Commission. "2007 Integrated Energy Policy Report." December 2007, page 7.

156 California Energy Commission. "2007 Environmental Performance Report." January 2008.

157 Gagnon, et al. "Life-cycle assessment of electricity generation options: The status of research in year 2001." (2002): 1267-1278.

158 California Energy Commission. January 2008.

wind turbine is generally 0.25 acres, and turbines must be spaced out in order to allow the blades to rotate effectively. Land between turbines is generally available for agriculture and grazing.[160]

Solar Thermal and Solar PV Plants

Solar plants require a relatively large amount of land. This has raised concern about habitat elimination and the creation of barriers to movement for the threatened desert tortoise and Mohave ground squirrel. In the 1980s and 1990s, the U.S. Fish and Wildlife Service, California Department of Fish and Games, and the Energy Commission mandated a habitat compensation ratio of 5:1 when licensing the LUZ SEGS in the Mojave Desert.

Proposed non-hybrid solar thermal projects in southern California would require 5.0-8.5 acres per MW (see Table 16).[161] Utility-scale PV systems use 2.5-13.3 acres of land per MW.[162] In California, 1,330 acres on average are needed to produce 100 MW.[163] The land use requirements for rooftop PV are essentially zero since the rooftop would generally not be otherwise utilized.

Table 16: Land Usage for Selected Proposed Solar Thermal Projects in California[164]

Project Name	Nameplate Capacity (MW)	Acreage	Acre/MW	Technology
Harper Lake	250	1,250	5.00	Parabolic Trough
Victorville 2	50 Solar Trough/ 563 Natural Gas	250	0.41	Hybrid Gas/Solar
Ivanpah SEGS	400	3,400	8.50	Solar Tower
Stirling 1 & 2	4,275	32,600	7.63	Parabolic Dish

159 California Energy Commission. January 2008.

160 California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

161 California Energy Commission. January 2008.

162 U.S. Department of Energy- Energy Efficiency and Renewable Energy. "PV FAQs: How much land will PV need to supply our electricity?" February 2004. Accessed: February 27, 2008. <http://www.nrel.gov/docs/fy04osti/35097.pdf>.

163 California Energy Commission. January 2008.

164 California Energy Commission. January 2008.

Geothermal Plant

An average of 1.7 acres per MW is needed for a geothermal power plant.[165] The plant must be built on or near a geothermal reservoir, often on previously undisturbed land. However, the well pad covers only about two percent of the area of the well field, and regrowth and revegetation can partially offset vegetation cleared for plant installation.[166]

Biomass Plant

Acreage requirements for biomass plants depend on the source of the feedstock. Residue biomass (i.e., leftovers and wastes from forestry, agriculture, and cities) does not directly require land and water for growth. However, if crops and trees are grown expressly to fuel the plant, hundreds of acres of agricultural land can be required per MW of power production. Conversion of natural ecosystems to such cropland also has effects on biodiversity, carbon storage, and water supplies.

Water Use and Pollution

Water is often used in the process of electric power generation. The quantity of water required for operation and the content of the discharge can have adverse environmental impacts. These issues are discussed below. For a discussion of once-through cooling, see Chapter 9.

Gas-Fired Power Plants

Natural gas-fired power plants can impact water quality via effluent and thermal discharge; spills from fuel transport tankers or pipelines; deposition of nutrients, toxins, and salts from power plant emissions into bodies of water; and storm water runoff.[167] Wastewater, which is produced during cooling processes and also during construction activities, can impact surface and groundwater resources. Disposal methods include discharge into evaporation ponds, surface waters, local sewer systems, or underground injection.

Solar Thermal Plants

Water requirements for a solar thermal plant depend on the plant configuration. Water used for the proposed Ivanpah project would come from one of two onsite wells. The groundwater would undergo treatment for later use as boiler make-up water and to clean the mirrors. In order to conserve water, Ivanpah 1 and 2 would each use a dry-cooling condenser. As a result, estimates for water consumption are relatively low: less than 100 acre-feet per year for all three project phases.[168] The proposed Carrizo project would obtain all of its raw water requirements

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165 California Energy Commission. January 2008.

166 Massachusetts Institute of Technology. "The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century." U.S. Department of Energy- Idaho National Laboratory, Idaho Falls, Idaho. 2006. Accessed: February 13, 2008. <http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf>.

167 California Energy Commission. January 2008.

168 CH2M Hill. "Application for Certification for the Ivanpah SEGS, Volume 1." August 2007.

from the Carrizo Plant Groundwater Basin by means of an existing on site groundwater well. The estimated average water usage for the proposed Carrizo project is 21.8 acre-feet per year.[169]

The solar thermal steam cycle results in similar environmental impacts as a steam power plant (i.e., chemical wastes from water treatment and effluent water from boiler blowdown and cooling water system blowdown). It additionally poses the risk of water pollution due to accidental solar system coolant leaks, which would most likely occur during coolant replacement.[170] The SEGS plants have reduced spills from accidents and pipe ruptures to very low levels. When a spill does occur, the impacted soil is removed to a passive bio-remediation facility where microbes restore the soil to a normal condition.[171]

Geothermal Plants

Geothermal plants use five gallons of freshwater per MWh.[172] The plants lose water to evaporation during well-drilling, circulation, and water-cooling, and they often use surface water as replacement. Water supplies are limited in California's geothermal range, much of which falls in relatively dry or desert areas. Air-cooling of geothermal fluids does not require water, but is not as effective during the summer. Hybrid air-water cooling systems, such as at the Mammoth Pacific plant, are being considered for future developments.

Geothermal fluid can contain poisonous boron, mercury, and arsenic, with increased concentrations in high temperature reservoirs. Well casings and holding ponds are used to prevent leakage into adjacent aquifers or surface runoff.

Biomass Plant

Cooling water needs for biomass-powered generation can be high; for example, a one MW gasifier requires 20,000 gallons of water per hour. [173] Once used, this water is treated for reuse or discharge. Liquid wastes require careful monitoring and treatment.

Other Environmental Issues

This section examines other environmental impacts of each power alternative. See also the discussions of tritium leaks in Chapter 9 and of spent nuclear fuel in Chapter 7.

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169 URS Corporation. "Application for Certification for the Carrizo Energy Solar Farm, Volume 1." October 2007.

170 Tiwari, G., and M. Ghosal. "Renewable Energy Resources: Basic Principles and Applications." Alpha Science International, Ltd. June 2005.

171 Aspen Environmental Group. "Solar Thermal Power." Unpublished Report for the California Energy Commission. December 2003.

172 Aspen Environmental Group. December 2003.

173 Global Energy Collaborations. "Technical Details of a 1MW Biomass Gasifier." 2004. Accessed: February 26, 2008. <http://www.biomassgasifier.com/TechDetails.htm>.

Nuclear Fuel Production

The traditional way of extracting uranium from the ground is to mine it. However, some of the uranium that is mined is not usable for fuel. Separating high from low grade ore leaves behind piles of low grade ore, which release radioactive dust and radon gas. From the high grade ore, uranium nuclides are then extracted at a mill; this leaves additional waste piles called mine tailings, which are left on the ground. Although both piles release radioactive dust and radon gas, the tailings from the high grade ore are the most hazardous. Approximately 85 percent of the radioactivity from the original ore remains in the tailings.

An alternative to conventional mining is in-situ leaching, in which a chemical solution is used to dissolve ore that it is in the ground. The liquid solution is then pumped upward to a uranium recovery plant. In in-situ leaching, the solid ore is not extracted so there are no waste piles, and the ground is not much disturbed. The chief environmental concern is potential ground water contamination from the leaching solution. [174] In addition, the uranium recovery plant generates liquid radioactive waste, which is typically disposed of in surface impoundments or in deep disposal wells.

Natural Gas Drilling and Transport

Drilling wells to extract natural gas disrupts the surface of coastal zones and onshore environments. Drilling also produces wastes, such as drilling mud, crushed rock, and produced waters, which may contain chemicals that are harmful to the environment if untreated. Advances in natural gas exploration technologies have reduced these impacts by improving the resource recovery rate (i.e., there are now fewer dry holes and fewer drilling attempts) and increasing the ability to tailor operations to avoid sensitive resources. Also, improved horizontal drilling technologies allow for reduced surface disruption.[175]

The majority of LNG liquefaction occurs outside of the U.S. in areas with less stringent environmental regulations than California. Environmental impacts of LNG liquefaction facilities may include habitat disruption, air quality impacts, and waste discharge. Transport of LNG via tanker may have direct adverse impacts to marine mammals, and potential leaks may adversely affect ocean water quality. Regasification of LNG using seawater has the potential to severely impact the marine environment similar to the thermal, impingement, and entrainment impacts of once-through cooling. While none of the LNG facilities that have submitted applications for a California site would use seawater for gasification, some of the facilities that could ultimately provide LNG to California employ this method. Additionally, offshore LNG facilities for liquefaction or regasification of LNG may require artificial night lighting, which may be disorienting or disruptive to seabirds and marine mammals.

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[174] Uranium Information Centre. "In-situ Leach Mining of Uranium." Accessed: February 28, 2008. <http://www.uic.com.au/nip40.htm>.

[175] U.S. Department of Energy, Office of Fossil Energy. "Environmental Benefits of Advanced Oil and Gas Exploration and Production Technology." October 1999.

Construction of natural gas pipelines results in temporary impacts that can generally be remediated once construction is complete. However, in arid environments habitats may require decades to recover.[176]

Avian and Other Impacts of Wind-Powered Plants

Wind turbines can disturb and even kill birds through collision, habitat disruption, and displacement.[177] Bird collisions with wind turbine blades is the biggest challenge to siting wind farms and presents the greatest potential for significant environmental impacts. Large wind farms are in operation in the Altamont Pass and Montezuma Hills wind resource areas, which are in a major avian migration corridor and winter foraging area for several raptor species. The Center for Biological Diversity estimates that wind turbines at Altamont Pass kill an estimated 880 to 1,300 birds of prey each year, including up to 116 golden eagles, 300 red-tailed hawks, 380 burrowing owls, and additional hundreds of other raptors including kestrels, falcons, vultures, and other owl species.[178] Bird collision reports by the Energy Commission of the Tehachapi and San Gorgonio wind resource areas found far lower levels of mortality. Bird mortality at the Altamont Pass and Montezuma Hills wind resource areas appear to represent worst-case scenarios.

Bat mortality is closely related to avian mortality. Bats have been found dead due to collision with wind turbine blades and support structures in Colorado, Minnesota, Oregon, Wisconsin, and Wyoming. Bat fatalities from wind turbines were not identified as a major concern until 2004, when hundreds of dead bats were found at wind farms in West Virginia and Pennsylvania.[179] Unlike avian mortality, there have not been any documented reports of endangered bat species fatalities due to collisions with wind turbines.[180] However, the deaths are still a concern because of the possible impacts on local ecosystems as bat fatalities compound.

In response to the controversy surrounding bird and bat collision with wind turbines, all new wind farm sites are evaluated for the presence of sensitive bat and bird populations, especially

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176 California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

177 National Wind Coordinating Committee. "Wind turbine interactions with birds and bats: a summary of research results and remaining questions." November 2004. Accessed: March 26, 2008. <http://www.nationalwind.org/publications/wildlife/wildlife_factsheet.pdf>.

178 Center for Biological Diversity. "Fact Sheet on Altamont Pass Bird Kills". 2005. Center for Biological Diversity: San Francisco, CA. Accessed: March 13, 2008. <http://www.biologicaldiversity.org/swcbd/Programs/bdes/altamont/factsheet.pdf>.

179 Blum, J. "Researchers Alarmed by Bat Deaths from Wind Turbines." *The Washington Post*. January 1, 2005, page A-1. Accessed: March 12, 2008. <http://www.washingtonpost.com/wp-dyn/articles/A39941-2004Dec31.html>.

180 Bat Conservation International. "Key Facts". 2007. Accessed: March 12, 2008. <http://www.batcon.org/home/index.asp?idPage=55&idSubPage=32>.

raptors. The *California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development* provides recommendations for assessing bird and bat activity at proposed wind energy sites, designing pre- and post-permitting monitoring plans, and developing and implementing impact avoidance, minimization, and mitigation measures.[181] In addition, the greater power of contemporary turbines means that fewer turbines are required.[182] The slower speed of the rotors may also translate into the reduced probability of a bird or bat collisions, although monitoring is ongoing.[183]

Visual pollution is another environmental impact from construction and operation of wind farms. Turbine blades may be up to 130 feet in length, and the support structure may be up to 300 feet tall. Wind turbines are typically sited on open landscapes with relatively high winds and are therefore visible from large distances. Shadow flicker, or the intermittent shadow created by turbine blades repeatedly moving across the sun, has been identified as a potential visual impact.

Wind turbines are typically constructed on mountainous topography where erosion can be a concern or in the desert where the hard-packed soil surface must be disturbed to install the support structure. Erosion can be prevented through proper design.

Noise pollution was an issue with early turbine designs but has largely been eliminated through improved engineering and increased setbacks from residential areas.[184] Noise emanating from wind turbines is now considered to be low-level. At 0.3 miles from the turbine, the noise level would be approximately 25-35 db(A),[185] comparable to the sound in the reading room of a library.

Hydrogen Gas Use at Solar Thermal Plants

Hydrogen gas is used as the fuel source for parabolic dish and Stirling engines. Occupational Safety and Health Administration regulations must be strictly followed for containment of the gas, and the gas piping systems must be regularly tested to ensure that they meet design working pressure standards. The systems are designed to shut down the facility automatically in the event of a leak.

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181 California Energy Commission. "California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development." October 2007.

182 The dominant turbine size at the Altamont Pass wind resource areas is 100 kW, 15 times less powerful than typical turbines installed today. California Energy Commission. October 2007.

183 California Energy Commission. "A Roadmap for PIER Research on Avian Collisions with Wind Turbines in California." December 2002.

184 American Wind Energy Association. "Facts about wind energy and noise." Accessed: March 26, 2008. <http://www.awea.org/pubs/factsheets/WE_Noise.pdf>.

185 British Wind Energy Association. "Are wind turbines noisy?" Accessed: March 12, 2008. <http://www.bwea.com/ref/noise.html>.

Hazardous Materials in Solar PV Systems

Silica mining involves open pit mining or dredging, which creates land and habitat disturbance but does not produce tailings that are associated with other types of mining. The major hazards from manufacturing silicon modules include hydrofluoric acid burns and silane gas (SiH_4) explosions. Amorphous silicon (a-Si) technology uses less than one percent of the silicon that crystalline technologies use, although with the tradeoff of lower sunlight conversion efficiency.

PV panels contain toxic materials such as cadmium, selenium, and lead.[186] These materials are often enclosed or insoluble and considered non-hazardous. Some modules, however, are considered hazardous. Large scale disposal may pose concerns as more PV cells reach the end of their 30 year life span. Recycling of intact PV components could eliminate the disposal problem and reduce lifecycle energy requirements.

Local Economic Impacts

By supplying employment opportunities and contributing taxes to local governments, power plants can have a positive impact on their surrounding communities. Some plants can also have negative economic impacts. This section describes the local economic impacts associated with the generation alternatives. A comparison of tax and employment impacts is provided in Chapter 9.

Nuclear Power Plants

Nuclear power plants tend to be larger, more capital intensive, and take longer to construct than other conventional power plants. This results in a large amount of property taxes, sales taxes, and employment, as discussed in Chapter 9.[187]

In the event of an earthquake or other disaster, areas around nuclear facilities can experience a loss of revenue from decreased local tourism. For example, after an earthquake hit the Kashiwazaki-Kariwa nuclear plant, the local tourism board reported massive cancellations at local hotels and beach houses on account of fears of radiation, even though there were no

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[186] Different PV technologies pose different hazards. CdTe and CIS technologies require less energy for manufacture and contain smaller amounts of toxic materials and carbon dioxide emissions than amorphous silicon technology. However, CdTe modules pose potential hazards from cadmium toxicity and carcinogenity, and CIS modules pose risk from hydrogen selenide toxicity. Fthenakis, V. and E. Anselma. "Photovoltaics Energy Payback Times, Greenhouse Gas Emissions, and External Costs: 2004-early 2005 status." *Progress in Photovoltaics: Research and Applications,* Volume 14. (2006): 275-280; Fthenakis, V.M. "Overview of Potential Hazards." National PV EHS Assistance Center, Brookhaven National Laboratory, 2003. Accessed: March 24, 2008. <http://www.pv.bnl.gov/art_170.pdf>.

[187] Approximately seven percent of San Luis Obispo County's annual revenue is derived from Diablo Canyon.

reported health hazards associated with the plant.[188] The perception of a hazard can negatively impact local tourism revenues, whether or not the hazard is real.

Gas-Fired Power Plants

Plant employment typically swells during peak construction periods, which may boost local sales and payroll taxes during the construction phase. Operations and maintenance jobs have a more sustained impact on local tax bases; however, they make up a small proportion of power plant jobs. For example, combined cycle plants in California constructed in 2001 employed roughly 250 peak construction workers and were anticipated to create 25 permanent operations jobs.[189] Modern natural gas-fired plants have fewer operations jobs relative to older steam-boiler plants, employing just 2 to 24 operations and maintenance workers whereas the older plants employ 40 to 50.[190]

The construction of gas-fired plants adjacent to private property may decrease property values, although there is little concrete evidence to support this claim. Two studies concluded that individuals find gas-fired power plants more desirable relative to coal or nuclear power plants in terms of land usage.[191, 192] The gas-fired plants considered in these studies have emissions levels comparable to coal-fired power plants.[193]

Wind-Powered Plants

The direct economic impacts of wind include increased revenues for local governments and private land owners, increased employment and demand for local goods and services due to construction and operation, and additional property tax revenues.

Using data from the California Energy Commission, the California Public Interest Research Group estimated the economic impacts of adding 3,700 MW of wind by 2010. The estimated effects on job creation are shown in Table 17 below. Relative to conventional power plants, wind facilities require fewer permanent operations employees.

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188 Kashiwazaki, Niigata. "Tourists Spurn Kashiwazaki." *Japan Times*. August 4, 2007. Accessed: April 2, 2008. <http://search.japantimes.co.jp/cgi-bin/nn20070804a3.html>.

189 California Energy Commission. "2001 Environmental Performance Report of California's Electric Generation Facilities." July 2001.

190 California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

191 Lindell, M., and Earle, T. "How Close is Close Enough: Public Perceptions of the Risks of Industrial Facilities." *Risk Analysis,* Volume 1, No. 4 (1983), pages 245-253.

192 Clark, D., and L. Nieves. "An Interregional Hedonic Analysis of Noxious Facility Impacts on Local Wages and Property Values." *Journal of Environmental Economics and Management*, Volume 27 (1994), pages 235-253.

193 McCann, T., and P. Magee. "Crude oil greenhouse gas life cycle analysis helps assign values for CO2 emissions trading." *Oil & Gas Journal,* Volume 97 (1999), pages 38-44.

Table 17: Economic Impacts of Adding 3,700 MW of Wind Capacity by 2015[194]

Jobs Created	Construction	Operations (jobs/year)
Total	21,574	740
per MW	5.88	0.2

Wind generation creates an economic opportunity for private property owners. A large wind turbine generally occupies only 0.25 acres of land but may generate $2,000 to $4,050 in royalties.[195] Farming and grazing practices can continue on the land while the landowner generates additional income from royalties.

Opponents to wind development have contended that lands within the viewshed of wind turbines may have lower property values than similar parcels of land not adjacent to wind turbines. In order to evaluate this claim, the Renewable Energy Policy Project (REPP) used a regression analysis to estimate the effect of wind turbines on property values. REPP found no statistically significant evidence that areas within the viewshed of wind developments experience relatively lower property values relative to other comparable areas. The majority of lands affected by wind development considered in the study had higher property value growth rates than non-affected areas.[196]

Solar Thermal Plants

Compared with conventional resources, the construction of solar thermal facilities provides relatively higher direct and indirect economic benefits. Black & Veatch estimates that each dollar spent on solar thermal construction adds $1.40 to $1.50 to the California gross state product, while each dollar spent on the construction of a natural gas-fired facility adds an additional $0.90 to $1.00 to gross state product.[197]

In 2006, Black & Veatch estimated the direct and indirect fiscal impacts associated with high and low deployments of solar thermal in California. Considering revenues from sales taxes during construction, income taxes paid by construction workers, income taxes paid by plant operators, income taxes collected from jobs indirectly created due to plant construction, and corporate income taxes assuming private ownership of the project, they estimated fiscal impacts

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194 Heavner, B., and S. Churchill, for California Public Interest Research Group Charitable Trust. "Renewables Work: Job Growth from Renewable Energy Development in California." June 2002.

195 California Energy Commission. "2005 Environmental Performance Report of California's Electrical Generation System." June 2005.

196 Renewable Energy Policy Project (REPP). "The Effect of Wind Development on Local Property Values." May 2003.

197 Black & Veatch. "Economic, Energy, and Environmental Benefits of CSP in California." April 2006.

associated with the low and high deployment scenario of $1.3 billion and $2.4 billion dollars (2005$), respectively.[198]

The impacts of a particular plant depend on size, ownership, and location. The Carrizo Solar Farm has an estimated total construction cost of $500 million. Of this, $55 million is attributed to employee salaries, wages, and benefits.[199] The Ivanpah SEGS will primarily benefit Clark County, Nevada. Just five percent of the $1.1 billion (2007$) estimated cost of construction is expected to be spent in California.[200] The proposed AB 1451 (Leno bill) would exempt both Carrizo and Ivanpah SEGS from paying county and local property taxes as long as the facilities do not change ownership.[201]

Solar PV Plants

To assess the economic impacts of solar PV development in the U.S., the Renewable Energy Policy Project (REPP) developed a scenario that assumes a total of 9,260 MW of incremental PV capacity installed at a price of $3.68 per watt by 2015.[202] This represents a total investment of $34 billion in PV manufacturing, construction, and installation. The manufacturing investment was allocated to each state based on the number of firms in the regions with technical potential to manufacture PV systems, and the installation investment was distributed on the basis of potential demand for installations of PV systems. REPP found that California would lead the nation in PV manufacturing, construction, and installation in terms of investment dollars and jobs created under this scenario (see Table 18).

Table 18: Total Solar PV Investment and Jobs in California for REPP Scenario[203]

Manufacturing (Jobs)	Manufacturing ($Million)	Construction and Installation (Jobs)	Construction and Installation ($Million)	Total (Jobs)	Total ($Million)
6,858	5,500	3,578	3,037	10,437	8,538

198 Black & Veatch. "Economic, Energy, and Environmental Benefits of CSP in California." Prepared for NREL. April 2006. Assumes a state income tax rate of 8.7 percent and a corporate tax rate of 8.84 percent.

199 URS Corporation. "Application for Certification of the Carrizo Energy Solar Farm, Volume 1." October 2007.

200 CH2M Hill. "Application for Certification for the Ivanpah SEGS, Volume 1." August 2007.

201 Kinnee, M., California State Board of Equalization. "Draft Staff Legislative Bill Analysis: AB 1541 (Leno et. al)." June 2007.

202 REPP. "Solar PV Development: Location of Economic Activity." January 2005.

203 REPP. January 2005.

Geothermal Plants

The development of geothermal power facilities creates permanent jobs as well as contractor services. A typical 50 MW geothermal plant can create between 30 to 50 full time jobs and 90 to 150 new secondary jobs.[204] Some counties receive a significant share of their total property tax revenue from the geothermal power plants located within the county. Inyo county's three geothermal power plants pay approximately $6 million annually in property taxes and are collectively the second largest taxpayer in the county.[205]

Geothermal plants located on state and federal lands pay royalties to the governments for use of the land and the steam produced.. In 2003 the operators of the Geysers Geothermal Field in Lake and Sonoma counties paid $6.15 million in royalties to the federal government for geothermal resources owned by the federal government in California and an additional $4.1 million in lease fees to the State of California for using the steam produced on state property for geothermal power.[206]

Biomass Plant

Biomass power facilities provide payroll, property, and sales tax revenues but are exempt from city and county sales taxes in California.

A large share of the fuels and feedstocks used by biomass power facilities are harvested in rural agricultural areas of California. The increased development of biomass resources could yield additional economic benefits to these regions. Biomass production creates additional opportunities for agriculture through the improved use of the non-crop share of agricultural production and the potential use of new crops.[207]

Demand-Side Resources

Demand-side resources are intended to reduce the demand for electricity. As such, they reduce customer electricity bills and prevent the need for costly power plant procurement. They do not provide a substantial tax and employment benefit to the local communities in which the efficiencies occur in the same way that a power plant or other industrial facility does. However, demand-side resources do provide local employment for engineers, implementation contractors, and utility personnel.

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204 National Geothermal Collaborative. "Geothermal Energy & Economic Development." Accessed: March 12, 2008. <http://www.geocollaborative.org/publications/Geothermal_Energy_and_Economic_Development.pdf>.

205 National Geothermal Collaborative. "Geothermal Energy & Economic Development." Accessed: March 12, 2008.

206 National Geothermal Collaborative. "Geothermal Energy & Economic Development." Accessed: March 12, 2008.

207 California Energy Commission. "Recommendations for a Bioenergy Plan for California." Prepared for the Bioenergy Interagency Working Group. April 2006.

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Blum, J. "Researchers Alarmed by Bat Deaths from Wind Turbines." *The Washington Post*. January 1, 2005. <http://www.washingtonpost.com/wp-dyn/articles/A39941-2004Dec31.html>.

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California Biomass Collaborative. “Biomass Resource Assessment in California.” PIER. California Energy Commission. April 2005.

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Appendix C: Literature Review - Diablo Canyon and SONGS Seismic Settings

Index of Literature Reviewed

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47	Geomatrix Consultants, 2001	Geomatrix Consultants and GeoPentech. "San Onofre Nuclear Generating Station Units 2 and 3 Seismic Hazard Study of Postulated Blind Thrust Faults." Report for Southern California Edison. 2001.

Summaries of Literature Reviewed

Title 01	A Probabilistic Seismic Safety Assessment of the Diablo Canyon Nuclear Power Plant
Year	1977
Study Area	Onshore/offshore central California within 100 km of the DC site
Authors	A. H-S. Ang and N.M. Newmark
Source	Report to the Nuclear Regulatory Commission
Scope	A quantitative evaluation of levels of safety for certain critical components and subsystems of the DC NPP against seismic hazards for an interim 2 year period and assuming a plant retrofit design level of 0.75 g
Data Used	Earthquakes M ≥4.0 between 1934 and 1971, active faults of west-central California including the Hosgri
Methodology	Probabilistic evaluation of annual exceedance frequencies associated with specified maximum accelerations using fault-rupture models and random background earthquakes along with evaluation of damage probabilities to critical components.
Summary Results	1. Two-year damage probabilities of the existing plant in the presence of the Hosgri fault are considerably lower (by a factor of about 2 to 7) than the corresponding thirty-year damage probabilities of the plant if the Hosgri fault did not exist. 2. If the plant were retrofitted for an SSE of 0.75 g, and assuming that the same safety factors can be approximately maintained for the upgraded plant, the thirty-year damage probabilities of the upgraded plant in the presence of the Hosgri fault are also consistently lower (by a factor 2 to 3) than the original thirty-year damage probabilities considered acceptable during the design of the plant.
Strengths	This early PSHA application models both fault sources and random background earthquakes which is a fundamental approach in current PSHA procedure.
Limitations	Small exceedance frequency estimates (i.e., long return periods) are based on only a short, 37 year history of earthquakes in the region, which was common for this era since paleoseismological studies of active faults were only in their infancy.
Comparisons/	This interim safety assessment apparently addressed the short time

Implications	period over which retrofit or other design changes were planned to be executed. The probabilistic results are consistent with respect to other results addressing longer exposure times..

Title 02	DC NPP: Probabilities of Peak Site Accelerations and Spectral Response Accelerations from Assumed Magnitudes up to and Including 7.5 in All Local Fault Zones
Year	1977
Study Area	Onshore/Offshore Point Arguella on the south to Santa Cruz on the north to about 20 km west of the San Andreas fault
Authors	J.A. Blume
Source	Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site, PG&E, Volume V, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 11, p. D11-1 to D11.29.
Scope	Probabilistic seismic hazard analysis (PSHA) of peak ground acceleration (PGA) at the DC facility based on recorded earthquakes in the study area
Data Used	456 earthquakes in the study area between 1930 and 1977 and locations of the Hogri, Nacimiento, Rinconada-Ozena, and Santa Lucia Banks faults at closest horizontal distances from the DC site of 6, 25, 33 and 50 km, respectively.
Methodology	PSHA using a fault-contained rupture model assuming that magnitudes from 4.0 up to and including 7.5 can occur on four faults in the DC site region with the faults having equal probabilities of activity that was developed from recurrence frequency analysis of earthquakes in the study area
Summary Results	1. Based on a comprehensive study of the seismic history of a large representative area surrounding the site, all faults in the region, all magnitudes up to and including 7.5 on local faults and 8M or greater on the San Andreas fault, and detailed probabilistic analysis, it is found that the probabilities of exceedance of the project ground accelerations and spectral response accelerations in 50 years 9or less) are exceedingly small. The average return periods are correspondingly large. 2. From table 11.8, the probability of exceeding instrumental PGA of 0.40 g in 50 years is 1.9%. The probability of exceeding instrumental PGA of 0.80 g in 50 years is 0.3%.
Strengths	An early state-of-the-art PSHA application to a site-specific problem that developed procedures for fault-rupture modeling, the concepts of which underpin modern PSHA applications.
Limitations	Small exceedance frequency estimates (i.e., long return periods) are based on only a 47 year history of earthquakes in the region, which was common for this era since paleoseismological studies of active faults were

	only in their infancy.
Comparisons/ Implications	Results differed from those of Anderson and Trifunac (1976), "Uniform Risk Absolute Acceleration Spectra for the Diablo Canyon Site, California", report to the Advisory Committee on Reactor Safeguards, US NRC. The PSHA was based on a short history of recorded earthquakes and was subsequently augmented by an additional study addressing all faults in the region and geologic data regarding their long-term displacements.

Title 03	Probabilities of Peak Site Accelerations Based on the Geologic Record of Fault Dislocations
Year	1977
Study Area	Onshore/offshore central California Point Sur south to the western Transverse Ranges including the San Andreas fault
Authors	J.A. Blume
Source	Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site, PG&E, Volume VII, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 41, p. 41-1 to D41.28.
Scope	Probabilitistic seismic hazard analysis (PSHA) of peak ground acceleration (PGA) at the DC facility based on long-term fault slip-rate data on faults of west-central California for time periods of 10,000 years (Holocene) and 20,000,000 (mid-Miocene)
Data Used	Total offset data during the two time periods that were provided by D.H. Hamilton. Faults addressed were: San Andreas, Sur-Nacimiento, San Simeon, Hosgri, Santa Lucia Bank, West Huasna-Suey, Rinconada, La Panza, Ozena, San Juan, Lion's Head-Los Alamos, Santa Ynez, Big Pine.
Methodology	PSHA using a fault-contained rupture model that implements a moment rate formulation and regional b-value of 0.92 to develop fault-specific recurrence frequencies and estimates of instrumental PGA exceedance frequencies at the DC site. Fault depth is taken as 15 km for San Andreas and 10 km for all others. Mmax is 8.25 for the San Andreas and no lower than 7.5 for all other faults. Hosgri Mmax is 7.5 with a fault length of 120 km at a distance of 6 km from the DC site.
Summary Results	1. Probabilities of peak instrumental accelerations at the site based upon dislocation rates of the 13 faults are consistent with those obtained from the more recent history of earthquake activity in the area as shown in report D-LL 11. 2. Increasing the number of faults to 13 from 4 used in report D-LL 11 had no significant effect on the results. 3. The annual rate of activity of the San Andreas fault has increased considerably as indicated by the 10,000-yr data as compared to the 20×10^6-yr data but this fault has no significant effect on the plant site accelerations except at very low values of acceleration. 4. The dislocation rate on the other faults west of the San Andreas and generally parallel to the coastline has decreased as indicated by the differences in the last 10,000 years as compared to the last 20×10^6 years. 5. Of all the faults used in the analysis, only the Hosgri and

	Rinconada have any significant effect at the plant site and the Hosgri alone determines the maximum accelerations. 6. The probabilistic study based upon fault dislocations rates indicates that the 10,000-year more recent period of time is less critical in producing accelerations a the plant site than the $20x10^6$-yr period of time extended back into the middle Miocene epoch. 7. The ratio of the average annual dislocation in a fault to the maximum annual dislocation, which ratio is designated α in this study, is not a strong parameter in the probabilistic analysis. 8. The maximum assigned value of the rupture length as compared to the fault length was found to be a very weak parameter in this probabilistic analysis except at extreme accelerations. 9. The Trifunac and Brady attenuation procedure using the same geologic input as for the Blume SAM attenuation procedures leads to similar results at low accelerations and to greater probabilities of exceedance of about an order of magnitude greater at 1.0 g, and somewhat greater probabilities at higher accelerations. This result is consistent with the data shown in report LL 43 in which the SAM results (by other comparisons) appear to be more consistent with recorded data and the values obtained by others for short epicentral distances than the Trifunac and Brady results. 10. The most reasonable solution is considered to be the 10,000-yr time period with the curve of log probability versus log acceleration falling very close to $\alpha = 1.0$ and $l_{max} = L$ as shown in Figure 41-J. The peak instrumental acceleration of 1.15 g from this curve has an average return period of 106,000 years as compared to 52,600 years in report D-LL 11 11. In general, the analyses based upon dislocations determined by geologic evidence for the 10,000-yr and the $20x10^6$-yr time periods provide results that are remarkably consistent with those from current time as used in report D-LL 11 and are reasonably consistent with each other. The average return period of 1.15 g instrumental acceleration based upon the average of all three time period determinations is 66,600 years. 12. All of the results indicate that the probability of high peak accelerations at this site are not only very low but also that there is no evidence to indicate that the probabilities are abnormally low in view of the geologic history of the area. In other words, there is no evidence found in this work that would support the concept of the Hosgri fault having been less active in the last 100 or 200 years than it has been for thousands of prior years. It can be concluded therefore that its activity would remain nominal, as it has been in the past, for thousands of years into the future.
Strengths	A supplement to D-LL 11 (Title 2) to examine the effect of long-term fault slip-rate data on the PGA hazard at DC NPP in order to address the issue of using only a short period of recorded earthquakes in the previous

	assessment.
Limitations	Mid-Miocene slip-rate basis samples geologic data from a different tectonic regime, which is not relevant to the current seismotectonics of the region. Nonetheless, it appears useful for an upper-bound estimate. The author notes that the 10,000-yr data is considered the most reasonable, although the total displacement data that was available in this era was highly uncertain and is still a matter of debate in geological literature. There was relatively little knowledge at the time on the continuity and exact location of the Hosgri fault offshore.
Comparisons/ Implications	Part of this study addressed the discrepancy between the Trifunac and Brady results which were higher than the D-LL 11 study. Differences are traced to the early form of ground motion attenuation relationships that were used in each of the assessments. This study concludes that the Blume SAM attenuation model is more consistent with recorded data. Even today, modeling differences among published, authoritative ground motion attenuation relationships [epistemic uncertainty] remains a primary source of uncertainty in PSHA.

Title 04	Diablo Canyon Plant: Plat-Boundary and Diffused Areal Probabilistic Considerations
Year	1977
Study Area	Western California state, Mendocino to Mexico international border
Authors	J.A. Blume
Source	Seismic Evaluation for Postulated 7.5M Hosgri Earthquake, Units 1 and 2 DC Site, PG&E, Volume VII, USNRC Docket Nos. 50-275 and 50-323, Appendix D, D-LL 45, p. 45-1 to D45.11
Scope	Probabilistic sensitivity studies on the effect of alternative modeling and proportioning of the total seismicity of the California plate boundary on faults and as diffused earthquakes in the vicinity of DC
Data Used	45-yr earthquake record for western California plate boundary zone and assessed recurrence frequency by Dr. S.W. Smith
Methodology	Probabilistic determination of the exceedance frequency and corresponding return periods for 1.15 g instrumental acceleration under various proportioning assumptions of the total earthquake rate for western California on faults and in the area of the DC site using two alternative recurrence frequency b-values.
Summary Results	1. Various methods of distributing the total California plate boundary seismicity on faults and throughout the area of the DC site results in the longest average return periods when compared to results of the D-LL 11 and DL 41, except for one extreme and illogical model for which the results are essentially equivalent to the previous investigations.
Strengths	The strength of this study perhaps lies in the fact that, in even another alternative modeling scenario that accounts for proportioned earthquake recurrence frequencies using a 45-year earthquake record from the entire western California plate boundary region, return periods are quite long..
Limitations	Physical reasons for the proportioning schemes that were investigated are not given, although as a sensitivity study, the objective was only to examine a range of cases from what seemed extreme to reasonable, regardless of physical underpinnings.
Comparisons/ Implications	Results were the lowest among the three PSHA studies at the DC site, but used only as a sensitivity study and not a design basis.

Title 05	The San Gregorio – Hosgri Fault Zone: An Overview
Year	1978
Study Area	Coastal central California San Francisco to Point Arguello
Authors	E.A. Silver
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p. 1 – 2.
Scope	Overview with summaries of work contained in the volume
Data Used	Existing stratigraphic and geological data.
Methodology	Review of existing knowledge, and new data and interpretations contained in papers of the volume
Summary Results	1. Major outstanding problems include details of fault location, continuity between San Gregorio and Hosgri segments, offset history of each segment, evidence for Holocene movement, and seismicity 2. Volume contains some papers from a symposium on the fault zone held in April 1977, which provide a good overview on the current state of knowledge. 3. From results in the volume's papers, the bulk of the evidence at least allows continuity between the Sur fault (through point Sur) and the Hosgri to the south. 4. The San Gregorio – Hosgri appears to be the largest subsidiary fault of the San Andreas system in both length and offset.
Strengths	Volume is an early compilation of geological research papers focused on the Hosgri fault zone that addresses outstanding issues of location and continuity between onshore and offshore faults that comprise the zone..
Limitations	N/A - Summary and overview of papers in the volume
Comparisons/ Implications	Refined location, fault continuity, and slip rate data is apparent in this volume from earlier Hosgri fault models used in earlier PSHA assessments that were included in D LL-11 and DL-41 (Titles 03 and 04).

Title 06	Apparent Offsets of On-Land Geologic Features Across the San Gregorio – Hosgri Fault Trend
Year	1978
Study Area	West central California
Authors	S.A. Graham and W.R. Dickinson
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p13 – 23.
Scope	Detailed attempt to reconcile differences in stratigraphic sequences across the San Gregorio fault
Data Used	Fault zone trends and morphology, stratigraphy and basement rock types
Methodology	Geological synthesis of observations on the data
Summary Results	1. San Gregorio fault is continuous southward with the Sur, San Simeon, and Hosgri fault zones with the linked traces of these fault termed the San Gregorio – Hosgri fault trend. 2. The San Gregorio – Hosgri fault trend is part of the San Andreas fault system and apparently controls the position of the modern coastline in central California. 3. Cumulative post-middle Miocene age right-lateral slip on the fault trend is estimated to be 115 km.
Strengths	An original work to suggest that the San Gregorio is continuous southwards with the Hosgri and that the San Gregorio does not turn inland to connect with the onshore Palo Colorado fault.
Limitations	Limited offshore data on the fault zone at the time
Comparisons/ Implications	Title 03 and 04 modeled the Hosgri fault zone as turning inland to connect with the onshore Palo Colorado fault, which this work now refines into a continuous offshore zone faulting between the San Gregorio and Hosgri faults. Post mid-Miocene displacement of 115 km in this work is an order of magnitude greater than the 10 km of post-mid-Miocene displacement used in D D-LL 11 (Title 03) and would give correspondingly higher long-term slip rate.

Title 07	Origin and Development of the Lompoc-Santa Maria Pull-Apart Basin and its Relation to the San Simion-Hosgri Strike-Slip Fault, Western California
Year	1978
Study Area	Central Western California
Authors	C.A. Hall
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p. 25 – 31.
Scope	Interpretation of onshore Santa Maria basin stratigraphy and structural development as related to local faults
Data Used	Local stratigraphy and geologic age data
Methodology	Geological synthesis addressing the stratigraphic and tectonic origin of the onshore Santa Maria basin.
Summary Results	1. The onshore Santa Maria basin developed as a wedge-shaped pull-apart structure in pre-late Miocene time with a maximum pull-apart of 50 km within a strike-slip system of faults bounded by the Santa Maria River fault on the north and the Lompoc – Solvang fault of the western Transverse Ranges on the south. 2. Following pull-apart rifting and sedimentation, the western part of this basin was displaced 80 – 95 km to the NW (right-lateral sense) since Pliocene time along the San Simeon – Hosgri fault zone.
Strengths	A novel interpretation for post-Mesozoic structural development of the Santa Maria Basin – Lompoc region
Limitations	A speculative model according to author based mostly on overall basin morphology and stratigraphic timing.
Comparisons/ Implications	80 – 95 km total post-Pliocene right-lateral offset estimate would appear to be in ball-park agreement with 115-km post mid-Miocene offset along the Hosgri-San Gregorio estimate in Title 06 with the same implications with regard to slip rate estimates used in D D-LL 11 (Title 03).

Title 08	Morphology, Recent Activity, and Seismicity of the San Gregorio Fault Zone
Year	1978
Study Area	Coastal California, Pillar Point south to Point Sur
Authors	K.J. Coppersmith and G.B. Griggs
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p. 33 – 43.
Scope	Resolution of faulting style and latest movement of the San Gregorio fault
Data Used	Contemporary seismicity, field fault data, focal mechanisms, geodetic strain, existing fault maps
Methodology	Examination and synthesis of data into resolution of faulting style and age of latest displacement
Summary Results	1. San Gregorio is a complex active fault zone up to 3 km wide. 2. A number of fault traces within the zone exhibit late Pleistocene and Holocene offsets. 3. Limited field investigations and triangulation data indicate no fault creep or strain accumulation along the fault zone. 4. Focal mechanisms of earthquakes associated with the fault indicate right-lateral shear and compressive stress.
Strengths	Compiles early observational data onshore/offshore with limited field data demonstrating Holocene right-lateral displacement on the San Gregorio fault. Indicates the potential for further Quaternary geological investigations along the fault zone
Limitations	According to the author, the second-order triangulation precision probably cannot resolve the long-term rate of fault offset. An estimate of slip rate is not provided.
Comparisons/ Implications	Demonstrates fault displacements in the last 10,000 years (Holocene) supporting the fact that the Hosgri-San Gregorio fault zone is active, as has been acknowledged in the previous seismic hazard investigations (Titles 01-04).

Title 09	Seismicity and Tectonics of the Central California Coastal Region
Year	1978
Study Area	Central coastal California and offshore between Point Conception and San Francisco
Authors	W.H. Gawthrop
Source	California Division of Mines and Geology Special Report 137, The San Gregorio – Hosgri Fault Zone, California, p. 45 – 56.
Scope	Earthquake relocations and seismicity patterns in central coastal California and offshore
Data Used	Historical intensity, instrumental earthquake data from the northern and southern California networks
Methodology	Master event relocations using the HYPOELLIPSE computer program and an assumed velocity model of the region.
Summary Results	1. Based on an improved crustal velocity model for the region, the 1927 Lompoc earthquake (M_s 7.3) was located near the coast just west of Point Sal compared to the previous 1930 location of Byerly, which was 70 km west of Point Arguello. Relocation of aftershocks suggests the probable limit of rupture was 50 – 70 km, possibly along the Hosgri fault. 2. The possibly continuous Hosgri – San Simeon – San Gregorio fault system is likely responsible for a large part of earthquake activity west of the San Andreas fault. 3. Regional seismicity pattern indicates most of the earthquake activity is occurring along several NW-trending faults throughout the region and at least some of the 2.3 cm/yr plate motion not attributable to the San Andreas must be relieved in this manner. 4. Focal mechanisms suggest that the driving motion has a component normal to the NW-trending faults resulting in some thrust faulting and folding. The relative motion vector is oblique to the main trend of the San Andreas Fault in central California. 5. Future earthquakes of magnitude 7 or greater should be expected in this region. 6. If continuous, the Hosgri – San Simeon – San Gregorio fault system is long enough to produce magnitude 8 earthquakes rupturing in excess of 200 km with greater than 4 m of displacement and a recurrence of 250 years.
Strengths	An original attempt at making the best use of sparse seismological data for the central coastal California at the time, but controversy prevails as other researchers have come to different conclusions.

Limitations	According to author, bias still exists in the reprocessed seismological data due to the lack of data to the SW (offshore) of the relocated epicenters. Considerable controversy surrounding the proposed location and mechanism of this earthquake is documented a series of published papers between 1978-79.
Comparisons/ Implications	Gawthrop (1978) more specifically suggests that this earthquake is associated with the southern Hosgri fault based on the right-oblique focal mechanism. However, he notes that geodetic data suggests a much larger component of thrust than can likely be accommodated on the Hosgri. Hanks (1979) locates the epicenter near 34.6º N and 120.9º W, approximately 40 km SW and farther offshore of Gawthrop's location, based on seismological observations in the local area. Based on analyses of teleseismic and regional seismograms, Helmberger et al. (1992) locates this earthquake 40 km west of Point Conception at 34.35º N and 120.9º W, consistent with tsunami modeling results of Satake and Somerville (1992) that indicates the event occurred below at least 200 m of water near the same coordinate position and about 25 km south of Hanks (1979) location. Helmberger et al. (1992) further find that the earthquake focal mechanism indicates a NW-striking reverse fault as the earthquake source with the fault parameters being; strike = N20º W, dip = 66º NE, rake = 95º with a source dimension of about 30 km. Their surface wave magnitude is 7.0 as well as that derived from tsunami data by Satake and Somerville (1992), as opposed to previous estimates of 7.3. These latest analyses (1992) are judged to be the most reliable to date because of the data brought to bear on the location and magnitude determinations. The surface wave magnitude assessment of 7.0 is significantly lower than the 7.5 magnitude used in assessments of seismic hazard at the DC site (Titles 01 through 04). Additional references: Hanks, T.C. (1979), "The Lompoc, California Earthquake (November 4, 1927; M=7.3) and its Aftershocks", *Bulletin of the Seismological Society of America*, Vol. 69, No. 2, p. 451-462. Helmberger, D.V., P.G. Sommerville and E. Garnero (1992). "The Location and Source Parameters of the Lompoc, California Earthquake of 4 November 1927", *Bulletin of the Seismological Society of America*, Vol. 82, No. 4, p. 1678-1709. Satake, K., and P.G. Sommerville (1992). "Location and Size of the 1927 Lompoc, California, Earthquake from Tsunami Data", *Bulletin of the Seismological Society of America*, Vol. 82, No. 4, p. 1710-1725.

Title 10	Post-Miocene Compressional Tectonics Along the Central California Margin
Year	1984
Study Area	Near-offshore area from approximately 20 km N of Point Sal southwards around points Arguello and Conception, then eastwards across the northern Santa Barbara Channel to Capitan with extrapolated interpretations to all of central coastal California
Authors	J.K. Crouch, S.B. Bachman, and J.T. Shay
Source	"Tectonics and Sedimentation Along the California Margin": Pacific Section of the Society of Economic Paleontologists and Mineralogists (SEPM), Vol. 38, p. 37 – 54.
Scope	Interpretation of high-resolution seismic reflection data offshore of the Santa Maria basin on the north and the western Transverse Ranges on the south with generalization to the broader area of west-central California
Data Used	High-resolution, deep-penetration (2.5 – 3.0 sec.) 36-fold, 400 cu-in, dual-water gun profiles.
Methodology	Geophysical interpretation of third-party high-res reflection data and synthesis with regional tectonics
Summary Results	1. Many of the major faults along the offshore central California margin are either thrust or high-angle reverse faults that flatten and become thrust faults at depth. Northern Santa Barbara Channel faults trend E-W, dip north, and probably have left-lateral as well as dip-slip motion. Thrust and reverse faults trend about N55ºW and dip N-NE offshore of points Conception and Arguello. Offshore of the Santa Maria Basin, thrust and reverse faults trend about N35ºW and dip predominantly NE. Right-lateral slip has probably occurred on some of these faults, however associated folds are usually asymmetric and their axes closely parallel the fault traces indicating compression is playing a dominant role in structural development. 2. Similar fault and fold relationships have been reported in the adjacent onshore region. Compressional structures are well known in the western Transverse Ranges. NW-trending structures in the Southern Coast Ranges are generally regarded as related to right-lateral wrench tectonics. Because many of the faults in this region are steeply dipping, high-angle reverse faults at the surface, the role of compressional tectonics is not fully appreciated. Many of these high-angle reverse faults flatten and become thrust faults at depth, like those in the offshore region. 3. Resolution of present-day plate motions coupled with estimates

	of the amount of crustal shortening suggest that in the past 5.5 my at least 30 km and perhaps as much as 70 km of NE-SW crustal shortening has occurred across the central California margin. These are comparable to estimates of right-lateral offsets along the NW-trending faults of the San Anreas. 4. Accommodation of major crustal shortening shallower than 12 km over the last 5.5. my along the central California margin is proposed to occur along an aseismic zone of detachment, which is possibly the top of an old oceanic crustal layer. Thrust faults extending upward from this zone are compressed into high-angle reverse faults at shallow crustal depths. 5. Compressional tectonics may be an important element of basin development along the central California margin. The offshore and onshore Santa Maria, the Huasna and Cuyama Basins all appear to have undergone NE-SW-directed compression in post-Miocene time. The predominance of thrust faults and parallelism of folds within these basins suggest that compression rather than right-slip has dominated the late stages of basin development. 6. New petroleum discoveries along the central California margin may come from subtle traps associated with compressional folding and faulting. Exploration concepts that have been used to discover petroleum in the Rocky Mountain Overthrust belt may also apply to major zones of crustal shortening along the California coast, perhaps only on a smaller scale.
Strengths	A provocative extrapolation of structural interpretations based on original data in a relatively confined offshore area to the whole of west-central California in order to illustrate the types of traps and oil potential that may exist in the region.
Limitations	Acknowledgement is given to Nekton, Inc. for providing the geophysical data, but processing, quality and limitations of the data are not discussed. One cross-section shows original data, while six cross-sections are only interpretive line drawings. Well control is available down to Oligocene stratigraphic units in at least the northern Santa Barbara Channel, but has not been incorporated as a constraint on interpretations. Descriptions of deep fault geometries outside of the areas of actual geophysical data are speculative and model-driven assuming a homogeneous tectonic process for all structures of the west-central California region.
Comparisons/ Implications	The primary implication of this paper is that late-stage basin development in west-central California is dominated by compressive tectonics, and accompanying reverse and thrust faulting rather than strike-slip faulting. Thrust and reverse faults and associated subparallel fold trends are mapped for more than 40 km along the southern segment of the Hosgri fault zone and the authors note that similar compressional features have been noted off Puisima Point and along the San Gregorio

	fault south of Point Sur. The general implication is that the Hosgri fault is dominantly a thrust or reverse fault with a NE dip. In detail, however, the authors are actually noncommittal with regard to a long central segment of the Hosgri fault offshore of the DC site. Their summary figure 11, which shows faults of the Southern Coast Ranges with varying degrees of certainty for having thrust and reverse displacement, shows the long central segment of offshore Hosgri fault as simply dashed lines with no indication of thrust or reverse faulting. This is more pointedly taken to indicate that authors have no specific evidence for thrust or reverse displacement on the section of the Hosgri fault of most importance to the DC site. A generalization of their thoughts is illustrated in a schematic block diagram in figure 13, which provocatively shows the Hosgri as a thrust fault along its entire offshore length. However, as is clear from summary conclusion item #6 above, the primary purpose of this paper is to illustrate a model with respect to the oil-trap potential for this region, and not to seriously address the earthquake hazard.

Title 11	PG&E Final Report of the Diablo Canyon Long Term Seismic Program
Year	1988
Study Area	Central coastal California and offshore
Authors	PG&E and its consultants
Source	PG&E Diablo Canyon Power Plant Docket Nos. 50-275 and 50-323
Scope	Reevaluation of the seismic design basis for DC
Data Used	Existing data and a wealth of new geological, geophysical, seismological and neotectonic data on and offshore bearing on the seismotectonic setting of DC
Methodology	Review of existing data and collection and analyses of a wide range of new geoscience data by a diverse team of experts with synthesis into a coherent seismotectonic model for the DC site region and implementation of the models elements in deterministic and probabilistic seismic hazard and risk analyses for DC.
Summary Results	Element 1 of the license condition: 1. Rotation of the Transverse Ranges has resulted in north-northeast-directed shortening east of the Hosgri fault zone, which is accommodated by W-NW-tending reverse faults and by uplift, subsidence or tilting of intervening crustal blocks. DC is located on the San Luis/Pismo structural block, which is bounded on the NW by the Hosgri fault zone, the most significant seismogenic structure for DC. 2. Crustal blocks east of the Hosgri are separated from the offshore Santa Maria Basin by the Hosgri fault zone. The Santa Maria Basin is characterized by gradual subsidence and scattered N-NW-trending reverse and thrust faults oriented sub-parallel to the Hosgri. Faults are mostly in the southern Santa Maria Basin south of Point Sal with little evidence of contemporary compressional deformation west of the Hosgri between Point Sal and the northern end of the Hosgri. 3. DC is located in the SW part of the San Luis/Pismo structural block, which is bounded on the NE by the Los Osos fault zone, on the SW by a diffuse zone of minor faults, and on the W-NW by the Hosgri fault zone. 4. Folding of the Pismo syncline ceased at least 1 – 2 my ago. Previously mapped faults within the block indicate an absence of activity in the past 500,000 years (late Quaternary) and demonstrate that these faults are not active. Marine and fluvial terrace mapping demonstrates the absence of any previously unrecognized Quaternary faults and folds.

	5. Tertiary age folds within the San Luis/Pismo block may have been associated with displacement on low-angle detachment faults at depth during a previous deformational episode that ceased 1 – 2 my ago. Lack of Quaternary age deformation of these folds demonstrates that, if low-angle faults are present, they are not active. 6. The Hosgri fault zone, extending from en echelon step with the southern part of the San Simeon fault (offshore of Cambria) to its termination NW of Point Pedernales, has been characterized by high-angle, strike-slip displacement for the last 2 – 3 my. 7. A compressive tectonic episode prior to 2 – 5 my ago (pre-Pliocene) produced reverse and thrust faults within and immediately west of the Hosgri, which are imaged in geophysical data. However, these data show many of these faults are truncated by erosional horizons and overlain by sediments 2 my old or older that are not displaced by the faults. These data demonstrate that these thrust faults are not active in the current tectonic environment. 8. Lateral slip on the north end of the Hosgri is evaluated to be 1 – 3 mm/yr and decreases significantly southward. The upper bound estimate of the vertical component due to uplift and subsidence along the fault zone adjacent to the San Luis/Pismo block is about 0.4 mm/yr in Estero and San Luis Obispo bays. 9. The Los Osos fault zone is a reverse fault that dips to the SW and forms the NE margin of the San Luis/Pismo block. The fault is a segmented, 2-km-wide zone of discontinuous, subparallel and en echelon fault traces that extends from Morro Bay SE to the Lopez Regulating Reservoir for a distance of 36 km. The fault has four segments with distinct physical and behavioral differences and displacement histories. Displacements of marine and fluvial deposits indicate a late Quaternary net slip rate of no more than 0.2 – 0.5 mm/yr. 10. The SW boundary of the San Luis/Pismo block is a diffuse zone of minor deformation consisting of NW-trending faults and monoclinal folds. The San Luis Bay, Wilmar Avenue, Pecho, and Oceano faults constitute a zone that is 4 – 6 km wide and about 60 km long. 11. Using waveform modeling of the original teleseismic records of the 1927 Lompoc earthquake and comparisons to modern western California earthquakes, the Lompoc earthquake was found to have a nearly pure reverse fault mechanism striking N20°W and dipping 66° NE. Surface wave magnitude was reevaluated to be 7.0 rather than 7.3 or 7.5 reported in earlier studies. The epicenter was constrained based on good-quality seismic recordings to be approximately 34.5° N and 120.9° W, about 25 km west of Point Arguella. These parameters for the earthquake do not allow it to be located near Point Sal or along the southern reach of the Hosgri fault zone.

Element 2 of the License Condition

1. Based on data developed in Element 1, PG&E reevaluated the magnitude of the earthquakes used to determine the seismic bases for the DC NPP and confirmed the Hosgri fault to be the controlling seismic source and exhibits dominantly strike-slip style of offset with a minor dip-slip component.
2. A multifactor logic-tree analysis indicated a best-estimate magnitude of M_w 7.0; however, a conservative maximum earthquake magnitude is M_w 7.2 at a distance of 4.5 km and was used in subsequent ground motion analyses.

Element 3 of the License Condition

1. Of three different approaches, it was found that response spectra developed from strong ground motion attenuation relationships from regression analyses envelope the corresponding response spectra obtained from the statistics of near-source records and those from numerical ground motion modeling studies. 84 %-tile level regression results were conservatively chosen for use in the seismic margin studies.

Element 4 of the License Condition

1. Soil/Structure Interaction effects (SSI): SSI was found to be substantial in short, stiff containment interior and the auxiliary building. SSI due to coherent ground motion input was found to be relatively small for taller more flexible containment shell and the turbine building. Spatial incoherence of ground motions generally results in reductions in the SSI responses that increase gradually with increasing frequency. Base-uplift of the containment structure generally results in small reductions in the horizontal acceleration responses and in base shear and overturning moment. However, it causes small increases in the horizontal and vertical displacements.
2. Seismic Hazard Analysis: Addressed all seismic sources that could affect DC. Logic trees were developed for the Hosgri, West Huasna, offshore Lompoc, Rinconada, Nacimiento and San Andreas faults. The Hosgri fault zone dominates the seismic hazard at the site. The Los Osos and San Luis Bay faults together only constitute 3 to 5% of the total hazard. Contributions from other faults are insignificant.
3. Seismic Fragility Analysis: Safety-related structures and equipment have high median seismic capacities.
4. Probabilistic Risk Assessment: Integrated the results of the seismic hazard and seismic fragility evaluations. Offsite power is potentially a large contributor when coupled with other component failures. Mean core damage frequency was determined to be 3.7×10^{-5}. The seismic component is a small contributor to the total mean core damage frequency of 2.0×10^{-4}. DC design is well-balance with no outstanding weak links.
5. Deterministic Comparisons: The deterministic 1977 Hosgri

	evaluation spectrum envelopes the site-specific 50th percentile at all frequencies and the 84th percentile spectrum below about 15 hz. Exceedance for frequencies above 15 hz is approximately 10%. Floor response spectra showed some exceedances over floor response spectra developed as part of the original design. However, the average of these exceedances at certain key frequencies are within approximately 10% of the design spectrum and are not significant in terms of design adequacy because they are accommodated by the existing design margin.
Strengths	PG&E's final report on the Long Term Seismic Program brings a wealth of new geological, seismological and geophysical data to bear on the wide range of seismic hazard issues relevant to the DC site. These new data and investigations identified previously unrecognized faults and also provided new constraints on the ages and styles of movement on known faults in the region. Integration of this data into a coherent model of crustal block rotations related to clockwise rotation of the western Transverse Ranges and the Quaternary transpressional tectonic stress environment of the Coast Ranges provides a compelling synthesis of the data. Comparison of DC seismic design criteria to results of state-of-the-art seismic hazard analyses generally provides a high level of confidence in the design ground motions.
Limitations	For the abundance of new field data collected as part of the PG&E seismic program, there is a rather striking lack of global positioning data (GPS) that could serve an important role in confirming the project's seismotectonic interpretations, or perhaps suggest alternative interpretations. Worldwide, GPS data has been an important tool in deciphering the contemporary seismotectonics of regions. As an example, one implication of the proposed crustal-block rotation model is that inter-block faulting would be expected to have a left-lateral strike-slip component, providing that the shortening rate is relatively uniform N-S throughout the region. However, focal mechanism data indicates a ubiquitous right-lateral component to the oblique-slip earthquakes. High-quality GPS data, over time, could serve to confirm, deny, or refine the block rotation model that has been synthesized from the current data.
Comparisons/ Implications	Seismological data from the network established as part of the LTSP indicates that the offshore Hosgri fault is a steeply dipping fault throughout the brittle crust (See also Title 26). While the original seismic design criteria for DC assumed that the 1927 Lompoc earthquake occurred on the southern Hosgri fault zone and have a magnitude 7.5, the most recent seismological work on this earthquake both by the USGS and PG&E places the epicenter farther seaward than Gawthrop's original interpretation where it is highly unlikely to have

	been associated with the Hosgri fault (See Title 09 and discussion therein). The reassessed magnitude has also been lowered from 7.5 to 7.0. Nonetheless, the 7.5 assumed in the DC seismic design is an element of conservatism.

Title 12	Late Cenozoic Fold and Thrust Belt of the Southern Coast Ranges and Santa Maria Basin, California
Year	1990
Study Area	Onshore Santa Maria Basin and southern Coast Ranges to the western Transverse Ranges
Authors	J. Namson and T.L. Davis
Source	The American Association of Petroleum Geologists Bulletin, Vol. 74, No. 4, p. 467-492
Scope	Implications of regional fold structures in the study area to potentially hidden faults at depth and to hydrocarbon trapping and timing
Data Used	Structural geologic data on folds and faults. Local and regional stratigraphy and stratigraphic correlations.
Methodology	Geometrical reconstruction analysis of fold structures using balanced cross sections and implied deep crustal faulting styles and mechanics
Summary Results	1. Fold structures of the Santa Maria, Pismo, and Huasana basins, and southern Coast Ranges are interpreted to be the result of a seismically active, basement-involved, fold and thrust belt. The anticlines are fault-bend and fault-propagation folds associated with thrust ramps that step up from thrust flats and a regional detachment at 11-14 km depth. 2. The range front of the San Rafael Mountains is interpreted to be uplifted above a ramp in the point San Luis blind thrust. The length and continuity of the range front across the northern margin of the Santa Maria basin suggests it is underlain by an important regional fault. 3. Total convergence across the southern Coast Ranges from the San Andreas fault to the Santa Lucia Bank is 26.8 km. The convergent structures probably began to develop between 2 – 4 Ma and the convergence rate is 6.7 – 13.4 mm/yr. The total convergence across the onshore western Santa Maria basin is 9.2 km, yielding a convergence rate of 2.3 - 4.6 mm/yr. 4. Compressive earthquakes, broad bands of seismicity, geodetic measurements, and folded Quaternary deposits indicate the fold and thrust belt is undergoing active convergence. The ramp parts of these thrusts are the most likely seismogenic sources. Most of the thrusts are blind, presenting a major problem with existing seismic evaluations of the region, which generally have considered only strike-slip and reverse faults with surface expression. 5. The historic record of compressive earthquakes in central and

	southern California and the 15 – 80 km length of the thrust ramps suggest the faults are capable of generating moderate to large earthquakes (5.0<Mw<7.5). If the convergence is relatively uniform over the last 2 – 4 my and is taken up seismically along the thrust ramps, then our slip rates indicate that moderate to large earthquakes can be expected every 75-299 yr on or near the southern Coast Range cross-section. These recurrence intervals do not account for areas away from the section lines and the regional recurrence interval for moderate to large compressive earthquakes of the entire area is probably more frequent. Additional structural analysis will be required to evaluate the recurrence interval of moderate to large earthquakes for the entire region. 6. Cross-section restoration shows early formed hydrocarbon trap settings along the Casmalia-Orcutt anticlinal trend and under the Santa Maria Valley and accounts for the major hydrocarbon accumulations along these trends. Miocene and early Pliocene normal faults have played an important role in oil maturation and trapping. Two relatively untested hydrocarbon trap styles are present in the Santa Maria basin: concealed normal faults along the flanks of major anticlines and the subthrust structures along the north flank of the Camalia-Orcutt trend.
Strengths	A detailed geometrical reconstruction of fold-fault kinematics using techniques that have provided geological reasons and justification for buried thrusts in the highly compressed Los Angeles basin region, some of which have been associated with recent earthquakes.
Limitations	Geometric reconstructions are nonunique and are based on estimates of lateral shortening in the planes of the crustal cross-sections that are being modeled. To the extent that crustal material has moved in and out of the planes of the cross-sections (i.e., strike-slip movement perpendicular to the section lines) over the time period of the reconstructions, errors are introduced into the convergence and slip rate estimates. The method is predisposed to expecting and predicting thrust and compressive fault movements and must infer mid- and deep-crustal faults and movements in order to replicate surface folds and structure. An underlying assumption is that virtually all lateral Pacific-NA plate margin slip is accommodated by the San Andreas, which is not supported by earthquake focal mechanisms in the area [26]. No additional resolution of faulting geometry in the brittle crust is gained in this modeling procedure. The summary cross-section in Figure 7 of this paper shows the Hosgri fault zone as a steeply dipping reverse fault that abruptly stops at a depth of approximately 7 km. No resolution of a possible intersection with the Point San Luis Thrust, if it exists, is provided by the method.

Comparisons/ Implications	Marine terrace data indicate folding of anticlines and synclines has not been active in the Pleistocene. Alternative geometric models have been proposed for the evolution of the Santa Maria basin and the Orcutt, Purisimal anticlines that allow for steeply dipping shallow crustal faults without the requirement for mid- and deep-crustal thrust ramps (i.e., Seeber and Sorlien, 2000). An alternative model has been proposed for the accommodation of deep and sub-crustal strain in a compressive/transpressive environment that does not require detachment faulting and associated thrust ramps (See Title 24).

Title 13	Review of Geological and Geophysical Interpretations Contained in "Pacific Gas and Electric Co. Final Reports of the Diablo Canyon Long Term Seismic Program for the Diablo Canyon Power Plant"
Year	1991
Study Area	Central coastal California and offshore
Authors	U.S. Geological Survey staff
Source	USNRC, Office of Nuclear Reactor Regulation, NUREG-0675, Supplement No. 34, Appendix C
Scope	Geological/geophysical review and comments on PG&E's LTSP
Data Used	LTSP geoscience data and interpretations and existing geoscience data in the region
Methodology	Examination and review of LTSP geological/geophysical data and interpretations in the context of state-of-the-art understanding of central coastal California geology and tectonics
Summary Results	1. Acknowledges that the LTSP is perhaps the most comprehensive study to date of earthquake hazards at an operating power plant, but that some issues remain unresolved or controversial due to the lack of definitive evidence. 2. Confirms the five capable faults identified in the LTSP near DC, four of which are newly identified (Los Osos, Olson, San Luis, and Wilmar Avenue) and one which was known to exist (Hosgri). Confirms the magnitudes expected along these faults. 3. Disagrees with the LTSP interpretation that the Hosgri is a strike-slip fault with little or no vertical component of slip that is chiefly supported by surface and shallow trench investigations near San Simeon Point. This data must be weighed with other lines of evidence relevant to the character of the Hosgri at depth. 4. Interprets the Hosgri fault as a broader fault system that includes the Hosgri fault zone and San Simeon faults as well as fault and fold belts towards the southwest, some of which neither cut nor deform the seafloor. Structures in the system are primarily compressional but may also exhibit right-lateral strike-slip (as the San Simeon fault). 5. Data for the seafloor fault zone and broader fault system suggest NE dips of 50 - 70º at depths of 4 – 10 km. Evidence is taken to include the focal mechanism of the Lompoc earthquake (Ms = 7.0 – 7.5). 6. Los Osos fault and others on the SW side of the Pismo syncline are lower hazard than the Hosgri, but surface measurements of low dips are largely discounted by PG&E. Segmentation

	arguments for the Los Osos fault are model-dependent and unconvincing but the probabilistic magnitude of 6.8 for an earthquake on this fault appears appropriate. Lower magnitudes and hazard posed by the faults on SW side of Pismo syncline appear appropriate although other, less likely, tectonic models could be chosen that would increase the hazard from these faults. 7. A logic-tree for the Hosgri fault is biased to favor a strike-slip faulting model and yields probability distribution functions for the fault that are similarly biased. Observed data over model-based values would increase the weight for oblique-slip and thrust earthquakes. Some questionable procedural steps in the logic tree also bias the number of outcomes in the same way. Greater reliance on the LTSP data will tend to raise the mean magnitude for the probabilistic earthquake and change its standard deviation. Many of these points apply to the seismic hazard analysis tree that is used in the PRA of DC. 8. Most significant differences with PG&E interpretations concern the dip and earthquake slip-mechanism for the Hosgri fault at depths of 4 – 10 km. If ground motion depends on fault characteristics, values for a vertical strike-slip fault may underestimate those for oblique slip, reverse or thrust faults.
Strengths	USGS staff has considerable experience addressing complex geological problems.
Limitations	Most significant differences with PG&E regarding Hosgri fault geometry at 4 – 10 km deep is where there is no direct imaging of the fault plane.
Comparisons/ Implications	USGS comments on the Hosgri fault appear to be based on acceptance of a more ubiquitous compressive thrust seismotectonic model for the central Coast Ranges region (See Titles 10 and 12). However, the authors of these compressive tectonic models themselves are either noncommittal on the dip of the Hosgri fault zone (Title 10) or show the Hosgri in cross-section as a steeply-dipping fault (Title 12). Nonetheless, NRC redefined PG&E's logic-tree PSHA Hosgri inputs to higher values for thrust faulting and required PG&E to demonstrate adequate seismic margins (See Title 15). The USGS broadens the definition of the Hosgri fault zone to include structure SW of the fault, including the 1927 Lompoc earthquake, which latest seismological research indicates is unlikely associated with the southern part of the Hosgri fault zone (See Title 09 and Additional References therein). Shallow surface dips of some fault traces in the Hosgri zone may be related to flower structure in a transpressional strike-slip fault zone (See Title 28) and are not indicative of fault attitude at depth.

Title 14	Independent Assessment of the Earthquake Potential at the Diablo Canyon Power Plant, San Luis Obispo County, CA
Year	1991
Study Area	Central coastal California and offshore
Authors	D.B. Slemmons and D.G. Clark
Source	USNRC, Office of Nuclear Reactor Regulation, NUREG-0675, Supplement No. 34, Appendix D
Scope	Independent geological evaluation of the earthquake potential at DC in support of USNRC review of PG&E's LTSP
Data Used	Independent field data collected and analyzed by the University of Nevada, Reno (UNR), and PG&E LTSP geoscience data and interpretations along with existing geoscience data in the region
Methodology	Review and synthesis of LTSP geological/geophysical data with independent UNR field data and interpretations of local fault zones in proximity to DC
Summary Results	1. UNR's parameterization of the Hosgri fault zone and its earthquake potential is similar to PG&E's with somewhat different weighting in the logic-tree characterization and somewhat different segment boundaries. 2. The Hosgri fault is primarily a strike-slip fault although it may have a subordinate oblique-slip component. Weightings are: Strike-slip = 0.65; oblique-slip = 0.30; thrust = 0.05. The fault extends to 12 km deep and is well segmented. Segment lengths and weightings are: less than 22 km = 0.20; 50 km = 0.55; 70 km = 0.20; 110 km = 0.05. Average displacement per event is expected to be 1 m (0.5) or 2 m (0.5). The slip rate is 2 – 3 mm/yr and within the range of slip rates estimated by PG&E (i.e., 1 – 3 mm/yr). The recurrence frequency is 300 to 2,000 yrs with a preferred frequency of 1,000 years. The maximum credible earthquake (MCE) is 7.2. 3. The characterization of the Los Osos fault is similar to that of PG&E although the UNR estimated MCE is slightly lower than PG&E's estimate. The fault is part of a zone 2 or 3 km wide and is strongly partitioned along the San Luis/Pismo subblocks. The activity rate may decrease eastwards. Weightings are: reverse-slip = 0.9; oblique-slip = 0.1; 60° dip = 0.7; 30° dip = 0.3. Full segment rupture 18 km long is preferred with an average displacement of 2.1 – 2.5 m. MCE is estimated to be 6.5 – 6.8. The vertical component slip rate is 0.2 mm/yr. 4. Although the PG&E model of the southwest border zone is

	consistent with field observations, an alternative also fits the seismologic and structural relationships. Active faults are considered to be distributed over a zone 4 km wide opposite the Irish Hills subblock and the zone is strongly segmented. Similar weighting for reverse-slip as the Los Osos fault. Irish Hills subblock rupture length is approximately 13 km. Vertical component slip rate is 0.2 mm/yr with about 70% of the deformation occurring on the Olson fault and San Luis Bay fault zones and about 30% occurring offshore on the Pecho and perhaps other unidentified structures. The integrated boundary zone gives an MCE of 6.5 with a seismogenic depth of at least 5 – 7 km.
Strengths	A detailed review and alternative assessment of geological evidence bearing on the earthquake potential of the DC region and PSHA logic-tree interpretations supported by independent field study, apparently commissioned by NRC in response to USGS review comments on the PG&E logic-tree inputs.
Limitations	Review appears very thorough with respect to fault lengths and segmentation that bears on estimates maximum earthquakes.
Comparisons/ Implications	Independent field studies of fault zones in the vicinity of DC commissioned by the NRC yielded relatively minor differences with PG&E LTSP interpretations, mostly related to the segment lengths of the faults that result in little impact on the estimated fault MCE's.

Title 15	Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant Units 1 and 2; Dockets Nos. 50-275 and 50-323
Year	1991
Study Area	Diablo Canyon NPP Site and surrounding area
Authors	USNRC
Source	USNRC, Office of Nuclear Reactor Regulation, NUREG-0675, Supplement No. 34
Scope	NRC staff review and conclusions regarding PG&E license condition regarding the Long-Term Seismic Program (LTSP)
Data Used	Data and materials submitted by PG&E related to the geological and seismological setting of the power plant site
Methodology	USNRC technical review and interaction with PG&E since submittal of the LTSP final report in July, 1988
Summary Results	1. PG&E has met its operational license condition, subject to submittal of analyses to confirm its statements that plant seismic margins are adequate to accommodate spectral exceedances discussed in the SSER. 2. Element 1: The geological, seismological and geophysical investigations conducted by PG&E for the LTSP are the most extensive, thorough, and complete ever conducted for a nuclear facility in the U.S. 3. Element 2: The Hosgri fault causes the maximum ground motion at the site and has a maximum credible magnitude of 7.2. Maximum credible earthquakes associated with other on any other fault in the site vicinity would produce smaller ground motions at the site. 4. Element 3: PG&E reevaluated ground motion at the site using a slip distribution on the Hosgri fault that is 65% strike-slip, 30% oblique-slip, and 5% thrust-slip. NRC staff concludes that that ground motion at the site should be evaluated for an earthquake on the Hosgri fault that is 2/3 strike-slip and 1/3 reverse slip. 5. NRC staff's own analysis of ground motions at the site from their preferred slip model of the Hosgri fault shows that both their 50th and 84th percentile horizontal ground-motion spectra at the site is equal to or less than the PG&E spectra at frequencies above 1 Hz, but exceeds PG&E spectra at frequencies below 1 Hz. The staff's 84th percentile vertical spectra exceed PG&E vertical spectra over the frequency range of 1 – 10 Hz. To fully satisfy Element 4, PG&E demonstrate that the plant can withstand these exceedances.

	6. Element 4: NRC staff found that the PG&E soil-structure interaction (SSI) analyses to determine the effect of dynamic interaction between the plant structures and foundation rock under the plant were comprehensive, thorough, and acceptable. 7. PRA analysis by PG&E for internal and external events estimated that the core damage frequency is $2x10^{-4}$, which is similar to other nuclear plants. The NRC staff estimate is $4x10^{-4}$. Internal events contribute 63% to the PG&E estimate, seismic contributes 18%, and other external events 19%. NRC staff estimates are 70%, 10% and 20%, respectively. 8. PG&E LTSP ground motion estimates show adequate margin for major plant structures. PG&E plans to modify all safety-related masonry walls. 9. NRC agrees that the seismic margins are adequate to accommodate horizontal and vertical spectral exceedances resulting from the staff's ground motion estimates, but requires PG&E to confirm its conclusion through analyses. 10. Subject to confirmation of seismic margins (#9 above), NRC concludes that PGE has met Element 4 of the license condition.
Strengths	NRC position was developed following extensive review of PG&E LTSP results from three years of investigations and the commissioning of independent verification studies..
Limitations	N/A - a regulatory document. Conditions of findings are stated above.
Comparisons/ Implications	Based on USGS review comments and NRC-commissioned independent evaluations, NRC raised the probability of thrust faulting on the Hosgri fault above PG&E's estimate and performed their own PSHA. NRC agreed that the DC seismic margins are adequate to accommodate horizontal and vertical spectral exceedances resulting from these modified ground motion estimates, but required PG&E to confirm its conclusion through analyses.

Title 16	Seismotectonic Framework of Coastal Central California
Year	1994
Study Area	Central coastal California
Authors	D.G. Clark, D.B. Slemmons, S.J. Caskey and D.M. dePolo
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 9-30.
Scope	Regionalization of central coastal California between Monterey Bay on the north and Los Angeles on the south into five distinctive seismotectonic domains.
Data Used	Physiographic relief, Quaternary fault and fold styles, basement rock types, historical earthquakes M ≥ 5.0 and contemporary earthquakes M_L ≥ 2.5 between1969-89, earthquake focal mechanisms, regional tectonic stress.
Methodology	Synthesis of the data into a descriptive model of domains exhibiting distinctive deformational styles along with definitions of the domain boundaries.
Summary Results	1. Contemporary deformation of coastal central California consists of 5 distinctive domains separated by major faults that accommodate much of the tectonic strain release in the region. The domains are. 1. The Transverse Ranges on the south; 2. The Santa Maria – San Luis Range domain on the west (host domain to DC NPP): 3. The Coastal Franciscan domain bordering the Santa Maria – San Luis Range domain on the east: 4. The Salinian domain neighboring the San Andreas fault on the west; and 5. The Western San Joaquin Valley domain neighboring the San Andreas fault on the east. 2. Styles of deformation progressively change from pure reverse and left-lateral reverse-oblique faulting in the Transverse Ranges and Santa Maria Basin – San Luis Range domains to reverse and right-lateral reverse-oblique displacement in the Coastal Franciscan domain and pure right-lateral faulting in the Salinian domain. The western San Joaquin Valley domain exhibits principally compressional deformation. 3. The Transverse Ranges domain exhibits a relatively high level of small earthquakes and the frequent occurrence of moderate and large earthquakes along with locally high rates of active tectonism. The Santa Maria Basin – San Luis Range domain is characterized by deformation similar to the Transverse Ranges,

	but with lower strain rates. The Salinian domain exhibits relatively little deformation compared to neighboring domains that is attributed to a high-strength crystalline basement that tends to resist deformation. Details of deformation in the Coastal Franciscan domain is poorly understood but earthquake data indicate broad internal deformation in the low-strength Franciscan Complex basement rocks. Deformation in the Western San Joaquin Valley domain east of the San Andreas Fault is characterized primarily by thrust and reverse faulting associated with folding, which is concentrated along the domain's eastern margin.
Strengths	A concise overview and synthesis of "map view" tectonic information available.
Limitations	Focus of the article is primarily on "map view" geology with relatively little discussion and constraint provided in the vertical crustal dimension of the defined domains.
Comparisons/ Implications	Provides the regional tectonic framework for Titles 17 – 22.

Title 17	Los Osos Fault Zone, San Luis Obispo County, California
Year	1994
Study Area	Northeastern boundary of the San Luis Range/San Luis – Pismo structural block, which is host to DC NPP
Authors	W.R. Lettis and N.T. Hall
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 73-102.
Scope	Detailed geological investigation of the Los Osos fault zone including surface geological mapping and paleoseismic investigations.
Data Used	Original field geologic, geomorphic and geophysical data.
Methodology	*Onshore*: Interpretation of black & white, color infrared, and low sun-angle aerial photographs; field geologic surface mapping; subsurface exploratory drilling; excavation and mapping of trenches across fault traces; marine and fluvial terrace mapping and correlation. *Offshore*: Interpretation of sea-floor bathymetry, side-scan sonar, and high-res seismic reflection profiles.
Summary Results	1. The Los Osos fault zone is a complex reverse or thrust fault along the northeastern margin of the San Luis – Pismo structural block that extends a distance of at least 36 km between Morro Bay on the northeast and the Lopez reregulating reservoir on the southwest. The fault may extend another 13 km northwesterly offshore and intersect with the Hosgri fault as well as an additional 8 km southeasterly and intersect with the West Husana fault near Twichell Reservoir for a total possible length of 57 km.. 2. The Irish Hills and Lopez Reservoir are two well-defined central segments that total 36 km. 3. The Irish Hills segment has subparallel traces up to 2 km wide, multiple late Pleistocene and Holocene surface ruptures, and a slip rate of 0.2 to 0.8 mm/yr. 4. Although the Lopez Reservoir segment is interpreted to have been active in the Quaternary, it has poor geomorphic expression, no definitive evidence for late Quaternary faulting, and a slip rate less than 0.1 mm/yr. 5. The northwestern and southeastern extensions of the Los Osos fault zone are not clearly expressed in the geomorphology and are not clearly active in Quaternary time. These are the Estero Bay and Newsom Ridge segments, respectively.

	6. The Los Osos fault zone accommodates regional NE-SW-directed Quaternary crustal shortening and appears to accommodate motion between the uplifted San Luis – Pismo structural block from the subsiding or tilting Cambria block. If this deformational style is representative of the domain as a whole, late Quaternary crustal shortening is occurring primarily as rigid block uplift, subsidence and tilting controlled by reverse displacements on NW-trending faults.
Strengths	Significant new and detailed geological and geophysical data is developed and synthesized into a coherent deformational fault model for the NE boundary of the San Luis – Pismo structural block, which is the host structural feature to the DC NPP.
Limitations	Lack of deeper geophysical data to define fault geometry greater than about a few hundred meters deep.
Comparisons/ Implications	Provides the geological basis for faulting along the NE boundary of the San Luis – Pismo block in the LTSP (Title 11).

Title 18	The Wilmar Avenue Fault: A Late Quaternary Reverse Fault Near Pismo Beach, California
Year	1994
Study Area	Southwestern San Luis Obispo County, California. Southeast margin of the San Luis Range.
Authors	S.P. Nitchman and D.B. Slemmons
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 103-110.
Scope	Report on field investigation of the 7-km long Wilmar Avenue fault along the southeastern boundary of the San Luis Range.
Data Used	Local stratigraphy, uplifted and offset marine terraces, water well logs to constrain interpretations at shallow depths.
Methodology	Geological mapping and field methods
Summary Results	1. Wilmar Avenue fault strikes N60ºW along a 7-km length on land between Arroyo Grande Creek and Wilmar Avenue Beach at the southeastern margin of the San Luis Range and has been the primary structural boundary of the range at this location since late Pliocene time. The fault is part of the seismogenic southwestern boundary of the San Luis – Pismo structural block. 2. Two discrete structural sections of the fault are recognized: A western section of the fault that exhibits block uplift and an eastern section marked by a monoclinal warp that is interpreted to be a fault propagation fold above a blind reverse fault. 3. Vertically offset marine terraces indicate vertical displacement along the fault since the late Pleistocene at a rate approximately between 0.04-0.07 meters per thousand years (i.e., 0.04-0.07 mm/yr).
Strengths	An insightful synthesis of field mapping with available data to explain a rather complex relationship of faulting and folding over a relatively short distance.
Limitations	This paper is well-focused on structural delineation of the Wilmar Avenue fault on land. A possible continuation with inferred faults offshore is implied in Figure 2 and suggests follow-up offshore studies to better define an offshore extension, if any.
Comparisons/ Implications	Provides the geological basis for faulting style and rate along the SW boundary of the San Luis – Pismo block in the LTSP (Title 11).

Title 19	Quaternary Deformation of the San Luis Range, San Luis Obispo County, California
Year	1994
Study Area	San Luis Range, San Luis Obispo County, California
Authors	W.R. Lettis, K.I. Kelson, J.R. Wesling, M. Angell, K.L. Hanson, N.T. Hall
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 111-132.
Scope	Quaternary deformational model specific to the San Luis Range is placed in a regional context of central coastal California and the broader Pacific/North American plate boundary.
Data Used	Local stratigraphy, fault-specific mapping and trenching data, uplifted and offset marine terraces.
Methodology	Synthesis of the data into a Quaternary deformational model specific to the San Luis Range and placed in a regional deformational context.
Summary Results	1. NE margin is the Los Osos fault zone; a SW-dipping reverse fault with recurrent late Pleistocene and Holocene displacement and a slip rate of 0.2-0.7mm/yr. Range uplift is facilitated along this zone. 2. SW margin is complex Quaternary reverse faults including the Wilmar Avenue, San Luis Bay, Olson, Pecho and Oceano faults that dip moderately to steeply NE. Cumulative net dip-slip displacement rate is about 0.16 – 0.30 mm/yr. Slip rates on individual faults generally range from 0.04 to about 0.11 mm/yr. The complex of faults separates the uplifting or tilting San Luis Range from the subsiding Santa Maria Basin to the SW. 3. Styles and rates of deformation in and bordering the San Luis Range are inferred to be representative of that occurring in the Los Osos – Santa Maria (LOSM) domain. Crustal shortening is accommodated by reverse faulting and uplift/subsidence, or tilting, of blocks. In the southern and SE LOSM, shortening also may be accommodated by folding and thrust faulting. The LOSM is transitional between the western Transverse Ranges on the south and the N-NW trending structures of the Santa Lucia and San Rafael Ranges on the NE. 4. Quaternary deformation in the LOSM is related to: a) transpression along the NA/Pacific plate margin, b) clockwise rotation of the western Transverse Ranges, and c) convergence of LOSM against the rigid Salinian crust that underlies much of the Santa Lucia and San Rafael Ranges to the NE.

Strengths	A compelling synthesis that brings together a wide range of new geological data and interpretations in a coherent model of Quaternary deformation of the San Luis Range and its bordering fault zones.
Limitations	Proposed block deformation model for the San Luis Range, and the LOSM in general, is based on surface, or very near surface, geological data. Deeper crustal geophysical/seismological data that might bear on the block deformation model is not part of this discussion.
Comparisons/ Implications	Provides the geological basis for faulting style and rate along the margins of the San Luis Range in the LTSP (Title 11). Issue of deeper seismological data bearing on block boundaries was later addressed in Title 26, supporting the block-model concept proposed here.

Title 20	Estimated Pleistocene Slip Rate for the San Simeon Fault Zone, South-Central Coastal California
Year	1994
Study Area	South-central coastal California, generally Point San Simeon on the south to Ragged Point on the north.
Authors	K.L. Hanson and W.R. Lettis
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 133-150.
Scope	Determination of style and rate of movement on the San Simeon fault zone primarily from detailed mapping and analysis of deformed and offset marine terraces.
Data Used	Detailed geologic field map data, marine terrace elevations and ages, shoreline configurations, geomorphic drainage deflections
Methodology	Age dates of marine terraces and displacement amount and sense by strands of the San Simeon fault are used to determine the slip rate and offset style along the San Simeon fault zone.
Summary Results	1. Terraces are offset and warped within a zone of shearing 500 m wide with ratios of vertical-to-horizontal (V:H) slip between 8:1 and 50:1 demonstrating the San Simeon fault zone is dominantly right-lateral strike-slip. 2. Based on present locations of strand lines on the marine terraces and reconstruction of past shoreline configurations, slip rates range between about 0.4 - 11 mm/yr. Best constrained values are 1 – 3 mm/yr. Slip rates from offset drainages across the fault corroborate the 1 – 3 mm/yr slip rate estimates from the marine terrace study. This geologically determined rate is comparable to geodetically modeled estimates of shear west of, and parallel to, the San Andreas fault. 3. The San Simeon fault zone accommodates a significant amount of transpressional strain along the NA/Pacific plate margin and is part of the larger San Gregorio-San Simeon-Hosgri near-coastal fault system.
Strengths	Careful treatment and analysis of difficult data and uncertain paleogeographic reconstructions to obtain constraints on slip rate.
Limitations	Large uncertainties are inherent in the type of geological data and shoreline reconstructions that are used in this investigation, although corroboration of several lines of evidence lends credibility to the best

	constrained slip values of 1-3 mm/yr.
Comparisons/ Implications	Provides geological constraints on the faulting style and slip rate along the San Simeon fault zone as a basis for modeling the fault zone in the LTSP (Title 11).

Title 21	Holocene Behavior of the San Simeon Fault Zone, South-Central Coastal California
Year	1994
Study Area	San Simeon and a few km to the NW
Authors	N.T. Hall, T.D. Hunt, P.R. Vaughan
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 167-189.
Scope	Detailed geologic investigation of the San Simeon fault to determine the style of faulting, slip rate, slip per event, and recurrence frequency.
Data Used	Geological fault-trench mapping and related field data, radiocarbon and TL age dates, geomorphic analysis, auger borings and exploratory pits.
Methodology	Detailed fault trenching; shallow boring and pit excavation geologic investigation methods, marine terrace analysis
Summary Results	1. Approximately 2.5 km NW of San Simeon, the San Simeon fault consists of two and possibly four or more strands across a 400-m-wide zone that narrows to about 120 m wide at San Simeon. 2. Geologic and soils data from four sites indicate that the San Simeon strands are NW-striking, vertical to near-vertical, right-slip faults exhibiting sub-horizontal slickensides. 3. Strike-slip to dip-slip ratios range from about 8:1 to greater than 10:1. 4. Slip rate is 0.9 - 3.4 mm/yr. Best constrained value is 1.0 -1.4 mm/yr along one major fault strand with marine terrace analysis suggesting that this estimate may approximate the slip rate for the fault zone as a whole. 5. Net slip estimates are 1 - 2 m per event with recurrence frequency of 265 – 2,000 years. Best constrained values are between approximately 600 – 1,800 years with events not occurring at uniform intervals.
Strengths	Most detailed paleoseismological investigation performed on the San Simeon fault zone.
Limitations	Holocene slip rates are regarded as preliminary and are sensitive to assumptions including flat-lying beds. As an example, slip rate increases approximately 33% for an initial bed dip of 2^{o}. Limits of measurements lie within 1^{o} to 2^{o}.
Comparisons/	Provides additional geological constraints on the faulting style and slip

Implications	rate along the San Simeon fault zone as a basis for modeling the fault zone in the LTSP (Title 11).

Title 22	Hosgri Fault Zone, Offshore Santa Maria Basin, California
Year	1994
Study Area	Hosgri fault zone, defined as the southern section (south of Purisima Point) of a 435 km-long major coastal fault system.
Authors	J.W. Steritz and B.P. Luyendyk
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 191-209.
Scope	Structural and geological interpretation of more than 1,500 mi of processed offshore seismic reflection profiles to define the southern termination of the Hosgri fault zone (HFZ), its style of faulting and its relationship to neighboring structures.
Data Used	More than 1,500 mi of processed offshore seismic reflection data
Methodology	Mapping of a Miocene-Pliocene age unconformity and reflective upper Miocene horizons from the seismic reflection data to discern the early deformational history of the HFZ.
Summary Results	1. The HFZ is a structural boundary separating the offshore Santa Maria Basin structure to the west from the onshore Santa Maria Basin and western Transverse Ranges to the east. Fold and fault trends east of the HFZ generally trend.20°- 25° more westerly than these trends west of the HFZ and fold wavelengths east of the fault are approximately one-third of those west of the fault. 2. The HFZ changes trend over three sections: a southern section south of the Honda fault of the western Transverse Ranges trends close to N 47° W, a middle section from the Honda fault to south of Purisima Point trends close to N 5° W, and a northern section that trends N23° W. 3. The middle section is best imaged in the reflection data and shows two major fault traces with subvertical offsets of Pliocene and Miocene reflectors with fault widths not exceeding 300 m wide. The two HFZ strands bound a central graben with the sense of separation reversing across a "scissors pivot" from north to south along the structure. HFZ fault planes appear subvertical for more than 4,000 ft deep extending along narrow zones of faulted deformation. Vertical separation is variable on the main trace which is nearly linear in map view. Drag folds are consistent with right-lateral movement and reverse fault features are absent. 4. The southern HFZ section trends more northwesterly and widens to an average width of 1.8 km. On two lines, fault planes of the

	zone were dipping 30º to the northeast. Left-lateral oblique faults of the western Transverse Ranges do not offset the HFZ but their motion appears to be accommodated along the HFZ. Oblique right-slip and reverse-slip is expected on this southern segment of the HFZ. 5. The northern segment displays characteristics intermediate between the northern and central segments, although interpretation of fault planes and inter-fault zone reflectors is difficult. Where observed, the HFZ exhibits subvertical eastward dips through the upper 3,000 ft that are interpreted to be flower structure consistent with right-slip movement. 6. The HFZ pre-dates widespread Pliocene orogeny when compression across the NA-Pacific boundary increased. Contractile structures and thrust faults of the offshore Santa Maria Basin are clearly distinguished from the HFZ, which is better described as an oblique right-slip fault. Discrepant estimates of total offset along the HFZ over the years might be explained by releasing right-steps in the HFZ south of Point Sur and dissipation of right slip by folding and faulting east of the HFZ. However, larger offsets likely may have been accommodated west of the HFZ along the Santa Lucia Bank fault.
Strengths	The most detailed geophysical investigation of the HFZ to date examining a large data base of nonproprietary seismic reflection profiles. The HFZ appears to be well imaged by the data in at least its central and southern segments lending credibility to the interpretations.
Limitations	Seismic lines across the northern section of the HFZ are more widely spaced than along the central and southern segments and interpretation is more difficult lending less certainty the nature of the fault in this area.
Comparisons/ Implications	Provides geophysical constraints on faulting style along the offshore Hosgri fault zone fault zone as a basis for modeling the fault zone in the LTSP (Title 11). Notably, The change in offset style N-S along the fault and the interpretation of flower structure in the upper part of the central segment ameliorates previously contradictory interpretations of thrust/reverse and strike-slip faulting along the zone.

Title 23	Shallow Geologic Structure, Offshore Point Arguello to Santa Maria River, Central California
Year	1994
Study Area	Offshore central California, Point Arguello to Santa Maria River
Authors	D. Cummings and T.A. Johnson
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 211-222.
Scope	Collection and interpretation of seismic reflection profiles for assessment of potential shallow geological hazards within the 3-mi. zone of state waters.
Data Used	A total of 1,338 km (831 statute mi.) of geophysical lines with five separate seismic data sets recorded simultaneously: a) 24-channel digital watergun (deep data quality poor to fair) , b) analog watergun (deep data quality poor to fair), c) boomer (poor to fair data quality), d) subbottom profiler (poor to fair data quality), and d) echo sounder (good data quality).
Methodology	Interpretation of the collected geophysical data
Summary Results	1. West of Point Sal and east of the HFZ, the informally named the Offshore Point Sal fault is newly identified and follows a strike mostly parallel to the HFZ. The Offshore Point Sal fault offsets the more westerly trending Lions Head fault with a right-lateral sense. The Offshore Point Sal fault does not appear to offset a Pleistocene erosional surface and is considered to be potentially active. 2. The HFZ does not cut the Pleistocene erosion surface but does exhibit flower structure in the shallow subsurface consistent with strike-slip faulting in a convergent wrench tectonic system. 3. Southern splays of the HFZ appear to merge with the onshore Lompoc-Solvang and Santa Ynez River faults of the western Transverse Ranges. 4. Potential geologic hazards from earthquakes in the study area include ground shaking, slumps, debris flows, liquefaction and sediment de-gassing. There is a tsunami potential from subsea landslides or surface fault movement. 5. Focal mechanisms and structure in the region are consistent with approximate N-S horizontal compressive stress.
Strengths	A new source of geophysical data that bears on the shallow structure and

	structural relationships of the HFZ.
Limitations	Interpretations restricted to the upper 0.2-sec two-way travel time, approximately 500 m (1,600 ft) deep due to deep data quality and processing limitations.
Comparisons/ Implications	Provides geophysical constraints on faulting style along the offshore Hosgri fault zone fault zone as a basis for modeling the fault zone in the LTSP (Title 11). The interpretation of flower structure in a convergent wrench tectonic system in the upper part of the fault zone ameliorates previously contradictory interpretations of thrust/reverse and strike-slip faulting along the zone.

Title 24	Seismotectonic Patterns Across a Part of the Central California Coast Ranges
Year	1994
Study Area	65-km-wide corridor across the central California Coast Ranges between Lopez Point on the north and point Estero on the south.
Authors	D.P. Dehlinger and B.A. Bolt
Source	Geological Society of America Special Paper 292, "Seismotectonics of the Central California Coast Ranges", I.B. Alterman, R.B. McMullen, L.S. Cluff and D.B. Slemmons, eds., p. 223-229. *See also:* Bulletin of the Seismological Society of America, 1987, Vol. 77, p.2056-2073, "Earthquakes and Associated Tectonics in a Part of Coastal Central California" by the same authors.
Scope	Upper crustal structures in an area west of the San Andreas fault to seaward of the HFZ.
Data Used	Focal mechanisms, focal parameters (M_L 2.3 - 6.0, 1976 - 86) , and crustal basement rock types
Methodology	Geological/seismological synthesis of the data
Summary Results	1. The study area is divided into three provinces: a) the seismically active San Andreas province, b) the seismically quiescent province from the San Andreas fault westwards to near the Nacimiento fault, which is underlain by crystalline Salinian crust, and c) a compressive belt along both sides of the coastline that extends from the Nacimiento fault to about 15 km seaward of the HFZ. 2. San Andreas is characterized by horizontal shear. Faulting in compressive belt either side of the coastline is predominantly oblique reverse along moderate to steeply NE-dipping planes and right-lateral horizontal components where displacements are horizontal along NE-dipping planes. 3. The provinces appear to be relatively rigid blocks of contrasting upper crustal strength whose focal mechanisms are rotated relative to one another and that are separated by narrow transition zones. The base of the seismogenic zone is interpreted to be a thermally controlled boundary rather than a lithologic boundary. 4. No earthquake evidence has been observed to indicated a the presence of a detachment surface within the seismogenic zone (12 km deep) and no direct evidence of a deeper detachment has

	been observed. 33 earthquakes across the domains indicated fault planes that dip more than 35º which appears inconsistent with thrust faults that sole into near-horizontal detachment faults at the base of the crust. 5. Any detachment associated with horizontal shortening, if present, will be restricted to the region of reverse faulting southwest of the Nacimento fault. But the need for invoking deep detachment for conservation of crust in shortening is obviated by a model of creep and deep plastic deformation in ductile rocks. The stress and fault patterns in the study corridor are more consistent with creep and flow modes of deformation beneath the upper crust than with a widespread detachment surface.
Strengths	An original interpretation of deep/sub-crustal strain dissipation not requiring horizontal detachment faulting and accompanying thrust ramps (i.e., See Title 12)
Limitations	Distinctions between upper crustal stress distribution and resulting strains between a deep crustal detachment and deep "creep and flow modes" are alluded to but not made explicitly clear.
Comparisons/ Implications	Offers an alternative concept to detachment faulting (i.e., Title 12) for the accommodation of deep crustal shortening in which more heterogeneous stress and strains are allowed in the brittle upper crust.

Title 25	Block Rotation and Termination of the Hosgri Strike-Slip Fault, California, from Three-Dimensional Map Restoration
Year	1999
Study Area	South-Central California offshore including the Santa Maria Basin
Authors	C.C. Sorlien, J.J. Kamerling, D. Mayerson
Source	Geology, Vol. 27, No. 11, p. 1039-1042
Scope	Implications of geological block models to displacement style and amount of the Hosgri fault.
Data Used	Digital structure contour maps developed from offshore seismic reflection data, well logs from 77 exploration wells, and published geologic and subsurface maps.
Methodology	Post-Miocene finite block displacements for the study area are inferred by restoring faults and folds to their pre-deformed horizontal attitude using a computer algorithm.
Summary Results	2. Total post-Miocene right-lateral strike-slip displacement on the Hosgri fault is determined to be 10.5 km. 3. 3.5 km of the total slip along the southern Hosgri is absorbed by folding, thrust overlap, and rotation of elongate blocks between fault strands. 4. The Hosgri fault terminates southeastward into east-trending folds and reverse-separation faults of the western Transverse Ranges Province. 5. A decollement thrust in the lower crust interpreted by others beneath the Santa Maria Basin could facilitate proposed block rotations in the upper crust. 6. Block rotations between the Hosgri fault on the west and an inferred dextral (right-lateral) shear zone onshore will be accompanied by oblique-sinistral (left) reverse earthquakes along northwest-southeast-trending block boundary faults.
Strengths	Novel application of an existing algorithm to gain insight to issues regarding the Hosgri fault as well as offering a predicted deformational style of the study area in general.
Limitations	The algorithm (UNFOLD) requires a fixed reference line against which maps are "unfolded". Algorithm assumes no layer-parallel displacements occur during deformation. Errors will be introduced if these conditions do not actually exist.
Comparisons/	Demonstrates the geometric plausibility of the tectonic block-rotation

Implications	model for the south-central California coastal region (See Title 26) that underlies the seismotectonic model for the DC site in the PG&E LTSP (Title 11).

Title 26	Seismicity of South-Central Coastal California: October 1987 through January 1997
Year	2001
Study Area	South-central coastal California and offshore
Authors	M.K. McLaren and W.U. Savage
Source	Bulletin of the Seismological Society of America, Vol. 91, p. 1629-1658
Scope	Seismological analyses of 9 years of earthquake data recorded by PG&E's 20-station Central Coast Seismic Network (CCSN) and interpreted in the context of previously recorded seismicity, Quaternary faults, and tectonic features of the central coast region.
Data Used	October 1987 – January 1997 CCSN earthquake recordings augmented with recordings from the USGS northern and southern California seismological networks.
Methodology	Development of S- and P-wave velocity models to improve location accuracy accounting for laterally inhomogeneous crustal rocks and for establishing calibrated duration magnitudes with corresponding station corrections. CCSN magnitudes were calibrated to the two USGS networks. Final catalog is 1184 well-constrained earthquake locations using HYPOINVERSE with 212 well-constrained focal mechanisms using FPFIT.
Summary Results	1. Detailed network seismicity delineates the northern Hosgri fault as a near-vertical fault through the brittle crust exhibiting dextral strike-slip focal mechanisms. 2. The geophysically-defined step-over between the Hosgri and San Simeon faults exhibits strike-slip seismicity within the step-over. 3. The Santa Lucia Range, north of the Hosgri fault and Los Osos domain, is a seismically active compressive stress domain buttressed on the north by the Salinian terrane. 4. The Hosgri fault separates the Los Osos domain in the east from the offshore Santa Maria Basin. 5. Uplifiting blocks of the Los Osos domain exhibit reverse and reverse-oblique focal mechanisms while structurally low areas are quiescent. 6. The Santa Maria Basin is seismically quiescent the northern and central basin areas and seismically active in the southern area exhibiting reverse focal mechanisms and Quaternary deformation. 7. The observed patterns of micro- and macroseismicity are consistent with observed locations and style of Quaternary

	deformation and transpressional deformation of the Hosgri fault zone overprinted with rotation and west-migration of the western Transverse Ranges. 8. Seismicity in south-central California extends to a maximum depth f 12 km and overlies, and is decoupled from, the subducted remnant of oceanic crust.
Strengths	Refined crustal velocity models and related sensitivity tests, and careful event processing, provides a level of confidence in small-magnitude hypocenter locations and subsequent associations/interpretations that are made regarding faults and tectonic features of the region.
Limitations	Station distribution is entirely onshore (See Figure 2). Most of the San Simeon fault and the entire Hosgri fault zone (and Santa Maria Basin) lie offshore to the west of the network coverage. While ample background is provided documenting the history of network development onshore, no discussion is provided of possible biases (if any) in offshore event locations and magnitudes due to their locations outside of the network. This issue plagued early seismological investigations of offshore earthquakes in this region and was exacerbated by poor velocity models at that time.
Comparisons/ Implications	This study was performed in association with Lettis et al. (2004; Title 26) and Hanson et al. (2004, Title 28). This work cites these other papers with a pre-published year of 2001. The tectonic model for the study region is the same among the trilogy of papers. The proposed model is the most compelling to date due to the broad range of geoscience evidence that has been brought to bear and the consistency among the various lines of evidence that have been presented. This paper focuses on the seismicity aspect of the tectonic model. Interestingly, these authors avoid any implications of subordinate lateral displacements between the blocks of the Los Osos domain and only refer to these block boundaries as accommodating shortening (reverse) displacements. As previously mentioned under the other two papers, a kinematic model of block rotation in the Los Osos domain driven by clockwise rotation of the western Transverse Ranges to the south implies subordinate sinistral slip along the block boundaries in the Los Osos domain. Apparently, however, only dextral components of slip have been observed in the block-bounding seismicity to date.

Title 27	Quaternary Tectonic Setting of South-Central Coastal California
Year	2004
Study Area	South-central California coast and near offshore
Authors	W.B. Lettis, K.L. Hanson, J.R. Unruh, M. McLaren, W.U. Savage
Source	USGS Bulletin No. 1995, Evolution of Sedimentary Basins/Offshore Oil and Gas Investigations – Santa Maria Province, Chapter AA, 21 p.
Scope	Geological, seismological and geophysical synthesis of the triangular region bounded by the San Simeon-Hosgri fault system, the southern Coast Ranges and the western Transverse Ranges, (informally named the "Los Osos domain") to ascertain the kinematics of Quaternary deformation.
Data Used	Results from previously published investigations that include: *Onshore*: marine terrace mapping; fault zone geological studies; borehole and water well records; aerial photography; seismic reflection data. *Offshore*: near-shore bathymetry, high-resolution shallow seismic reflection, side-scan sonar, deep (2-4 sec) seismic reflection, bottom sampling. In addition, instrumental seismicity, deep-crustal seismic reflection and refraction, and plate kinematic data.
Methodology	Synthesis of a wealth of existing data based on authors' experience.
Summary Results	1. Locations of active and potentially active faults in the Los Osos domain are compiled at a scale of 1:250,000. 2. Active and potentially active north-west-trending reverse faults partition the domain into distinct structural blocks. 3. These reverse faults and localized folds accommodate northeast-directed crustal shortening across the domain while the block interiors exhibit little or no deformation. 4. Hangingwall blocks are uplifted at rates of up to 0.2 mm/yr while footwall blocks are either static or subsiding at rates of 0.1 mm/yr or less. 5. Cumulative shortening across the northern domain is 1-2 mm/yr. Cumulative shortening across the central and southern domain is poorly constrained but may be as much as 2-3 mm/yr. 6. Seismicity is associated with the uplifted blocks and the high-angle border reverse faults to about 10 km deep.

	7. Geological, seismological, and deeper crustal geophysical imaging indicate that the reverse faults penetrate the entire brittle crust at a high angle. The base of the brittle crust may be a decollement or mid-crustal detachment into which the reverse faults root. 8. The Los Osos domain is structurally detached from the offshore Santa Maria Basin along the San Simeon-Hosgri fault zone. Crustal shortening west of the San Simeon-Hosgri (the Santa Maria Basin) is occurring at only one-tenth the rate or less than is occurring in the Los Osos domain. 9. Post-Miocene clockwise rotation of the western Transverse Ranges along the southern boundary is accommodated by northeast-directed crustal shortening across the Los Osos domain.
Strengths	A compelling synthesis that brings together a broad range of existing geological, geophysical and seismological data and interpretations in a coherent model of Quaternary deformation.
Limitations	A limited number of seismological focal mechanisms from small earthquakes that appear to be spatially associated with proposed reverse faults of the Los Osos domain block boundaries indicate a dextral (right-lateral) slip component when the deformational model implies that these faults should exhibit a component of sinistral (left-lateral) slip.
Comparisons/ Implications	The Quaternary kinematic model from this synthesis fits well with, and expands upon, the kinematic model proposed by Sorlien et al. (1999) (Title 25) that was based on retrodeformed post-Miocene structure contour maps. Both papers conclude that the Hosgri fault is a steeply dipping dextral strike slip fault through the brittle crust that might root into a mid-crustal decollement or detachment surface.

Title 28	Style and Rate of Quaternary Deformation of the Hosgri Fault Zone, Offshore South-Central California
Year	2004
Study Area	Near-shore south-central California
Authors	K.L. Hanson, W.R. Lettis, M.K. McLaren, W.U. Savage, N.T. Hall
Source	USGS Bulletin No. 1995, Evolution of Sedimentary Basins/Offshore Oil and Gas Investigations – Santa Maria Province, Chapter BB, 33 p.
Scope	A complimentary study to Title 002 by mostly the same authors that provides more detailed analyses and data syntheses specific to faults of the Hosgri fault zone.
Data Used	Shallow high-res and deep crustal seismic reflection, geologic and geomorphic data, near-coastal seismicity, tectonic kinematic data, worldwide analogous fault zones.
Methodology	Synthesis of a wealth of existing data based on authors' experience.
Summary Results	1. The Hosgri fault zone is a convergent right-slip (transpressional) fault exhibiting deformational features characteristic of slight changes in strike relative to northeast-oriented compressive tectonic stress. 2. Quaternary slip rate is 1-3 mm/yr 3. Strike-slip faulting is indicated by the long, linear, narrow zone of faulting; kinematically consistent restraining and releasing bends and features with right lateral strike-slip; asymmetric flower structures; changes in sense and magnitude of vertical separation along trend and vertically within the fault zone; strike-slip focal mechanisms within the fault zone; a distribution of seismicity that delineates a high-angle fault through the brittle crust; high ratios of vertical-to-horizontal (V/H) slip; separation of the Santa Maria Basin and Los Osos domain that are undergoing different styles of deformation and orientations of crustal shortening. 4. Net slip of 1-3 mm/yr is transferred from the San Simeon fault to the Hosgri in the north probably decreases southward as it is consumed by shortening along more west-trending faults and folds in the Los Osos domain. 5. Based on deformation of a Pliocene unconformity, a compressional component of slip also exists along the Hosgri in the present tectonic setting, consistent with implications of relative plate motions that suggest the Hosgri is in a

	transpressional tectonic environment. 6. Post-Pliocene vertical slip rates across the Hosgri range from 0.1-0.4 mm/yr, but may be as high as 0.44 mm/yr if the rate of right-slip is greater than 1 mm/yr.
Strengths	A well-reasoned, compelling synthesis that brings a broad range of existing geological, geophysical and seismological data and interpretations to bear in a coherent model of deformational and displacement styles exhibited along the Hosgri fault system.
Limitations	Lateral displacements in and out of section are, at best, difficult to identify in seismic reflection data along strike-slip fault zones. Authors provide discussion of this topic and are mindful of this limitation in the seismic reflection data.
Comparisons/ Implications	Hosgri fault system tectonic model is consistent with the Los Osos domain tectonic model of Title 27 and serves to refine the kinematics of previous model block boundaries in the south-central California offshore that provided in Title 25. The interpretation of changing structural style of the Hosgri fault in a convergent wrench tectonic system ameliorates previously contradictory interpretations of thrust/reverse and strike-slip faulting along the zone.

Title 29	Diablo Canyon Spent Fuel Storage Installation (ISFSI) Safety Analysis Report (SAR)
Year	2002
Study Area	10-mile radius of the DC site (i.e., DC site region)
Authors	PG&E
Source	2.6. Geology and Seismology; ISFSI SAR Amendment 1, October 2002
Scope	Description and evaluation of geologic and seismologic conditions in the site region
Data Used	Geologic and seismologic data for the DC power plant including the LTSP with further geotechnical/geologic investigations for the ISFS and CTF sites
Methodology	Description and evaluation of information in compliance with Appendix A of 10 CFR 100, and 10 CFR 72.102
Summary Results	1. The ISFSI and CTF sites are approximately the same distance from the Hosgri fault zone, the controlling earthquake source for the DC power plant. The foundation conditions and ground motion response characteristics are the same as those at DCPP. 2. Because the ground-motion response characteristics at the ISFSI are the same as those at the DCPP, the DCPP earthquake ground motions are appropriate for use in the licensing of the ISFSI, in accordance with 10 CFR 72.102(f). 3. Because the ISFSI pad sliding, slope stability and stability of the transporter are affected by longer-period ground motions than those characterized by the DCPP ground motions, response spectra having a longer-period component were developed that incorporates the near-fautl effects of rupture directivity and fling. 4. Several minor bedrock faults were observed at the ISFSI and CTF sites. These minor faults are not capable. There is no potential for surface faulting at the ISFSI or CTF sites. 5. The bedrock that underlies the ISFSI and CTF sites has sufficient capacity to support the loads imposed by ISFSI pads and casks and the CTF without settlement or differential movement. 6. There are no active landslides or other evidence of existing instability at the ISFSI and CTF sites, or on the hillslope above the site. 7. The slopes have ample factors of safety under static conditions. The cutslope above the ISFSI site may experience local wedge movements or small displacements if exposed to the DBE. Mitigation measures to address these movements are developed.

	8. The transport route follows existing paved roads, except for a portion of the route that will be constructed to avoid a landslide at Patton Cove along the coast. The route will have foundation conditions satisfactory for the transporter. Small debris flows could potentially close portions of the road during or immediately following severe weather. Because the transport route will not be used during severe weather, the flows will not be a hazard to the transporter.
Strengths	Augmentation of long-period motions specifically for facilities for the ISFSI and inclusion of transport route geologic hazards
Limitations	Much DCPP material is included by reference and not directly available herein
Comparisons/ Implications	Seismic hazard assessment and design earthquakes are adopted from DCPP with augmentation at long periods accounting for near source effects.

Title 30	A Kinematic Model of Southern California
Year	1986
Study Area	Southern California offshore to the San Andreas Fault
Authors	R. Weldon and E. Humphreys
Source	Tectonics, Vol. 5, No. 1, p. 33-48
Scope	A kinematic model based on late Quaternary fault slip rates and orientations of major faults in the region.
Data Used	Quaternary fault slip rates from various authors, major mapped faults of southern California, and tectonic plate velocities from trilateration networks in southern California.
Methodology	Velocities of tectonic blocks are calculated along several paths in southern California that begin in the Mojave Desert and end off the California coast.
Summary Results	1. The existence of a zone of active deformation in southern California that is interpreted to include the western Transverse Ranges and northwest trending, predominately strike-slip faults close to the coast both north and south of the Transverse Ranges. 2. Strain on this system accounts for about a third of the total North American-Pacific plate motion. 3. The kinematic model developed is a block model of the upper crust (upper 10 km) and assumes that no deformation occurs within the interior of the blocks. 4. Convergence in the western Transverse Ranges is due to a left step in the coastal system faults, and is unrelated to the San Andreas fault. 5. The magnitude of the offshore activity (seismicity) implies that the region between the San Andreas Fault and the coastal system is neither part of the North American plate nor the Pacific plate and may be considered a miniplate.
Strengths	Provides a regional context to the style of fault movements and their relation to published fault slip rates and tectonic plate velocities.
Limitations	The major uncertainties in the tectonics of southern California are due to motion external to the region modeled. The opening of the Great Basin appears to control the motion of the Sierran block, which in turn controls

	then amount of convergence along the central California coast.
Comparisons/ Implications	The primary tectonic elements of Southern California are major block-bounding strike-slip faults. One third of the plate tectonic motion is assumed to be distributed on the faults of the western Transverse Ranges and northwest-trending, predominately strike-slip faults close to the coast both north and south of the Transverse Ranges.

Title 31	Crustal Strain Partitioning: Implication for Seismic-Hazard Assessment in Western California
Year	1991
Study Area	Western central California
Authors	W.R. Lettis and K.L. Hanson
Source	Geology, Vol. 19, p. 559-562
Scope	A theoretical study to delineate seismogenic surface faults from non-seismogenic faults for use in seismic hazard analysis.
Data Used	Geologic and geomorphic data, seismicity, tectonic kinematic data, worldwide analogous fault zones.
Methodology	Synthesis of a model to determine seismic and non-seismic sources for inclusion to seismic hazard analysis.
Summary Results	1. The concept of strain partitioning affects the assessment of seismic hazard primarily with respect to the identification and characterization of seismic sources. Critical to this assessment is the scale of partitioning and whether structural features should be treated as individual seismic sources or collectively as a single seismic source. 2. Oblique strain in the lower lithosphere may partition upward in the brittle curst into nearly pure strike-slip and dip-slip deformation, the dip-slip component being expressed as reverse faults and folds. 3. Depending on the depth of partitioning, these partitioned structures may be independent regional sources of seismicity or they may be dependent local structures above a single seismic source at depth. 4. The upper seismogenic part of the lithosphere is divided into a region of low-moment release and a few large earthquake above 5 km depth, and a region of high-moment release during large earthquakes below 7 km depth, separated by a 2 km thick zone transition zone from 5-7 km depth.. 5. Faults in western California confined to the upper crust above a depth of 5 to 7 km are capable of releasing small earthquakes, not larger events. These faults are located within a zone of less than 3 to 6 km from a main seismogenic fault (i.e. San Andreas Fault) and are dependent on movement on the main seismogenic fault.

	6. Faults that originate deeper that 5 to 7 km generally extend more than 3 to 6 km from the main seismogenic fault are considered independent seismic sources.
Strengths	A general guideline for determining seismic source parameters to be cinsidered in seismic hazard analysis with possible application to some of the offshore fault zones in southern California.
Limitations	Usefulness of application outside of California is dependent on locally available geological and seismological data and its quality.
Comparisons/ Implications	The dependent and independent nature of subsidiary faults to main seismogenic faults could affect the nature of fault modeling for the proposed blind thrust under the San Joaquin Hills that has been proposed in Titles 32, 37, and 38.

Title 32	Neotectonic Uplift and Ages of Pleistocene Marine Terraces, San Joaquin Hills, Orange County, California.
Year	1992
Study Area	San Joaquin Hills, Orange County, California
Authors	D. Barrie, T.S. Tatnall, and E. Gath
Source	The Regressive Pleistocene Shoreline, Southern California: South Coast Geological Society, Inc. Annual Field Trip Guide Book No. 20. Heath, E.G. and Lewis, W.L, (eds.), p. 115-122.
Scope	Establishing the age and tectonic uplift rates for of the northern San Joaquin Hills
Data Used	Marine terrace ages included oxygen-isotope chronology, amino acid racemization, zoogeographic signatures, geomorphic correlation, and comparison of shoreline angle elevations with a paleo-sea level curve.
Methodology	The study of the attitudinal spacing of a suite of uplifted (emergent) marine terraces makes is possible to draw conclusions about marine terrace ages and tectonic uplift in coastal areas.
Summary Results	1. Investigation of a locally well-preserved suite of elevated marine terraces on the western flank of the San Joaquin Hills between Newport Beach and Laguna Beach indicates a uniform uplift rate of approximately 0.25 m/1000 years. 2. Terrace ages range from about 80,000 years for the lower (18 m) terrace to about 1,230,000 years for the upper (335 m) terrace. 3. All terrace platforms exhibit seaward dips comparable to modern wave-cut platforms, suggesting little or no progressive seaward rotation during Pleistocene time indicating that the uplift was nearly vertical with no folding of the San Joaquin Hills. 4. Assuming a constant uplift rate, the San Joaquin Hills became emergent as a positive topographic feature approximately 1,230,000 years.
Strengths	Documentation that where the Newport-Inglewood fault is very close to, or comes on shore (just north of the San Joaquin Hills), there has been a persistent uplift that has lasted 1.23 million years. The uplift of the San Joaquin Hills seems to have been nearly vertical, because all the terrace platforms exhibit seaward dips comparable to modern wave-cut

	platforms that would rule out folding as the mechanism of uplift.
Limitations	The process of uplift that persists for 1.23 million years without deformation or rotation of the marine terraces remains unclear.
Comparisons/ Implications	The authors of Title 37 determined that San Joaquin Hills are an anticline and therefore deformation of the marine platforms is required.

Title 33	The Cristianitos Fault and Quaternary Geology, San Onofre State Beach, California.
Year	1992
Study Area	San Onofre State Beach, California
Authors	R. J. Shlemon
Source	The Regressive Pleistocene Shoreline, Southern California: South Coast Geological Society, Inc. Annual Field Trip Guide Book No. 20. Heath, E.G. and Lewis, W.L, (eds.), p. 9-12.
Scope	Determining the age of the last movement on the Cristianitos Fault that is in close proximity to the SONGS site.
Data Used	Geologic field observations and dating of sediments using marine isotope dates along with amino-acid and uranium-series age dates.
Methodology	Geologic field observations.
Summary Results	1. The Cristianitos fault is overlain by about 3.3 ft. of marine gravels and sands and does not offset the marine deposits. 2. Mollusks collected from the overlying marine deposits are of a late Sangamon (marine isotope substage 5e) about 125,000 years old. 3. The marine sediments have also been dated using amino-acid and uranium-series methods from this and other localities on the southern California coast confirming the age of the marine deposits. 4. Because these marine deposits are clearly not offset by the Cristianitos fault, last displacement took place at least 125,000 years ago and most likely well before that time.
Strengths	A compelling set of geologic field observations that limits the last age of movement on the Cristianitos fault to happening at least 125,000 years ago.
Limitations	None
Comparisons/ Implications	The determination that the Cristianitos fault has not been active in the last 125,000 years removes it from being considered as an active fault for both local surface offset and seismic hazard calculations.

Title 34	Late Quaternary Geology of the Dana Point-San Onofre-Carlsbad Margin, California
Year	1992
Study Area	Dana Point to Carlsbad, California
Authors	P.J. Fischer, D.S. Gorsline, and R.J. Shlemon
Source	South Coast Geological Society, Inc., 1992 Annual Field Trip Guide Book No. 20, "The Regressive Pleistocene Shoreline Coastal Southern California", E.G. Heath and W.L. Lewis, eds., p. 195-218.
Scope	Tectonics and sedimentary history of Dana Point to Carlsbad, California
Data Used	Seismic reflection profiling and borehole data.
Methodology	Synthesis of the data into a Late Quaternary deformational model specific to the Dana Point to Carlsbad continental margin, California.
Summary Results	1. Late Quaternary sedimentary history of the coastal shelf from Dana Point to Carlsbad, California 2. From Newport Beach 43 km south to Las Pulgas Canyon (10 km south of San Onofre) the Newport-Inglewood fault zone is narrow (about 500 meters or less in width). From seismic reflection profiles the fault is a positive flower structure. 3. Activity on the Newport-Inglewood fault decreases southward from Newport Beach, where Holocene faulting and related seafloor "bowing" are present. At Dana Point the last fault activity was some 5,500 years ago. At San Mateo Point Holocene sediments are not displaced. 4. "Near San Onofre, Holocene faulting and related bowing and displacement of the shelf surface are present along the Newport-Inglewood fault, in direct contrast to the findings of Southern California Edison's study for San Onofre Nuclear Generating sites 2 and 3. This active part of the Dana Point segment was named the San Onofre subsegment by Fischer and Mills (1991)"
Strengths	Sedimentary history of the shelf from Dana Point to Carlsbad, California was the main focus of the paper. Tectonics was a minor part.
Limitations	A line drawing from Fischer and Mills (1991) of a seismic reflection section directly adjacent to San Onofre that is included in this paper shows the Newport-Inglewood fault with approximately 150 meters of

	undeformed Holocene sediments overlying the fault. Contrary to the conclusions in this paper, this figure indicates that there is no faulting and related bowing present for at least as long as it took to deposit 150 meters of sediment across the fault.
Comparisons/ Implications	A contradiction exists between the conclusions of the paper and the seismic reflection data illustrated in the paper.

Title 35	Holocene Activity of the Rose Canyon Fault Zone in San Diego, California
Year	1995
Study Area	San Diego, California
Authors	S.C. Lindvall and T.K. Rockwell
Source	Journal of Geophysical Research, Vol. 100, No. B12, pp. 24,121-24,132
Scope	Determination of slip-rate, recurrence interval, and sense of slip for the onshore segment of the Rose Canyon Fault in San Diego, California over the last 10,000 years of activity
Data Used	Stereo air photo analysis, 3-D fault trenching, ^{14}C radiometric age dating, geomorphology, and total station surveying.
Methodology	Fault location using stereo aerial photography and 3-D trenching of identified surface fault traces to determine slip-rate, recurrence intervals, and sense of slip for the onshore segment of the Rose Canyon Fault.
Summary Results	1. Trenches across the Mount Soledad strand of the onshore Rose Canyon Fault demonstrate a minimum of 8.7 meters of right-lateral strike slip displacement on a distinctive gravel-filled channel that crosses the fault zone. 2. Radiocarbon dates on detrital charcoal from beneath the gravel filled channel yield a maximum age of about 8,100 ± 200 years. 3. Stratigraphic evidence from the trenches that indicate that the 8.7 meters of offset of the gravel-filled channel was the result of three different surface faulting events. 4. The most recent surface rupture displace the modern soil, suggesting that this event probably occurred within the past 500 years. 5. The minimum slip rate of 1.07±0.03 millimeters per year was determined from the trench site. Taking into account limiting factors at the site the authors estimate a maximum slip rate of 2 mm/yr and a best estimate of 1.5 mm/yr. 6. Stratigraphic and structural relationships observed in the trenches suggest the return time for surface-rupturing earthquakes is no more than about 4 thousand years.
Strengths	This is a good example of basic paleoseismological research that is needed for developing a broader regional tectonic picture. Authors present their results with a clear description of the limitations of the data and interpretation.
Limitations	Extrapolating the slip rate determined at the trench site for the Rose Canyon Fault to the offshore Newport-Inglewood Fault to where the two

	faults meet offshore north of San Diego. The authors did not make this extrapolation, but others have.
Comparisons/ Implications	If the Rose Canyon and Newport-Inglewood fault are considered to be extensions of the same fault system, then the slip rate for the Rose Canyon in this study can be applied to the offshore segment of the Newport-Inglewood fault.

Title 36	Paleoseismicity of the North Branch of the Newport-Inglewood Fault Zone in Huntington Beach, California, from Cone Penetrometer Test Data
Year	1997
Study Area	Huntington Beach, California where the Newport-Inglewood Fault comes onshore.
Authors	L.B. Grant, J.T. Waggoner, T.K. Rockwell, and C. von Stein
Source	Bulletin of the Seismological Society of America, Vol.87, No. 2, p. 277-293.
Scope	Detailed geological investigation of the Newport-Inglewood fault zone including surface geological mapping and paleoseismic investigations.
Data Used	Original field geologic studies, soil borings, radiocarbon age dates, seismic reflection profiles, and cone penetrometer data.
Methodology	Cone penetrometer data were used to establish different stratigraphic horizons and the depth of the stratigraphic horizons across a previously mapped trace of the Newport-Inglewood onshore at Huntington Beach area. Soil borings were taken at specific locations to correlate the cone penetrometer data and to also obtain organic material for radiocarbon age determination.
Summary Results	1. The Newport-Inglewood fault zone at the study site has generated at least three and most likely five recognizable surface ruptures in the past 11,700 ± 700 years. 2. The minimum right-lateral Holocene slip rate of the Newport-Inglewood Fault at the site is estimated to be 0.34 to 0.55 mm/yr. The actual slip rate may be significantly higher. 3. Mapped surface trace of the Newport-Inglewood fault at the study site is graben structure produced by a right step in a right-lateral strike-slip fault.
Strengths	Documentation of the presence, location, and the number of faulting events during the last 11,700 years for the Newport-Inglewood Fault where it comes onshore at Huntington Beach.
Limitations	Estimates of slip rates for the studied faults rely on data published in an abstract from another researcher.
Comparisons/	Although this region of the Newport-Inglewood fault had previously been identified by other investigators, these authors used a proven

Implications	geotechnical investigation method (cone penetrometer) to help identify the location, number of faulting events, and slip-rate for the onshore segment of the Newport-Inglewood fault.

Title 37	Late Quaternary Uplift and Earthquake Potential of the San Joaquin Hills, Southern Los Angeles Basin, California
Year	1999
Study Area	San Joaquin Hills, Orange County, California
Authors	L.B. Grant, K.J. Mueller, E.M. Gath, H. Cheng, R.L. Edwards, R. Munro, and G.L. Kennedy
Source	Geology, Vol. 27, No. 11, p. 1031-1034.
Scope	Analysis of emergent marine terraces in the San Joaquin Hills with implications for paleo-earthquake magnitudes
Data Used	^{230}Th dating of corals found on marine terraces and geologic field examination of uplifted marine terraces using geotechnical investigations, borings, natural exposures and topography.
Methodology	Synthesis of the data into a descriptive model that employs a blind thrust fault beneath the San Joaquin Hills to account for the uplift of the area for a period of 122,000 years.
Summary Results	1. The late Quaternary uplift rate, anticlinal structure, and indications of Holocene uplift imply that the San Jooaquin Hills are the surface expression of an active contractile fold formed above a potentially seismogenic thrust fault. 2. A fault-bend fold model with movement on a northeast-vergent thrust best explains the elevation of marine terraces on the northeast limb of the San Joaquin Hills anticline. 3. The magnitude of a maximum credible earthquake is estimated by assuming that the San Joaquin Hills thrust extends to the base of the seismogenic crust at 17 km, dips between 20^{o} and 30^{o}, and extends upward to within 2 km of the surface. In this interpretation the San Joaquin Hills thrust is a back thrust that soles into the Oceanside detachment as part of a wedge-thrust structure. 4. Dating of corals reveal that the San Joaquin Hills have risen at a rate of 0.21-0.27 m/1000 years during the last 122,000 years. Movement on a blind thrust fault has uplifted the San Joaquin Hills and has the potential to generate an M_w 7.3 earthquake.
Strengths	Provides a mechanism to explain the uplift of the San Joaquin Hills by a blind thrust fault that could be seismogenic. The determined uplift rate is

	in good agreement with those determined by previous workers (Title 032)
Limitations	The authors prefer to interpret movement of the San Joaquin Hills blind thrust to be the product of partitioned strike slip and compressive shortening across the southern Newport-Inglewood fault zone. If the San Joaquin Hills are the result of movement on Newport-Inglewood fault and not related to movement Oceanside thrust then the fault geometry determine in number three of the Summary Results section is in question.
Comparisons/ Implications	The determination that the San Joaquin Hills is an anticlinal fold contradicts previous findings of no folding of the marine terraces on the uplift (Title 32). Title 38 cites the San Joaquin Hills as a back thrust to the proposed Oceanside thrust fault. Yet, this paper prefer interprets the San Joaquin Hills to be related to movement on the Newport-Inglewood fault.

Title 38	Oceanside and Thirtymile Bank Blind Thrusts: Implications for Earthquake Hazards in Coastal Southern California
Year	2000
Study Area	Southern offshore California (Inner California Borderland) and coastal southern California
Authors	C. Rivero, J.H. Shaw, and K Mueller
Source	Geology, Vol. 28, No. 10, p. 891-894
Scope	Report that proposes that the Thirtymile and Oceanside low angle offshore faults of southern California are present day thrust faults that are reactivated older normal extensional faults.
Data Used	Seismic reflection profiles, digital elevation data, geologic stratigraphy, earthquake locations, and earthquake focal mechanisms
Methodology	Geologic interpretation of offshore seismic reflection profiles coupled with earthquake aftershock sequences and onshore mapping of surficial folds.
Summary Results	1. The Oceanside and Thirtymile faults in the offshore Borderland of southern California are interpreted as active thrust faults. 2. The Oceanside and Thirtymile faults originally formed as extensional detachment faults in the Miocene. 3. Large portions of these detachment faults have been reactivated to form the Oceanside and Thirtymile Bank blind thrust faults, which compose the Inner California Borderland blind thrust system in the Pliocene. 4. The Oceanside thrust dips at 14° to 25° to the northeast, occupies the surficial feature of the Coronado Banks, and extends from San Joaquin in the north southward to the international border near San Diego. 5. The onshore anticline fold of the San Joaquin Hills is at the onshore projection of the Oceanside thrust and is interpreted to be a structural wedge formed as a back thrust to the Oceanside thrust. 6. Uplift rates of 0.07-0.17 mm/yr for the Oceanside thrust were calculated and are considered to be a minimum value because they are derived from uplift rates. 7. Maximum uplift rate of 2.2 mm/yr for the Oceanside thrust is

	calculated from geodetic observations that indicate as much as 2 mm/yr of northeast-southwest convergence between Catalina Island and the coast. 8. Four possible fault interaction models are proposed for the intersection of the Oceanside and San Joaquin thrust faults with the intervening Newport-Inglewood strike-slip fault. A.) The younger strike-slip fault (Newport-Inglewood) cuts and precluding further activity on older thrusts (Oceanside and San Joaquin faults). B.) The thrust faults terminate in the strike-slip faults. C.) The thrust faults may cut the strike-slip fault zones. And D.) The thrust and strike-slip faults may merge into a single structure at depth.
Strengths	A novel reinterpretation of the tectonics of the Inner California Borderlands influenced by the 1994 Northridge earthquake that was a blind thrust in the Los Angeles basin.
Limitations	This paper sites the onshore anticline at the San Joaquin Hills is the result of back thrusting from movement on the Oceanside thrust fault. This requires the Oceanside thrust extends under the coast of California in the vicinity of San Joaquin California. Between the mapped trace of the Oceanside thrust and the San Joaquin anticline resides the mapped Newport-Inglewood strike-slip fault. If the Oceanside thrust extends eastward under the coast it then must limit the depth extent of the Newport-Inglewood fault to be above the Oceanside thrust. Projecting a 25^{o} eastward dip of the Oceanside thrust would result in the depth of the thrust to be about 7 km under the coast. This would limit the depth of the Newport-Inglewood fault to be 7 km. Continued movement on the Oceanside thrust would carry the Newport-Inglewood fault westward. Since the mapped surface trace of the Newport-Inglewood fault extends north of the surface intersection of the two faults there should be a marked right sense of displacement on the surface trace of the Newport-Inglewood fault were the two faults intersect near San Joaquin. The fault activity map of California shows no such offset in the surface trace of the Newport-Inglewood fault.
Comparisons/ Implications	This paper expains the San Joaquin Hills as the result of a back thrust to the Oceanside thrust fault. Title 37 infers that the San Joaquin Hills results from movement on the Newport-Inglewood fault. Title 41 determined the offshore portion of the Newport-Inglewood Fault extends to a depth of 13 kilometers. This would require that the Newport-Inglewood fault terminates the Oceanside Thrust since the thrust is limited to 7 km deep at the intersection with the Newport-Inglewood fault.

Title 39	A Northward-Propagating Earthquake Sequence in Coastal Southern California?
Year	2002
Study Area	Northern Baja California, Mexico, the offshore boarder lands of southern California, and the Los Angeles Basin.
Authors	L.B. Grant and T.K Rockwell
Source	Seismological Research Letters, Vol. 73, No. 4, pp. 461-469
Scope	The concept of stress transfer and earthquake triggering along strike slip faults has been documented for the North Anatolian Fault in Turkey. The authors suggest that an analogous rupture sequence spanning the last few centuries may be in its later stages along southern California coastal faults.
Data Used	Historic seismicity, paleoseismic investigations, and radiocarbon age dating.
Methodology	Analysis of historic seismicity and paleoseismic investigations along the entire length of kinematically linked faults (Coastal Fault Zone) to determine if there is a temporal sequence of propagating fault movement.
Summary Results	1. Recently published fault investigations in the northern Baja California peninsula (Mexico) and coastal southern California (USA) reveal evidence for geological contemporaneous or sequential earthquakes along a > 300-km-length, predominantly strike-slip zone. This coastal fault zone includes structures previously mapped as the Agua Blanca, Rose Canyon, San Joaquin Hills, and southern Newport-Inglewood Fault zones. 2. Radiocarbon dating and historic records indicate that moderate to large earthquakes occurred after A.D. 1640 ± 160 on the Agua Blanca fault, 1523 to 1769 on the Rose Canyon fault, 1635 – 1855 on the San Joaquin Hills fault, and a Mw 6.4 earthquake in 1933 on the southern Newport-Inglewood fault. 3. The 1933 earthquake on the southern Newport-Inglewood fault increased the Coulomb stress on the northern Newport-Inglewood zone in the Los Angeles basin. 4. The date of the last surface rupture of the northern Newport-Inglewood Fault (Los Angeles basin) is not known. 5. A sequence of moderate magnitude earthquakes in late 2001 in the Los Angeles basin suggests the possibility that the northern Newport-Inglewood fault zone is close to failure and that a future earthquake on this fault segment may culminate a multi-century

	northward-propagating sequence of earthquakes.
Strengths	Compares the 300-km-long strike-slip fault zone of the Agua Blanca, Rose Canyon, San Joaquin Hills, and Newport-Inglewood fault zone of southern California and northern Mexico to the North Anatolian strike-slip fault of Turkey. Stress transfer and earthquake triggering have been documented on the North Anatolian Fault with a historic sequence of earthquakes that progressed from east-to-west with time along the fault.
Limitations	The authors imply that the San Joaquin Hills are a structural part of the 300-km-long strike-slip fault zone. The San Joaquin Hills are to the east of the mapped trace of the Newport-Inglewood fault zone, which brings the linkage of the two structures into question. Removing the San Joaquin Hills from the analysis yields two earthquakes at the southern end of 300-km-zone (Agua Blanca and Rose Canyon) at about the 1600's and a 1933 earthquake on the southern Newport-Inglewood fault at the north end of the zone.
Comparisons/ Implications	The concept of stress transfer and earthquake triggering along strike slip faults would advance the clock on earthquakes in the Los Angeles Basin.

Title 40	Coastal Uplift of the San Joaquin Hills, Southern Los Angeles Basin, California, by a Large Earthquake Since A.D. 1635
Year	2002
Study Area	The San Joaquin Hills of coastal Southern California.
Authors	L.B. Grant and L.J. Ballenger, and E.E. Runnerstrom
Source	Bulletin of the Seismological Society of America, Vol. 92, No. 2, pp. 590-599
Scope	Radiocarbon dating of uplifted Holocene marsh deposits at the San Joaquin Hills, southern California indicates that the marshes were uplifted after A.D. 1635. Uplift of the marshes is attributed to tectonic movement that produced a M> 7 earthquake.
Data Used	Geomorphology, shoreline platforms, surveying techniques, pollen analysis, historic seismicity, and radiocarbon age dating.
Methodology	Analysis of uplifted marine platforms and marshes to determine the amount of and timing of the uplift event. Radiocarbon ages were derived for organic materials on the platforms and marshes to determine the age of the uplift. Surveying techniques were used to determine the amount of uplift.
Summary Results	1. Late Holocene marsh deposits and a shoreline along the coast of the San Joaquin Hills, southern Los Angeles basin, range from 1 to 3.6 meters above the active shoreline. 2. Radiocarbon dating of the marsh deposits shows that emergence occurred after A.D. 1635. 3. The age, distribution, and geomorphic expression of the elevated marsh and shoreline are best explained by tectonic uplift due to a M>7 earthquake. 4. Radiocarbon dates and the historic record of seismicity suggest the earthquake occurred between A.D. 1635 and 1855, possibly in 1769.
Strengths	Constrains a range of dates for the timing of the latest uplift event on the San Joaquin Hills anticline. The study also determines an amount for the uplift event to be between 1 to 3.6 meters.
Limitations	Although the authors state the San Joaquin Hills are an anticline, they do not present basic geologic structural data of strike and dip measurements on strata that would confirm the structure is an anticline. The authors of Title 32 (Barrie and others) indicate that uplifted marine terraces on the San Joaquin Hills are not warped away from angles that are comparable with modern wave cut terraces. This would indicate that there is no

	folding of the San Joaquin Hills and that the structure is not an anticlinal fold.
Comparisons/ Implications	Expands and refines the study of the San Joaquin Hills done by Grant and others in Title 37.

Title 41	Activity of the Offshore Newport-Inglewood Rose Canyon Fault Zone, Coastal Southern California, from Relocated Microseismicity
Year	2004
Study Area	Southern offshore California (Inner California Borderlands)
Authors	L.B. Grant and P.M. Shearer
Source	Bulletin of the Seismological Society of America, Vol. 94, No. 2, p. 747-752
Scope	Determining if the Newport-Inglewood Rose Canyon fault is a through going feature from San Diego north to Newport beach or if it is offset by the Oceanside and San Joaquin thrust faults.
Data Used	Analysis of clusters of microseismicity.
Methodology	Application of waveform cross-correlation algorithm to identify clusters of microseismicity consisting of similar events.
Summary Results	1. An offshore zone of faulting connects the strike-slip Newport-Inglewood fault in the Los Angeles metropolitan region with the strike-slip Rose Canyon fault in the San Diego region, here referred to as the offshore Newport-Inglewood Rose Canyon fault (ONI-RC). The activity and seismic potential of the ONI-RC has been the subject of debate for decades. Recent attention has focused on blind thrusts that may intersect the ONI-RC fault zone and accommodate some of the regional deformation (Titles 37 and 38). Interaction with the thrust system could limit the magnitude of earthquakes on the strike-slip faults in the ONI-RC fault zone, if they are active. 2. Two clusters of microearthquakes within the northern and central ONI-RC fault zone were identified, relocated and analyzed to examine the fault structure, minimum depth of seismic activity, and source fault mechanism. 3. The first cluster of examined microearthquakes were from a 1981 swarm of 19 M <3.0 earthquakes approximately 10 km northwest of Oceanside. Results showed that the events align along a north-northwest trend about 0.5 km long. In cross section, the events define a nearly vertical plane between 12.5 and 13.0 km depth. The strike, dip, and location of a plane fit by these events are consistent with active strike-slip faulting on the ONI-RC fault zone. 4. The second set of microearthquakes examined were from a cluster of seven events near Newport Beach in 2000 at a depth of

	6.5-7.0 km. In cross section five of the seven events are aligned in a pattern consistent with a shallow (7 km), north-northwest-striking vertical or steeply dipping active fault. 5. If strike-slip faults do not terminate the Oceanside thrust, the authors of Title 37 estimate an Mw 7.5 maximum magnitude earthquake could result from rupture of the entire thrust fault. However, the location and ~13 km depth of the Oceanside cluster suggests that the Ocean side thrust is terminated by active strike-slip faults. According to Title 37 authors, this geometry would lead to an Mw 7.3 maximum magnitude earthquake on the Oceanside thrust.
Strengths	A good study using microseismicity to determine that the Newport-Inglewood Rose Canyon fault system is a through going active strike-slip fault zone that extends to seismogenic depths of 13 km.
Limitations	None
Comparisons/ Implications	This conclusion limits the possible fault geometry relationships listed by the authors of the Title 38 paper.

Title 42	San Onofre 2&3 FSAR (Updated)
Year	2005
Study Area	320-km radius of site
Authors	Southern California Edison Company
Source	San Onofre 2&3 UFSAR, 2.0 – Site Characteristics, p. 2.5-1 - 2.5-281
Scope	Review and assessment of geological and seismological conditions and hazards for the San Onofre NPP site
Data Used	Geological/geomorphic field data, seismological network data, geotechnical boring and laboratory test data
Methodology	Analysis of original data and synthesis with existing data to establish interpretations of geological and seismic hazards at the plant site
Summary Results	1. The San Onofre site is located near the SW margin of the Peninsular Ranges geomorphic province of southern California, which is characterized by NW-trending mountain ranges that extend southward into Mexico. The Peninsular Ranges Province is physiographically distinct from the offshore basin-and-range topography of the Continental Borderland Province between Point Conception and Central Baja California. 2. The present tectonic environment within 320 km of the site is dominated by interaction between the Pacific and North American crustal plates. The Pacific plate is moving northwestward at about 6 cm/yr relative to North America. The main plate boundary extends northward from the Gulf of California and Salton Trough to Cape Mendocino with most of the interpolate motion accommodated by right-slip on the San Andreas fault. Smaller faults and a reduced order of seismicity are associated with structural adjustment away from the plate boundary. The San Onofre NPP is located 92 km (57 mi) to the southwest of the San Andreas fault. 3. The most compatible model of known geologic and tectonic conditions combines the effect of the interference of the Pacific and North American plate motions due to the bend in the San Andreas fault at the Transverse Ranges, and the variable rates of crustal spreading in the Gulf of California. This model accommodates the compressive stress field in the Transverse Ranges, which would block the northward motion of the crust immediately to the west of the San Andreas system and would require right-lateral shear motion to be concentrated on faults to the east and west of the Transverse Ranges. This could be occurring on the San Clemente or Coronado Banks faults to the west and on the San Andreas, San Jacinto, and Elsinore faults to

	the east. In this manner a lower stress field would exist south of the Transverse Ranges in the area of the hypothesized Offshore Fault Zone. This suggested lower stress field is consistent with the observed lower degree of activity and low total offset on the hypothesized Offshore Fault Zone as compared to faults to the east and probably to the west. 4. The 32-km-long (20 mi) Christianitos Fault is located approximately 0.8 km (0.5 mi) south of Units 2&3 and forms the eastern boundary of the Capistrano Embayment. The fault dies out offshore into a series of folds. The last movement on the fault is limited by undisturbed marine terrace deposits that have been dated at 125,000 years old. The fault is therefore not a capable fault as defined by 10CFR100, Appendix A. 5. The Newport-Inglewood Fault Zone (NIFZ), the South Coast Offshore Fault Zone (SCOFZ), and the Rose Canyon Fault Zone (RCFZ) are structural components of a hypothetical continuous zone of capable faults within 8 km (5 mi) of the site. The US Geological Survey (USGS) expressed an opinion that these three structural components of the trend cannot be dissociated. Southern California Edison contends that the hypothesized Offshore Fault Zone comprises independent faults zones that are dissociated based on structure, trend, and strain pattern differences between the three components. They note that the NIFZ terminates at the compressive San Joaquin Structural High where local faults exhibit reverse movement. Fault styles on opposite sides of the South of the San Joaquin Structural High were produced by different strain patterns and are not directly associated. The 40-km-long South Coast Offshore fault was active after the San Joaquin Structural High was formed. Differences in timing of movements and tend serve to dissociate the SCOFZ from the Rose Canyon Fault zone to the south. 6. The 1933 Long Beach earthquake, M 6.3, occurred on the northern part of the hypothesized Offshore Fault Zone, which is the Newport-Inglewood fault zone. No historical seismicity is associated with the central part offshore of SONGS. The southern part, the Rose Canyon fault, has not been associated with earthquakes greater than M 4.0. No historically reported earthquakes can be reasonably associated with faults within 5 miles of the site. 7. The apparent alignment of structural features offshore along the southern California coast has resulted in the hypothesis of a continuous Fault Zone, extending from the Santa Monica Mountains to Baja California for a distance of 200 km (125 mi) or more. Extensive geophysical investigation indicates that the hypothesized OFZ is in actuality composed of three structural features; from north to south: The Newport-Inglewood Fault Zone (NIFZ), South Coast Offshore Fault Zone, and Rose Canyon fault zone. In the interest of conservatism, the hypothesized OFZ has been evaluated as a continuous Fault Zone capable of

	generating significant shaking at the site. The hypothesized OFZ quantitative earthquake potential has been based on the conservative assumption that the maximum earthquake which could occur anywhere along the length of the zone could occur offshore of the SONGS site at the closest approach of 8 km (5 mi). Slip rate is not directly available for the OFZ. However, 0.5 mm/yr calculated for the NIFZ is considered to be conservative for the OFZ. 8. Conclusions regarding the maximum earthquake of the hypothesized OFZ are summarized as follows: Ms = 6.5 is a reasonable maximum earthquake magnitude consistent with geological and seismological features of the Newport-Inglewood Fault Zone (NIFZ). Because the NIFZ is considered to conservatively represent the earthquake potential of the hypothesized OFZ, transferring Ms = 6.5 to the OFZ provides a degree of conservatism for the maximum magnitude estimate for the OFZ opposite the site. However, based on incorporation of additional conservatism through evaluation of ranges in the slip-rate data and review of other elements for assessing the degree-of-fault-activity of the hypothesized OFZ, the most conservative maximum magnitude is Ms = 7.0. A larger earthquake is inconsistent with the geological and seismologic features of the hypothesized OFZ and is therefore not credible. 9. 56 earthquake records were selected to correspond closely to the conditions of the estimated maximum earthquake and analyzed to develop the 84^{th}%-tile spectrum for Ms = 6.5 and carefully extrapolated to Ms = 7.0. The resulting 0.67 g bedrock acceleration is conservative based on subsequent work that developed Ms = 7.0 as the maximum magnitude on site-specific analysis of empirical data showing a corresponding peak instrumental acceleration of 0.63 g. Comparison to the Design Basis Earthquake (DBE) of empirical response spectra scaled to 0.67 g shows that the DBE time history used for the site is much more severe than the scaled real earthquake records, which include acceleration spikes up to 0.75 g.
Strengths	Compilation and synthesis of wide range of geological, geophysical and seismological data to assess hazards at the SONGS site with interpretations that acknowledge uncertainty in the data and accommodate alternate, conservative hypotheses.
Limitations	Newer concepts of possibly widespread compressive thrust faults in the Continental Borderland Province offshore and at the southern end of the NIFZ are not addressed in the UFSAR, but are subsequently investigated with respect to ground motion hazard implications in more recent probabilistic seismic hazard analyses in 2001.
Comparisons/ Implications	Historical regulatory document.

Title 43	Seismic Hazard At Son Onofre Nuclear Generating Station
Year	1995
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Risk Engineering, Inc.
Source	Report for Southern California Edison Co.
Scope	Assessment of annual probabilities of exceedance for spectral accelerations at SONGS incorporating seismological and fault data including representation of data variability and modeling uncertainty for application in IPEEE vulnerability assessments
Data Used	Southern California earthquake data from USGS, NOAA, and California Institute of Technology, length-width-depth dimensions of active faults with slip-rate data, five published strong-motion attenuation relationships
Methodology	Logic-tree probabilistic seismic hazard assessment implementing fault and area seismic sources
Summary Results	1. The hypothesis of a nearby fault (either connected to the Newport-Inglewood or the Rose Canyon-SCOFZ faults) dominates the hazard for the larger ground motions (spectral accelerations ≥ 0.15 g). At lower ground motions the San Andreas, Elsinore and San Jacinto faults contribute most to the hazard. Area sources do not contribute much to the hazard compared to the faults. 2. 0.25 Hz (0.04-sec period) mean and median SSE spectral acceleration is determined to be 0.735 g and 0.681 g, respectively, on generic stiff soil at a return period of 7,215 years. 3. Deaggregation of the 10 Hz hazard (0.1-sec period) at the SSE level results in a magnitude 6.7 earthquake at 9.3 km from the site. Deaggregation of the 1 Hz hazard (1.0-sec period) results in a magnitude 7.0 at 17 km from the site.
Strengths	A state-of-the-art PSHA incorporating aleatory variabililty and epistemic uncertainty.
Limitations	Newer concepts of possibly widespread compressive thrust faults in the Continental Borderland Province offshore and at the southern end of the NIFZ are not addressed in the UFSAR, but are subsequently investigated with respect to ground motion hazard implications in more recent probabilistic seismic hazard analyses in Title 47.
Comparisons/ Implications	Incorporates seismic sources and earthquake parameters presented in Titles 44 through 46.

Title 44	Appendix A (to Title 43) - Seismic Source Characterization
Year	1995
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Geomatrix Consultants
Source	Report for Southern California Edison Co.
Scope	Definition of seismic sources (faults and area sources) for input to the IPEEE PSHA documented in Title 43
Data Used	Length-width-depth dimensions of active faults with slip-rate data, regional tectonic data, historical earthquakes
Methodology	Synthesis of available fault, regional tectonic, and historical earthquake data into a coherent model that describes earthquake potential of all seismic sources within 100 km of the SONGS site using a logic-tree format to incorporate modeling uncertainties
Summary Results	1. Offshore faults included the 1) the Newport-Inglewood (NI) /South Coast Offshore Fault Zone (SCOFZ)/Rose Canyon, 2) Palos Verdes-Coronado Bank-Aqua Blanca, 3) San Diego Trough, and 4) San Clemente-San Isidro fault zones. Onshore faults included the 1) Elsinore, 2) Whittier, 3) Aguanga-Agua Tibia, 4) San Jacinto, 5) San Andreas, 6) Malibu Coast-Santa Monica, 7) Hollywood-Raymond, 8) Sierra Madre, 9) Cucamonga, 10) Peralta Hills-Norwalk, 11) Temescal, and 12) La Nacion faults. Earthquake potential of buried or blind thrust faults were implicitly subsumed in regional background area seismic source zones. 2. NI fault extends 70 km from Santa Monica Mountains to offshore of Newport Beach and is a through-going zone of right-lateral strike slip in basement rocks. Two segments identified that are separated by a 2+ km-wide restraining bend north of Long Beach. The 1933 Long Beach earthquake (Ms 6.3) ruptured most of the 30-km-long southern segment. 3. Fault continuity offshore (the SCOFZ) less well known. Offshore seismic data indicate wrench-related fold and flower structure. North (43 km) and south (32 km) segments offshore are recognized with apparent subsegments in each. Holocene activity recognized in both the north and south segments. Rose Canyon fault (approx. 62 km) lies in-board of the the SCOFZ-south segment and also has a north and south segment (32 km and 24-30km, respectively). 4. NI-SCOFZ-Rose Canyon fault system modeled with two alternative segmentation hypotheses, both with equal weight. Model A assumes the NI fault zone and SCOFZ is one fault in

	which ruptures can propagate across the step-over segment boundary and the Rose Canyon fault is treated as an independent fault source. Model B assumes NI fault zone is independent from the SCOFZ-Rose Canyon combined fault source and has a lower activity rate. Model A median slip rate is 1.5 mm/yr with a range of 0.8 to 3.0 mm/yr. Model B NI model median slip rate is 0.8 mm/yr with a range of 0.1 to 1.5 mm/yr. Model B SCOFZ-Rose Canyon median slip rate is 1.5 mm/yr with a range of 1.0 to 3.0 mm/yr. Fault dips for the zone are all assumed to be 90º from the horizontal. 5. Based on uniform uplift of marine terraces in the nearby vicinity of SONGS, anticlinal folding related to blind thrust faults is not occurring thereby precluding the existence of these faults in the site region that are capable of generating significant earthquakes. Unknown sources including small-scale blind thrusts are subsumed in the area seismic sources.
Strengths	A careful synthesis of existing data related to known southern California faults.
Limitations	Existence of possible blind thrust ramps and faults are implicitly included in background area seismic source zones and not explicitly modeled.
Comparisons/ Implications	Developed models were used in the PSHA (Title 43). Subsequent explicit representation of thrust faulting models was included in a 2001 PSHA (Title 47).

Title 45	Appendix B (to Title 43) - Maximum Magnitude Distributions
Year	1995
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Geomatrix Consultants
Source	Report for Southern California Edison Co.
Scope	Establishes maximum magnitude ranges for seismic sources defined in Appendix A (Title 31)
Data Used	Fault rupture parameters of Appendix A (Title 44)
Methodology	Empirical regression analysis between magnitude and subsurface rupture length and rupture area using the Wells and Coppersmith (1994) equations
Summary Results	1. Modal values for NI-SCOFZ-Rose Canyon fault Models A and B (Title 31) are between approximately M 6.6 and 6.8 with low probability values extending up to M 7.5. 2. Southern San Andreas fault modal value is approximately 7.6 with lower probability of M 8+.
Strengths	Newest worldwide empirical correlation equations were used at the time of this study.
Limitations	Very terse treatment of the maximum magnitude topic. Tabulated values would be beneficial for recognition of exact values rather than the distribution plots that are provided. A rather unnatural division of topics related to seismic source characterization.
Comparisons/ Implications	Developed magnitude distributions were used in the PSHA (Title 43).

Title 46	Appendix C (to Title 43) - Earthquake Recurrence Relationships for Fault Sources
Year	1995
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Geomatrix Consultants
Source	Report for Southern California Edison Co.
Scope	Establishes maximum magnitude ranges for seismic sources defined in Appendix A (Title 44)
Data Used	Fault rupture parameters of Appendix A (Title 44)
Methodology	Development of exponential and characteristic earthquake recurrence frequency distributions for fault sources using the fault-rupture parameters and slip-rate estimates from Appendix A (Title 30)
Summary Results	1. Recurrence relationships established for the NI-SCOFZ-Rose Canyon are the most important to the hazard analysis due to proximity to SONGS. 2. Median estimate of M 7 recurrence frequency on the NI-SCOFZ-Rose Canyon fault scenarios is approximately 10,000 years as indicated by recurrence frequency plots.
Strengths	
Limitations	The descriptions of the NI-SCOFZ-Rose Canyon Models A and B are reversed in this text compared to the model descriptions presented in Appendix A (Title 44).
Comparisons/ Implications	Contradictory descriptions of Models A and B concerning the NI-SCOFZ-Rose Canyon fault zone in Appendix A (Title 44) and this appendix creates confusion as to which model description was actually implemented in the PSHA (Title 43).

Title 47	San Onofre Nuclear Generating Station Units 2 and 3 Seismic Hazard Study of Postulated Blind Thrust Faults
Year	2001
Study Area	Los Angeles Basin southwards to northern Baja California
Authors	Geomatrix Consultants and GeoPentech
Source	Report for Southern California Edison Co.
Scope	Logic-tree PSHA incorporating explicit models of postulated blind thrust faults in the vicinity of San Onofre as well as "near-source" directivity and fling ground motion effects
Data Used	Fault-specific geologic data, regional tectonic data and interpretations, local and region GPS data
Methodology	Logic-tree PSHA procedures incorporating three weighted seismic source models that account for blind thrust faults following a critical review and evaluation of the blind thrust hypothesis
Summary Results	1. Model 1: Assumes that the NI-SCOFZ-RC is an active strike-slip fault zone that truncates and displaces the Oceanside detachment of Rivero et al. (2000). This model is similar to Model A described in Appendix A of the 1995 PSHA (Title 31). Model 2: Allows for independent active strike-slip and blind thrust faults to be present in the inner continental borderland adjacent to SONGS. This model includes an active Oceanside blind thrust (OBT) as well as independent NI and RC strike-slip faults. Model 3: The OBT and SCOFZ-RC represent strain-partitioning above an oblique, shallow-dipping (14º - 24º) fault plane depth in the vicinity of SONGS. A maximum magnitude of M 7.6 is used with a range of slip values of 1.19 and 2.91 as given by Rivero et al. (2000). Based on critical evaluation of available tectonic and fault data, weighting of seismic source models 1, 2 and 3 in the PSHA were 0.70, 0.25, and 0.05, respectively. The very low weight given to Model 3 is based on the highly unlikely association of the oblique strike-slip component of faulting on the shallow-dipping fault plane. 2. A detailed evaluation of GPS data regarding implications of compressive strain across southern California (south of the Transverse Ranges) that could drive thrust components on generally NW-trending faults throughout the region is summarized as follows: 1) The overall patterns of relative displacement rates indicate that no compressional relative displacement fields exist behind the hanging wall of the OBT postulated as part of Model 2 and 3. 2) Both total and incremental relative displacement rates associated with 4 selected

	pairs of SCIGN GPS stations are adequately consistent with the slip rates associated with Model 1 sources. 3) Both total and incremental relative displacement rates associated with the 4 selected pairs of SCIGN GPS stations appear to become significantly inconsistent with the slip rates associated with the postulated Model 2 and 3 fault sources, with Model 3 being slightly less consistent than Model 2. 4) There may be some compressive stress occurring between some coastal areas near the SONGS site and Catalina Island. The small compressive strain that may be occurring is considered inadequate to load or drive the OBT. 5) The systematic evaluation of GPS data indicates that the weights assigned to Models 2 and 3 may be significantly lower than those used in the PSHA. 6) The absence of unaccounted compressional components in the direction perpendicular to the major strike-slip faults in the region of SONGS makes it difficult to postulate significant active thrust faults in the region. 3. When associated with 0.67g on the combined PGA hazard curve, the SSE uniform hazard spectrum from Model 1 (base result) corresponds to an annual probability of 1.74 x 10^{-4} (5,747 yrs.) and is shifted somewhat to lower frequencies than the compared to the previous IPEEE spectrum (Title 43). The equivalent IPEE annual probability is 1.39 x 10^{-4} (7,194 yrs). The previous IPEEE spectrum is significantly higher at 5 Hz. These differences are primarily due to different attenuation relationships between the studies. 4. From the study summary: 1) In general, the hazard curves, response spectra, and weighted hazard curves for the the combined OBT case are higher than those from Model 1 with the differences being greater at lower annual frequency of exceedance levels. 2) The effects of directivity appear to be no more than about a 2% increase at 1 Hz and 8% increase at 0.5 Hz for the SSE level. 3) Given the above observation and given that the evaluation of GPS data indicates that the weights assigned to Models 2 and 3 may be too high, the results of this PSHA for the combined OBT case should be conservative. 4) The effects of the fling step appear to be even less at no more than about a 2% additional increase in spectral acceleration values at 0.5 Hz and about 1% additional increase at 1 Hz. 5. The NI/OFZ/RC/OBT completely dominates the hazard for annual probabilities lower than about 3 x 10^{-3} (333 yrs return period and greater). Overall, the weighted hazard curve from this study is comparable to the SONGS IPEEE weighted hazard curve.
Strengths	A careful evaluation of the implications of proposed blind thrust faults in the vicinity of SONGS.
Limitations	Proponents of blind thrust models may disagree with weights associated with these models in the logic-tree PSHA.

Comparisons/ Implications	As a result of the fault and ground motion models in this investigation, the return period of the SSE bedrock acceleration value of 0.67 g has dropped from 7,194 years in Title 43 to 5,747 years. Safety of the SONGS power plant therefore depends on adequate engineering safety margins.