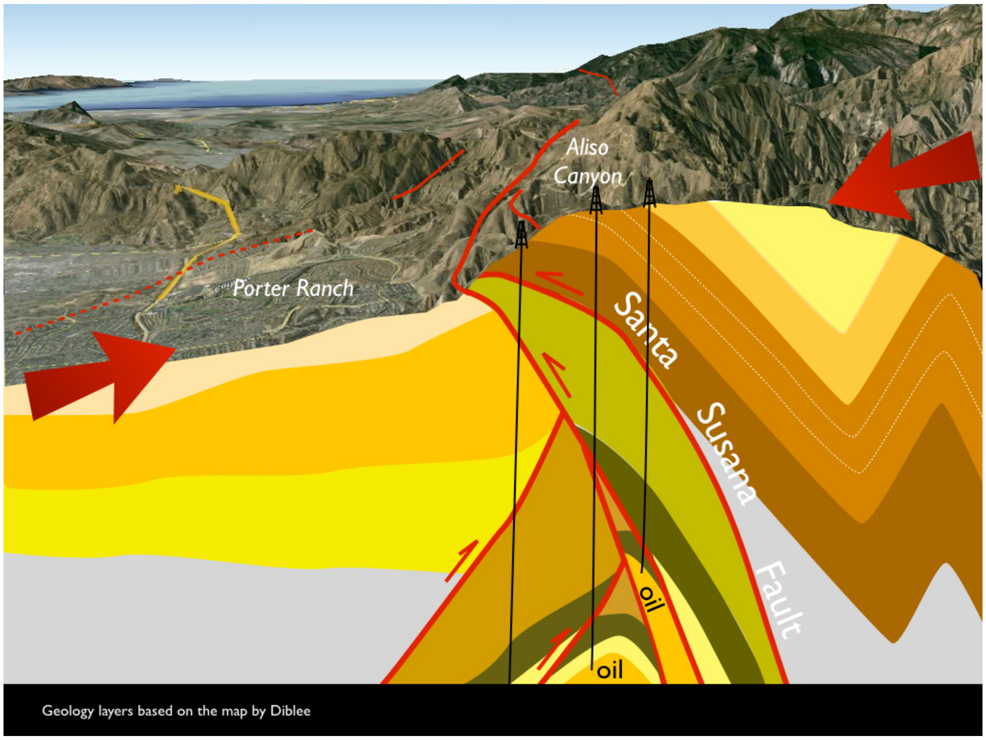

Aliso Canyon will leak in a large earthquake

Three key points:

- About **every 2,500 years**, expect the blocks to move about 6 feet and **rip every single well apart**.
- The **worst case scenario** results in an overall leakage rate from the facility **three times worse** than the 2015 blowout.
- The **most likely scenario**, according to the report's findings, actually has a leak rate **much lower** than the 2015 blowout. There are two issues with that finding: 1) Do we plan for the most likely or the worst case? And 2) I see a flaw in their assumptions that means they may not have the full picture of how likely each scenario really is. If they fix that flaw, they'd find that higher leak rates become more likely.

Summary

The Aliso Canyon Seismic Safety Study draft tells us what we already knew: that there is a significant earthquake hazard at Aliso Canyon. We can expect an earthquake every 1,000 years or so that will completely rupture the casing and tubing in about two thirds of the wells. There is a 5% chance of this earthquake happening in the next 50 years (1 in 20 odds). We expect an even bigger earthquake every 2,500 years or so that will tear every single well in two, offsetting the top of the well about 6 feet away from the bottom half. We do not know when the last earthquake has been on the Santa Susana fault, but it is likely more than 1,000 years ago.

In 2016, SoCalGas claimed that the wells sheared by an earthquake wouldn't normally leak. But when they tested models of wells in a laboratory as part of this study, they leaked in 16 out of 18 trials.

Figure 6.5. Sample 2 – Tubing Deformed by Shear Event

Figure 6.6. Sample 6 – Tubing Completely Parted by Shear Event

They then undertook detailed computer modeling to figure out how much gas will escape. Their modeling does a good job showing us the full range of scenarios from best to worst case. The best case is that all the gas remains trapped by impermeable rock underground with no leak. The worst case is that all 62 active wells fail and create leaks that add up to a flow rate three times worse than the 2015 blowout. While that worst case is extremely unlikely, many of the intermediate scenarios involve flow rates similar to the 2015 blowout, but releasing from dozens of wells simultaneously. Stopping the flow would require sealing off dozens of wells and not just one.

How probable is each scenario? That depends on what assumptions you make about the geology. While the study provides some detailed probabilities, their estimates are not realistic because they do not properly consider the fact that an earthquake will fracture the rock around the fault and will make it easier for leaks to reach the surface.

What does the report include?

The report is comprehensive and involves state-of-the-art modeling. There are actually 10 separate parts, most about a hundred pages each. Each part constitutes a couple months of work by a team of scientists.

It's done by scientists that I know and respect. These are the type of people that I think would do a good job. They are being paid by SoCalGas and refused to talk to me while they were working on the project (referring me to lawyers instead of engaging in scientific discourse), but the report they came up with is very professional and comprehensive. I look forward to the peer review process.

The report is broken up into several parts that examine what happens from one stage to the next:

Faults → Earthquakes → Well damage → Blowouts → Gas Flow

(It also includes a separate discussion of about landslides)

They address questions like: What faults are there? How often do they have earthquakes? How big are the earthquakes? How strong will the shaking be or how much will the earth shift? What will the effect of that shaking and shifting be on the wells? Will they break? When they break, how much will leak out? When the gas leaks, how fast will it flow to the surface and how quickly will it leak into the air?

Findings

Expect big earthquakes. About every 1,000 years, the study finds that the earth will shift 1-2 feet – this will be enough to rupture about 2/3rds of the wells. About every 2,500 years, expect the blocks to move about 6 feet and rip every single well apart. It's been more than 1,000 years since the last big earthquake.

When the well rips apart, it leaks. They did extensive laboratory tests where they simulated earthquakes, and the tubing leaked in 16 of the 18 cases. This shouldn't come as any surprise, but SoCalGas' Risk Management Plan Supplement #2 claimed (without evidence) that the tubing "normally does not" leak in earthquakes (p. 11). My public comment from back then said they needed to back that claim up with evidence, and now the evidence shows they were wrong.

Some of the gas will remain trapped underground... except for when it doesn't. The summary states, "Many cases show no gas flow to surface" – That's encouraging, but we don't plan for "many cases" – we should plan for the maximum credible worst case. Happily, the report writers quantify the risk for us: For a large earthquake, 10% of their model cases result in leaks about one tenth the size of the 2015 blowout. That flow rate would get released by just one single well.

There are 62 active wells that could all leak simultaneously. The worst case scenario results in an overall leakage rate from the facility three times worse than the 2015 blowout. Even I think that this worse case scenario is not very likely (all 62 wells rupture in the absolute worst possible way) and I encourage them to run similar simulations that involve a more realistic 'maximum credible' situation. I expect they will find a lower flow rate that is comparable to the 2015 blowout, but a situation that is much more dangerous because they would have to plug all 62 wells before the leak stopped. Remember how hard it was to plug one well…

Concerns. High leak rates might be more likely than they report. This is where I think they made an assumption that they shouldn't have. Read on to figure out why, but the take home message is that their model *does* a good job of describing the full range of what could happen but probably does *not* do a good job of telling us how likely each of those scenarios will be.

To estimate flow rates, they use measurements of the permeability of the rocks as they are right now. But in an earthquake, the rock around the fault gets broken up and gas can flow much more easily through all the newly opened cracks. Their flaw is not malicious but stems from a lack of scientific data – scientists have only been able to collect data rapidly enough in a few case to know how much permeability changes immediately after an earthquake. The report acknowledges this lack of data and they do consider some scenarios where the fault has high permeability to try to account for it (I'm not sure they do it well enough, but that would require more detailed investigation). But they also include the cases where the fault remains exactly the same as if there were no earthquake-related fracturing, and that seems unlikely. By mixing the unrealistic low flow cases with the realistic high flow ones, it makes it seem like low flow events are more likely than they will be in real life.

Interpretation of Detailed Quotes from the Report

Quote from the report	Everyday language translation and commentary by Professor d'Alessio
Report 3: Wellbore Landslide Loading Assessment *This part of the report answers the question, 'What happens if there is a landslide in the area?'*	
"Landslide displacements of more than 9 inches (22.9 cm) are expected to exceed the capacity of tubing in the gas storage wells."	Translation: If a landslide slides more than 9 inches, that's bad.
"Significant landslide displacements are unlikely to be supported by a typical well casing in the	Translation: A big landslide will break outer steel tube, destroying at least one of the two layers of protection.

field, and thus would lead to damage of the well."	
"Only a few gas storage wells are at potential risk in active landslide zones."	Comment: Pretty imprecise for a scientific report: How many is 'a few'? I took this quote from the summary hoping that the report would provide clarity. It does not.
Report 6: Aliso Canyon Probabilistic Fault Displacement Hazard Analysis *This part of the report answers the question, "How often do earthquakes occur on this fault?" and "How big can we expect them to be?"*	
"Exceedance displacements for the 475-year average return period range from zero to 9 cm; for the 975-return period from ≈ 50 to 70 cm; and for the 2,475-return period from ≈ 1.9 to 2.1 m."	Translation: About every 2,500 years, we expect the fault to slip about 6 feet in a sudden earthquake. This will tear all the wells apart. Earthquakes with smaller offset are more common and will happen more often.
"Estimated exceedance displacements are sensitive to the slip rates inferred for the Santa Susana fault."	Translation: We aren't entirely sure how much it will slip because we don't know enough about the Santa Susana fault. Comment: The values they used are very reasonable.
Report 7: Wellbore Loading Assessment Aliso Canyon Gas Storage Field *This part of the report answers the question, "How much will the ground shake at Aliso Canyon during the earthquakes we expect?" and "How far will the two blocks of crust shift when the Santa Susana fault moves in such an earthquake?"*	
Ground shaking summary	Overall, there is a risk of ground shaking damaging the facility, but it's not the most likely scenario or the most significant hazard. The 1994 Northridge quake was about as bad as shaking can possibly get for Aliso Canyon. In that earthquake, a single well collapsed, well SS-4O. We can expert similar results — a few well failures that may or may not result in leaks.
"At 475 ARP, mean anticipated levels of ground shaking do not exceed the capacities of any surface casing or tubing for any of the 62 operating gas storage wells. For the production casing the mean load exceeds the capacity for one well. When factoring in a range of uncertainties, the capacities of the tubing are still not exceeded, but the capacities of surface casing in 37 wells and of production casing of one well may be exceeded."	Translation: In a small earthquake, the wells will be fine because they have two layers of protection — the interior tubing and the exterior casing. The smaller earthquakes may damage the casing but not the tubing. The way they used to manage the field, this would have been disastrous. But now that they only use the tubing, a smaller earthquake will put more than half the field out of service but will not result in any major leaks or blowouts.
"At 975 ARP, mean anticipated levels of ground shaking may exceed the capacities of surface casing for 31 of the 62 wells and the production casing for one well, but do not exceed the capacities of any tubing. When factoring in a	Translation: For the next earthquake size up, one that we would expect to come about every 1,000 years, the most likely scenario is similar to above, but it is fully within the range of

range of uncertainties, surface casing capacities may be exceeded in 21 wells, production casing capacities may be exceeded in 10 wells, and tubing capacities in 7 wells."	uncertainty to have gas leaking out into the rock formation in 7 of the wells.
"At 2475 ARP, mean anticipated levels of ground shaking may exceed the capacities of surface casing for 43 of the 62 wells. The capacities may be exceeded for production casing in 5 wells and for tubing in 7 wells. When factoring in a range of uncertainties, some additional wells may exceed their capacities of surface (18) and production (41) casing, and 5 wells may exceed their capacities for tubing."	Translation: For the biggest earthquake we can imagine in this area, the results aren't much different than the medium size earthquake.
Ground Rupture Summary	Because all the wells cross the fault, this is the hazard I am most concerned about. The fault will move up to 6 feet, literally ripping the steel casing in two.
"At 475 ARP, depending upon well construction practices and fault crossing angles, it is likely that most wells' tubing capacity will not be exceeded. The anticipated levels of fault displacement may exceed the capacity of the production casing for 41 of the 62 wells. • At 975 ARP, anticipated levels of fault displacement may exceed the capacity of the production casing and tubing for 48 of the 62 wells. • At 2475 ARP, anticipated levels of fault displacement may exceed the capacity of the production casing and tubing for all wells."	For a small earthquake, the most likely outcome is that there won't be any well failures, but it does depend on some things we don't know. For a medium earthquake, 48 of 62 wells fail -- we expect an earthquake this size to happen once every 1,000 years. For a large earthquake, all 62 of the studied wells are completely compromised and gas leaks into the surrounding rocks.
Report 8: Shear Testing and Finite Element Analysis of 1:10 Scale Pipe Samples *This study answers the question, "If the fault moves 1-6 feet in an earthquake, what will that do to the steel casing and steel tubing?"*	
SoCalGas' Risk Management Plan Supplement #2 filed in October 2016 claimed (without evidence) that "The tectonically induced casing/tubing damage described above normally does not result in loss of hydrocarbon containment outside of the wellbore. Casing collapse and shear, by nature of the failure, pinches off the casing (and tubing) significantly reducing and often stopping flow potential."	Commentary: In my public comment, I challenged that claim and asked them to provide evidence for it. Thankfully, they went and did a serious and comprehensive investigation in this part of the report. Their lab simulations show that the tubing often does 'pinch off', but it cracks in other places such that it leaked in 16 of 18 trials. While sometimes that leak was not huge, other times it leaked nearly the full flow.
"Stress Engineering Services, Inc. (SES) conducted 1:10 scale shear testing of 9-5/8 in casing and 3-1/2 in tubing samples."	Commentary: I believe that since the blowout, SoCalGas has installed all new steel tubing inside each well (but not new casing in most cases). These simulations will accuartely represent fresh, new tubing. But in 10 or 20 years of continuous use, will the same yield strength

	still apply? It's not so important for the casing, since even new casing broke completely in every case in their simulation. The real barrier that we are concerned about is the tubing. How well does its material hold up?
Report 9: Well Modeling Report *This part of the report answers the question, "If a single well is sliced apart in an earthquake, how much gas will make it all the way up to the surface?"*	
"Many cases show no gas flow to surface because the tubing does not leak or the cement bond between the casing and rock formations is adequate to halt upward gas migration."	Commentary: They simulated thousands of possible leak scenarios. And in many cases, there was no leak. But we don't design for 'many' cases, we should be looking at some of the worst case scenarios.
In the set of cases (representing a 975 or 2,475 ARP type seismic event) where gas flows to the surface, average (P50) gas flow rates per well range from a few thousand to one hundred thousand standard cubic feet per day (0.01 to 0.1 MMscf/day). P90 flow cases per well are approximately 10 MMscf/day.	The most likely scenario is just a small fraction of an Aliso Canyon blowout PER WELL. Even in the worse case scenario, a single well only leaks at about 1/8th the rate of the 2015 blowout. But this finding is just an intermediate step because no single well works in isolation. The key is looking at the next report. For comparison… 2015 Blowout Peak: 80 MMscf per day.
Report 10: Aliso Canyon Dynamic Gas Flow Analysis This report answers the question, "How much will leak out of the entire facility since we expect many wells to fail at once?" It's not the same as just multiplying the previous study by 62 since each well relieves a little bit of the pressure for all the other wells.	
"Models that consider all wells damaged when operating at 3,600 psi reservoir pressure (equating to a working gas inventory of approximately 86 Bcf) and with flow governed by the P50 relationships show total gas flow to the surface from all operating wells peaking at 0.25 MMscf/day and declining quickly thereafter. Total gas releases are less than 1 MMscf over five years. Maximum flow cases for all wells using the P90 flow relationship peak at 250 MMscf/day and would release 40 Bscf over five years"	Translation: The median scenario is pretty modest with much less leaking than Aliso Canyon overall. But in 10% of the scenarios they considered, the flow rate is 3 times worse than the 2015 blowout. The total amount of gas leaking out over 5 years would be 8 times more than was released in 2015-16. 2015 blowout leaked 5.4 Bcf total (ARB, p. 5)