If you're like me, you're interested in how solar is going to change the energy landscape over our lifetimes. First order, the answer is "a shit-ton" (solar is already the cheapest energy, plus it's on track to be the majority source). Second order, there are tons of awesome, non-obvious changes that are already taking place.

The future of solar-dominated energy infrastructure resembles a weird larval organism, wriggling out of the primordial ooze, growing in the process. A few decades from now this creature will mature into a well-categorized, mature species, but its final state will only feel elegant and obvious in retrospect.

Solar and batteries are cheap and getting cheaper, but grid energy is still expensive and the cost is rising. In CA, where the solar-larval-organism is mutating fastest, the all-in cost of energy for commercial and industrial is usually >$0.50/kWh. And meanwhile LCOEs for solar are 3 or 4 cents / kWh. So what gives?

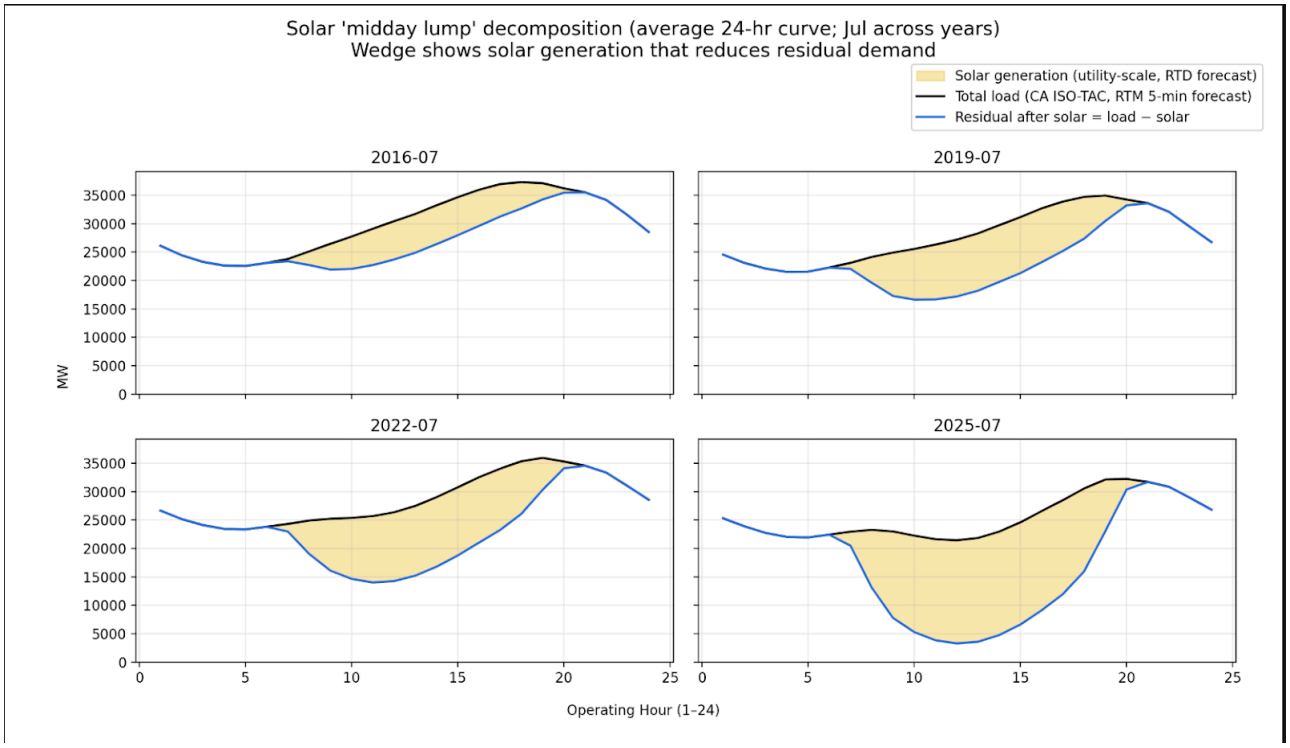
For one, transmission infrastructure in CA is a disaster. PG&E, the state's largest utility company, has bankrupted itself multiple times, most recently due to $50B+ in wildfire-related liabilities (19% of acres burned by wildfires are caused by power lines).

Plus, transmission infrastructure isn't very compatible with renewables: it's sized for peak-load, so you don't blow transformers and melt conductors during solar-noon in summertime, which means the rest of the year there's extra capacity sitting idle. Solar's capacity factor is ~25%, so the average power generation is 1/4th the maximum power generation. For contrast, the capacity factor of a combined cycle gas plant is 2-3x that. For the same load, solar needs 2-3x as much transmission infrastructure compared to CCGT.

Centralized energy production with giant distribution networks made sense when they were built: coal power plants are about ~1GW in size, and they benefit from scale because they have OPEX fuel logistics and are thermal processes subject to surface-area:volume (r^2:r^3) optimisations that justify bigger devices. Solar doesn't have OPEX and isn't a thermal process, so there's no argument to centralize production.

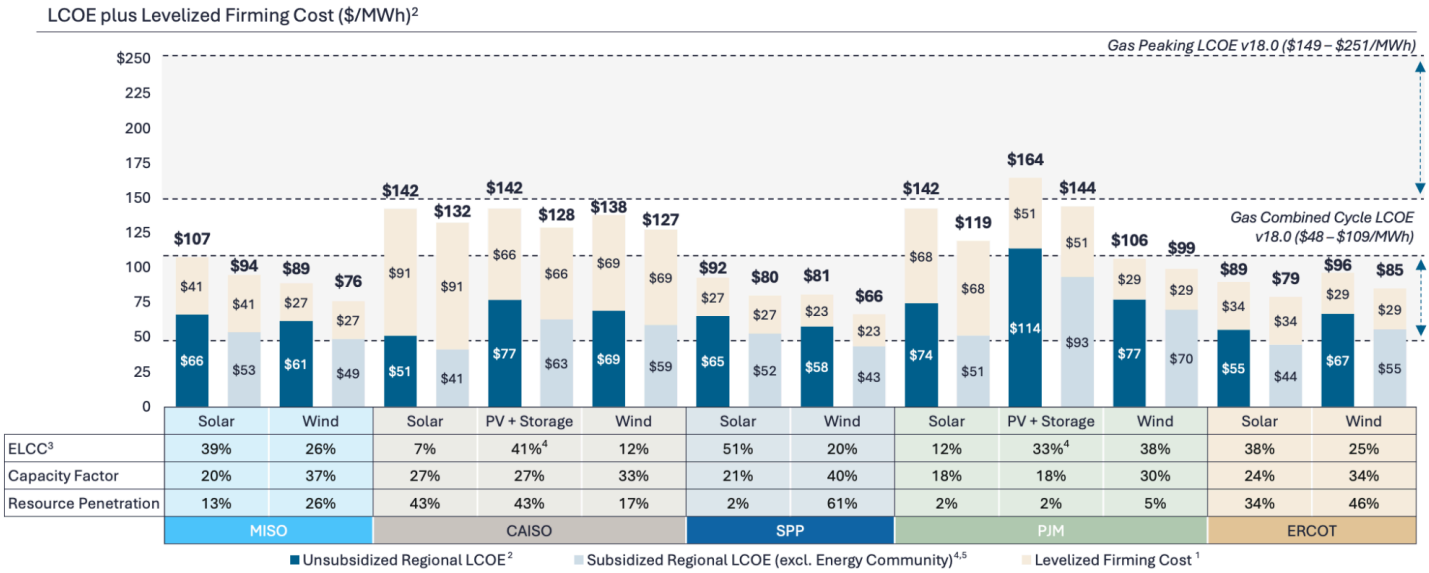
Additionally, transmission and interconnection are managed by organizations like CAISO, which are, get this, government-commissioned nonprofits. I literally cannot think of a worse type of organization, and they are extremely slow. Interconnection queues are regularly >5 years, leaving massive capital projects lingering in the hands of a government-nonprofit. Bookmarking massive amounts of capital is very expensive.

Another feature of the solar organism is that firming supply is becoming expensive. It will always be cheaper to consume solar, and only require solar panels, then to load-shift it across the day, and require solar plus batteries. I graphed the daily profile solar production vs total production in CAISO. Solar is eating the midday energy profile, and once the residual load (blue) "bottoms out", a solar-profile-shaped lump on the total load will start growing. Increasingly, heavy loads are being run during the day, and this trend will continue.



Data from Dataset from: https://oasis.caiso.com/mrioasis/logon.do

When you buy energy from the grid, you're paying for 100% uptime even if you don't need it. For example, see a graph from Lazard's energy report comparing LCOE vs "Firming Costs". While I find Lazard's presentation somewhat convoluted, the concept stands: in California, the cost of firming solar costs 2x as much as energy itself.



https://www.lazard.com/media/5tlbhyla/lazards-lcoeplus-june-2025-_vf.pdf
(Note, I think ERCOT's ELCC / Firming Cost methodology is flawed)

As solar de-costs and grows, a higher fraction of energy cost is just firming. The ratio increases from both directions: solar LCOE decreases, and firming costs increase with higher resource penetration. I suspect the latter happens because at low penetration, there are latent energy resources that can absorb firming needs, but as solar grows, entirely new projects are required for marginal firming.