Urgent Investment Opportunity To Scale Up Solar Industry in Atacama

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1. Summary

Chile has already made excellent progress in fulfilling key elements of its long-term plan to make solar farms in the Atacama desert a huge new source of revenue. New transmission lines are likely to go into service within Chile [1] within a year or so, solving the short-term problems of excess electricity production seen this past year [2]. Purchase Power Agreements actually available now in Atacama [3] have gone down to 2.9 cents per kwh, due in part to the way in which solar farms can operate for more hours per day in Atacama with higher intensity than anywhere else on earth [4].

Nevertheless, there is more work to be done, in order to fulfill the realistic dream of Atacama becoming the "Saudi Arabia of electricity" for all of Latin America. There are no really reliable forecasts of electricity markets in Latin America for 2024, but quick calculations based on best available data [5,6] suggest that it reasonable to expect 1500 terawatt hours total consumption by that year in non-OECD Latin America (all of Latin America beyond Chile and Mexico), of which 500 would be supplied by hydro under normal conditions. At 10 cents per kilowatt hour, that leaves a net potential market worth $100 billion dollars per year. This paper has been motivated by the key question:

What needs to be done, here and now, *in addition to* what Chile is already doing, and *in addition to* domestic market expansion, in order to capture that larger market as soon as possible, with maximum probability of success, and maximum profit potential and minimum risk in the initial investment?

This paper is not itself a business plan, but it proposes an intense collaborative effort by the Solar Energy Research Consortium of Chile, in communication with key policy authorities and other partners, to develop a business plan (or even request for proposals) to be addressed to organizations like the World Bank or Three Gorges Investment group to include three key elements as a package, for startup as soon as possible subject to project efficiency:

(1) A ten gigawatt high voltage line to run from Atacama to Brazil, expected to cost about $3 billion [7], linking to the highly developed Brazilian power grid, likely to be profitable no matter which source of solar electricity works out best in Atacama (PVs[3], power towers [4], new solar farm technology, or even energy from space [8]), substantially reducing seasonal and time of day problems in today's grid;

(2) A call for the immediate buildup of new solar farm production in Atacama, to connect to the new power lines, open to the full 10 gigawatts, assigned on a competitive basis, but not to exceed 8 cents per kwh in any case;

(3) $30 million in a hedge investment, $20 million to demonstrate a new solar Stirling technology expected to yield 6 cents per kwh without a need to import PV panels and assimilate that technology to Chile and Brazil, and $10 million to explore two competing new solar thermal alternatives (Kettering and Excellatron) with similar potential. The goal here is to reduce the risk of not being able to supply the 10 gigawatts at 8 cents per kwh or less, due to risks of PV panel suppliers raising prices in the future, an important concern raised by Abengoa [4]. Abengoa itself should be able to reduce its costs both with scale and with upgrades in the grid which substantially reduce the need to invest in storage, assuming we would use intelligent grid control and [9] to balance supply and demand, especially hydro supply, across the new integrated grid.

Again, this would be intended as a start towards building up to 300 gigawatts, and should be implemented in a way to facilitate that expansion. In technical terms, a 10 gigawatt line consists of 10,000 megavolt-amperes [7] and intelligent control designed to prevent wasting the transmission capacity on reactive power [9].

The initial investment would almost certainly be met by generation bids of 3 cents per kwh, as in recent Purchasing Power Agreements (PPA) [3]. Based on discussions with PJM (the largest operator of transmission systems in the US), I would estimate that 2 cents per kwh would cover cost plus reasonable profit for transmission on a line of this length. This would leave 5 cents per kwh additional profit for the initial investment, if the electricity is sold at 10 cents per kwh. Because of the intense sunlight in Atacama, we would estimate that the 10 gigawatt installed solar capacity would produce about 28 terawatt-hours (TWH) of electricity, yielding $1.4 billion per year of additional profit above and beyond the reasonable charges for generation and transmission.

For the petrochemical industry of Latin America, the huge increase in renewable electricity would have the benefit of freeing up supplies of oil and gas which are expected to rise in price in the coming years [10]. It is not profitable to sell these now at a lower price, when higher prices are coming, especially in the export market. Chinese oil and gas companies are increasingly active and powerful, in many areas, and their first imperative is to free up supplies of oil and gas worldwide so as to enhance the security of their distribution systems and markets within China; this investment would be a big step up to serving that imperative.

Honesty demands that I reveal my own motives here, which I hope that other human beings will be sane enough to share, even when making economic decisions. I am worried that present trends in ocean chemistry, due to a combination of global warming and agricultural runoff could result in emissions of H2S from the oceans, large enough to kill every human on earth, with a rapid increase starting 40 years from now but nonetheless inexorable and nonetheless a concern to those of us who do not want our grandchildren to choke to death or worse. More precisely, the main source of oxygen to the Pacific ocean seems likely to zero out in about 40 years [11], and the big initial outgassing would probably be greatest in those parts of Chile and Peru including Atacama and its neighbors [12].

The remainder of this paper will give more details on the long-term upside potential and on the new emerging risks from climate change. Further details on the immediate investment opportunity would be crucial in the development of the business plan, especially as they depend on government policies and on specific arrangements with potential markets and suppliers.

2. Long-Term Upside Potential

Fortunately, in order to justify the immediate investment proposed here, it is not essential to know whether the upside potential for electricity exports from Atacama by 2024 is for 1000 TWH/year ($100 billion at 10 cents per kwh) or half that or double that. Anything in that range would be very exciting.

The key numbers needed to estimate the upside potential are:

(1) total electricity consumption in 2024 in non-OECD Latin America (which is approximately the same as South America outside of Chile);

(2) total hydro capacity expected in 2024;

(3) the level of expansion which would result in diminishing returns to the point of negative additional profit.

2.1. Total electricity market by 2024 in nonOECD Latin America

For the first number, we assume that the total market for non-OECD electricity will be about 1500 TWH in 2024, a little less than twice the 791 TWH predicted for Brazil according to Brazil's own estimate [6]. Why twice? This assumes that the rest of nonOECD Latin America will not fall behind much behind Brazil in its growth, and that its electricity consumption was a little larger than Brazil's in 2013; according to the International Energy Agency [5], Brazil generated 570 TWH total electricity in 2014 (.27, consistent with [6]), but nonOECD Latin America as a whole generated 5.1% of the world's 23322 TWH in 2013, which works out to 1189 TWH, a bit more than twice Brazil's generation. Because Brazil is not a member of OECD, Brazil's own projection of its future electricity markets is the most credible we can find, short of a major new study.

2.2. Total hydro capacity by 2024 in nonOECD Latin America

For the second number, we start from IEA data ([5], p.19) showing that Brazil generated 391 TWH from hydro in 2013, the dominant source of hydro in nonOECD Latin America. Hydro was formerly a larger share of electricity generation in Brazil, but has slipped, despite the high costs of alternatives and despite good intentions, because of the difficulties involved in expanding dams beyond a certain point. Brazil's government does hope [6] to expand hydro capacity from 84 gigawatts in 2014 to 111 in 2014, but for a rough best estimate, I would sooner expect 500 TWH in 2024, if Atacama provides an easier new source of electricity, also renewable. Reliance on hydro had helped cause not only costs, delays and overruns in Brazil in recent years, but also painful power shortages, related to unpredictable droughts. It is hoped that Brazil would welcome the greater resilience and security which comes from having two large renewable energy sources, and not just one, especially if Brazil is a full partner in the execution of the initial investment and follow-ons, as it should be, given its ability to make technical contributions in parts (1) and (3) of the investment.

2.3. Bottom Line

Our guesstimate of 1000 TWH per year potential market comes from simply subtracting 500 TWH hydro from 1500 TWH market, and aiming to free up the rest of the market from fossil fuels of all kinds, in order to make those (more expensive) fossil fuels more available for the export market, and create a totally sustainable electricity system for Latin America.

2.4. Risks of Diminishing Returns

But what about the third issue: at what level of production do diminishing returns set in? There are actually two concerns here: (1) is there enough suitable land in Atacama to produce 1000 TWH per year with the same kind of favorable economics now being experienced [3]?: and (2) will the suppliers now offering 3 cents per kwh [3] somehow be exhausted or strained by such a higher level of production, and cease to bid such a favorable price?

2.4.1. Adequacy of the Resource in Atacama and Need for Government Blessings

The first concern appears to be no problem. Patricio Rodrigo, CEO of Chile Ambiente, has assessed the generation capabilities from Atacama in detail, and sees no problem in getting as high as 1000 TWH per year [4]. At the high levels of sun found in Atacama, we estimate 2.8 TWH of production per year per gigawatt of installed capacity; for 1000 TWH, 357 gigawatts of installed capacity would be required. The US National Renewable Energy Laboratory estimates that it requires about 9 US acres of land per megawatt of installed capacity, at the levels of sunlight in the best US sites, including both land for generation and land for balance of system; even at that lower level of production per acre, it would require (357,000*9/247)= 13,000 square kilometers of land to generate 1000 TWH per year. That compares with 139,860 square kilometers available for solar farm use in the Atacama desert. [15] .

Still, it is essential that the governments of Chile and of Brazil (and on the transmission path) reach some agreement before this is presented to investors, to ensure that there will be minimum risk of absurd blockages, like those which have reduced output from the new Ivanpah solar farm in the US [16] and which forced cancellation of the Stirling Energy Systems (SES) solar farm for 500 megawatts which had been under construction. In both cases, political opposition groups exploited environmental laws – which is absurd when only one rare desert species was at stake (the kind of species which often goes extinct anyway in normal evolution) on one side, but most of the species on earth (including ours [11,12,13]) are at stake if we do not accelerate the shift to renewable energy.

2.4.2. Adequacy of Technology and Need for a Hedge to Minimize Risk

The second concern about diminishing returns is far more serious. For example, Abengoa has noted [4] that the low price now available from PV solar farms depends on very low prices for solar power now available from China. To some extent these low prices are the result of short-term excess capacity in China (as is the low price of natural gas from fracking in the US, already undergoing massive adjustment). On the other hand, the US Department of Energy has announced a target of 5 cents per kwh total real cost for PV solar farms [17], beyond such short-term factors; if we believe that progress towards these goals is rapid, then the superior sun in Atacama should translate this into 4 cents per kwh long-term or better.

Nevertheless, there is significant risk in these assumptions, a risk well worth hedging when so many billions of dollars are at stake. To minimize that risk (not only in Latin America but for the earth as a whole), it is essential to hedge that risk by modest investments to develop alternative solar farm technologies with a high probability of getting to less than 8 cents per kwh even if progress in PV solar farms turns out to be less than expected. In addition, developing alternative technology sources creates the kind of market competition which reduces the risk that some kind of monopoly effect could get in the way of holding down generation costs. The encouragement of Abengoa's power tower technology already provides some hedge to the uncertainties of PV, but I would strongly urge small but critical investments in three other solar thermal technologies:

(1) The SunDish technology of Lennart Johansson Associates (LJA).

For $10 million, LJA has offered to install a fully operational demo of a more advanced version of the type of solar dish technology previously proven out by the company STM at Sandia National Laboratories in the US and in many beta test sites, currently under commercial development from China. (This was also the type of solar farm being installed by Stirling Energy Systems (SES) on a large scale before legal injunctions stopped them.) Johansson, developer of the 31% efficient Stirling engine design which made these unique systems work, has a well-defined clear path to developing a 50-55% efficient version of the same type of engine, allowing almost twice as much electricity to come from the same physical structure at about the same cost. Sandia estimated (in discussion, with access to proprietary data from many companies) that the old engine could easily yield 10 cents per kwh cost or less, in the US; thus the new technology offers a path to a real cost of 5 cents per kwh.

Formerly Chief Scientist of STM, Johansson is simply not willing to accept the kinds of restrictions which US venture capital places on such new developments. China is funding development of uses of the older engine, enough to provide a revenue stream, but has also requested terms which Johansson considers unacceptable for release of the "crown jewels," the new engine design. However, he has stated clearly that he would be happy to offer an arrangement with immense upside potential to the new corporate entity which this investment proposal would create. He would offer total rights, unconditionally, to this entity, for manufacture of the new engine and of the SunDish, for all of the entire Latin American market. For the new entity, this would provide security against the risk of PV price increases, and some possibility of building up a new generation enterprise in Latin America worth many billions of dollars. For Johansson himself, he retains 100% full rights to the other 22,000 TWH per year in the rest of the world; a successful full scale demonstration of the SunDish would make it possible for him to raise capital to address that market on terms far more favorable than the type of venture capital available before such a demonstration. He has also offered to transfer the technology necessary to produce SunDishes in Latin America, starting from suppliers available in Latin America and from engine parts available from new generation foundries, as deliverable in the contract.

Development of a complete business plan should include negotiation of the contract with LJA, and funding of an additional $10 million to support Antofagosta in assimilating, receiving, understanding and better connecting the new technology, working with LJA personnel.

(2) The JTEC technology of Excellatron

We recommend that $5 million be allocated to develop at least a small-scale practical prototype of the "engine" [18,19] of another radical new dish-based solar technology, through collaboration between SERC and the company Excellatron. Johnson, the CEO and founder of Excellatron has developed a radical new alternative to the Stirling engine, called "JTEC," to convert temperature differences directly to electricity, without any moving parts aside from movement of the working fluid. (The working fluid both for JTEC and for LJA's Stirling engines in hydrogen; note that no hydrogen is actually consumed, and that Johansson has many patents for coating and other systems which make it possible to use hydrogen as a working fluid over many years without the problem of hydrogen embrittlement which destroyed many of his former competitors.) After a long evaluation process, the US National Science Foundation funded initial exploratory work on the JTEC concepts [28], and Excellatron is now ready for the next step in scaling up.

JTEC is certainly riskier than the LJA technology, simply because it is so new. However, simulations suggest it could reach about 65% efficiency, and have other applications as well. Johnson has a great track record of collaboration and outreach to universities in his area, and could work well with people in and from Chile and Brazil; this is no small matter in building an organization. Even if the total risk, between today and mass deployment in a solar farm, is about 50%, funding this work would reduce the overall risk of the investment project in half. Cutting overall risk in half would be well worth the small investment, especially considering the upside potential of the technology worldwide.

(3) Kettering University

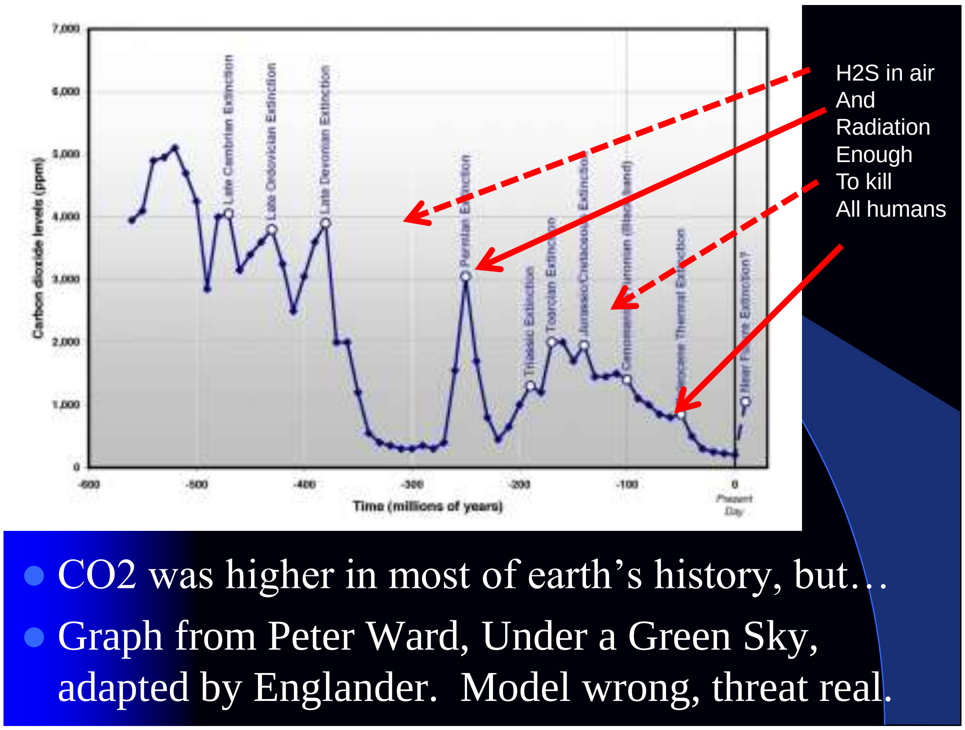
We also recommend that $5 million be allocated to Kettering University, the leading US university for research and teaching linked to the needs of the automobile industry (whose factories would be able to quickly mass-produce new Stirling engines and reflectors for the solar dishes). University exchange between Chile, Brazil and the US would be of value in any case in building up solar production capability in Chile and Brazil. However, Kettering also has professors who are leaders in advanced practical design for mufflers and engines, who may well have competing new ideas, to offer further new options and further hedge against risk here. This part can be led by Albert Sobey (for Division Director for Advanced Products at General Motors, now retired), who has strong ties with Kettering, but in any event with the professors he has worked with there in these areas. Sobey also has long experience in developing business plans, and is currently writing a book whihc includes that subject.

3. Serious Worst Case Risks to Chile, Peru and Humanity in General From An Emerging New Climate Threat

Years ago, in a seminal study of energy policy [20], posed the following question: "How would the financial world evaluate an investment opportunity which would double world income for the next ten years, to be followed by zero income and total death for everyone? Using conventional investment analysis with 15% interest rates, it would be considered irrational to do anything else." Economic theory does not require people to commit suicide, or even to neglect actions necessary to ensure their survival in the long-term. The key challenge here is to manage interest rates [21] in a way which reflects our true starting points, the "utility functions" which reflect our most fundamental values, which certainly do include survival. But if current analysis tells us we should not do what we need to do in order to survive, we should revisit the analysis, and not neglect what we need to do. Climate threats are not the only reason why new technologies for renewable energy might decide whether humans survive on earth or not, but there is new information in the climate area which calls out both for new research and for immediate upscaling of our efforts to support all large-scale renewable energy.

In 2009, the year when President Obama pushed as hard as he could for major climate change legislation in the US, the leading climate skeptics argued: “You people are all so worried about CO2 reaching 500 or 600 ppm in the atmosphere, but for more than half the world’s history it was 2000 or above, and life went on as usual.” But did it? No one in the room knew the real answer to this at the time, though Senator Boxer had an entertaining response, visible in part in the video proceedings [22].

Later that year, I learned a key part of the answer, when the Geosciences Directorate (GEO) of the National Science Foundation invited us to a public lecture by Peter Ward of the University of Washington. GEO introduced Ward as the world’s leading expert on mass extinctions of life on earth, the person whose focused and diligent collection of data in the field, and analysis, led to the most credible current picture of what happened in those past scary times. The most important part of his message is summarized in a slide previously presented in Santiago, Chile, and again in Antofagasta:

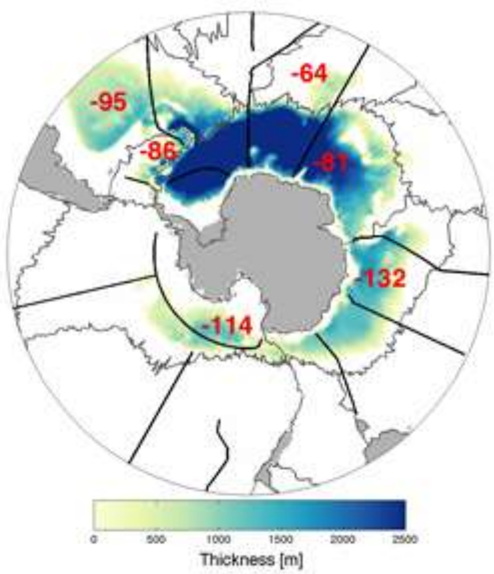


At the end of his talk, Ward noted that the current curves and trends in effect on earth appear very similar to those he saw in the past, and that it is his gut feeling that if CO2 reaches 1000 ppm (as it does seem likely to do given the limited effectiveness of current world policies, despite good intentions) we will probably all die. Personally, I found it amazing that everyone else I met in that audience fell into one of two groups: (1) those with a kind of religious or quasi-religious conviction that no scientific research about climate could possibly be worth studying further, partly by people who say “God promised us in the Bible that the world will never be destroyed by fire and brimstone “ (which is not what I see in that book); (2) politically correct and proud people who mainly concluded that they should continue voting for existing policies and research on global warming. But should there not be a systematic world effort to do something new, to get a more precise understanding of this threat, following up on Ward’s call [23] for new interdisciplinary efforts bringing together paleogeobiologists like him and physical scientists who understand the crucial thermohaline ocean currents which will decide how soon we fall into “stratified ocean,” one of the key triggers for the H2S event?

In the absence of such efforts, I have endeavored to learn all I can on my own about this threat, in spare moments, building in part on my own knowledge of physical dynamical systems (e.g [24]). It was clear from the start that the kind of event Ward has observed is called “euxinia,” and that it results from the proliferation of a certain kind of archaea which grow wild very quickly [25] when and where two conditions are met: (1) low oxygen in the ocean, as in the “stratified ocean” Ward talks about; and (2) a supply of the nutrients which that type of archaea use. (It is not hard to replicate this in the laboratory. For example, it is interesting to google on “stinky aquarium,” and learn of parents who confronted problems in their children’s rooms much worse than they had imagined possible.) Of course, the world really should be monitoring and modeling these factors much more completely than it does yet, taking advantage of new technology for wireless sensor networks.

At an early stage of asking these questions, I noticed that the Arctic ocean is not so far away (10 years?) from the critical temperature where, at the prevailing level of salinity, the northern "lungs of the planet" might cut off. (More precisely, the Arctic thermohaline current would cut off rather precisely when the temperature of minimum water density is reached at the surface.) In the past, H2S production in just the North Atlantic was already enough to produce the "eocene extinction' [23], which was enough to kill off all mammals larger than a mouse, but not enough to kill off the mouse.

I arranged to discuss this with Professor Marty Hoffert of Columbia, a leading physical oceanographer, who urged me to shift my attention to the Antarctic currents, the more important by far of the "lungs of the planet." The Antarctic THC is the one large and serious enough source of oxygen to the Pacific Ocean, among others. Following up, I was startled to learn that the southern THC has already shut down. Fresh water and water ice ringing the Antarctic has already cut off this current, resulting in a steady drop in the thickness of the deep water containing oxygen which supplies the Pacific Ocean. The following figure from the website of US National Oceanic and Atmospheric Administration (NOAA) [26] summarizes the results, discussed in more detail in [11]:



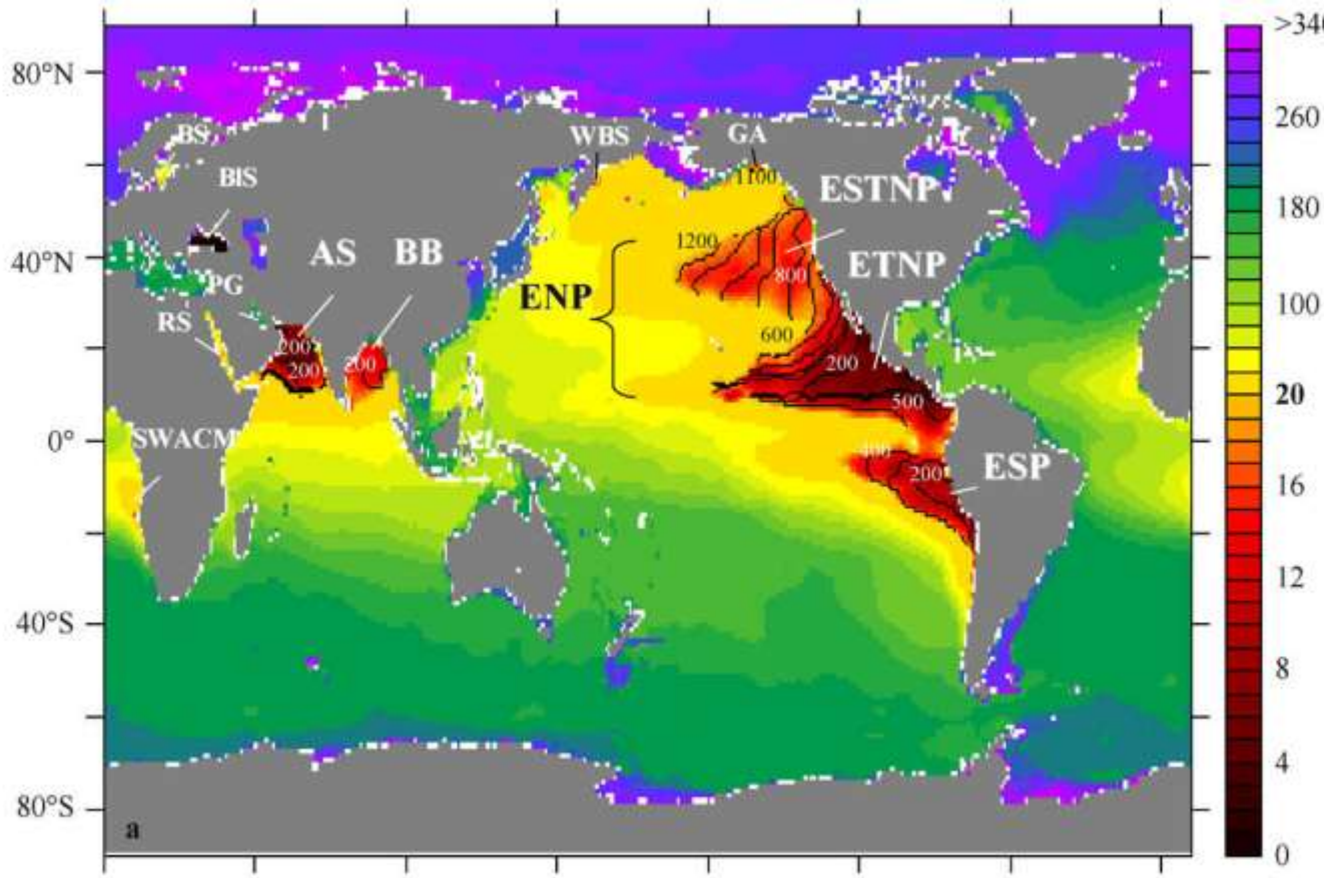
The key thing to notice is that the thickness of the deep oxygen bearing layer on the Pacific side is down to about 500 meters now on average (much worse than the Atlantic side), and that it is decreasing at a rate of 114 meters per decade. Clearly this calls for more sophisticated modeling, but by reasonable eyeball it looks like 40 years left, more or less. (It is rational to remember that "more or less" means precisely that: the situation could be better than it appears here, or it could be worse.) I picture a man who is already underwater, whose lungs are not getting more oxygen, but has 40 years of oxygen left in those lungs.

But what about the second trigger required before we see massive H2S production in the Pacific – the supply of nutrients?

In fact, the earth already experienced a cutoff of the southern THC, and stratified ocean, relatively recently – just 50,000 years ago or so [12]. The subject of Oxygen Minimum Zones (OMZ) in the ocean is a large area of research, offering us many important clues.

Unfortunately, the situation today is far riskier than it was in those years, because of another massive change which we humans have already created [27] – agricultural runoff. We have not yet seen really huge consequences from agricultural runoff pouring into the oceans, because the high levels of oxygen were enough to prevent proliferation of archaea. But this runoff is truly massive already, by historical standards. Bear in mind that humans now manage more than half the plant life of earth, and that the productivity of that plant life has been more or less doubled [27] precisely by a massive application of fertilizers, which is now accompanied by an equally massive discharge into the oceans, unprecedented in the history of this planet. Agriculture in China, California and Japan, for example, inserts huge amount of runoff into the Pacific. This needs to be studied in more detail, and perhaps there is even some hope of controlling it, but for now the best guess is that we are cooked.

Or are we? There is one more natural thing which might intervene to save us: limits to upwelling, to the release of poison gasses from the ocean to the atmosphere. The Black Sea already has become vast reservoir of H2S poison, but, due to quiet seas it has not yet led to outbreaks of mass death of black clouds in the night (as has happened in a few small villages in Africa near euxinic lakes). What is the situation with upwelling from the Pacific? The following figure from [12] shows what this situation is:



Upwelling from the Pacific is clearly substantial by northern Chile, Peru and Mexico especially, but also California. Because the water is not as deep in the Arctic Ocean and areas like the Baltic, they may actually see some of these kinds of effects sooner than Peru does, due to euxinia in the North. H2S-producing archaea are probably active already in many areas with environmental problems, but when low oxygen hits most of the Pacific and the Arctic, things will immediately become very much worse.

H2S is actually more poisonous than hydrogen cyanide, in equal concentrations, but from the historical literature I would expect it would take something like two thousand years for it to build up to fatal levels. However, even at much lower concentrations, the global effects would be severe [28]. Roughly speaking, within a decade or two or so from the start of H2S upwelling, I would expect the world to smell so bad that reproductive behavior of most mammals would be severely curtailed, except for a few species like nasty rats which might be stimulated by such smells. Initially, H2S would mostly break down to other gasses, causing immediate problems with acid rain and a new "ozone hole" leading to fatal radiation sooner than outright H2S poisoning. Effects would appear sooner and faster in the upwelling zones.

All of this is a reasonable best guess, but again more research is needed, not to reassure us, but to give us a more precise understanding of the worst case and best case, the range of uncertainties, and a better understanding of what might help in reducing the probability of human extinction. Renewable energy would not be enough by itself to save us, but it would be a major help in making the possibility of survival more plausible. A greater, faster expansion of renewable electricity may be even more essential to other serious threats of extinction of the human species [29].

References

[1] Andrew Baker, Chile watch: Renewable, transmission project updates, *Business News Americas*
Friday, September 16, 2016

http://www.bnamericas.com/en/news/electricpower/chile-watch-renewable-transmission-project-updates
[2] Vanessa Dezem and Javiera Quiroga, Chile Has So Much Solar Energy It's Giving It Away for Free, *Bloomberg Business Week* June 1, 2016
http://www.bloomberg.com/news/articles/2016-06-01/chile-has-so-much-solar-energy-it-s-giving-it-away-for-free
[3] Vanessa Dezem (Bloomberg) , Solar Sold in Chile at Lowest Ever, Half Price of Coal, *Renewable Energy World*
http://www.renewableenergyworld.com/articles/2016/08/solar-sold-in-chile-at-lowest-ever-half-price-of-coal.html
[4] Jonathan Watts, Desert tower raises Chile's solar power ambition to new heights, *The Guardian*, 22 December 2015
https://www.theguardian.com/environment/2015/dec/22/desert-tower-raises-chiles-solar-power-ambition-to-new-heights
[5]. International Energy Agency, *2015 Key World Energy Statistics*, OECD/IEA, 2015
[6] Office of Strategic Energy Studies, Ministry of Mines and Energy (Brazil), *Electricity in the 2024 Brazilian Energy Plan (PDE 2024)*,
http://www.mme.gov.br/documents/10584/3642013/02+Electricity+in+the+2024+Brazilian+Energy+Plan+(PDF)/
[7] Edvard Csanyi, *Analyzing the Costs of High Voltage Direct Current (HVCD) Transmission*, Electrical Engineering Portal, 2014, http://electrical-engineering-portal.com/analysing-the-costs-of-high-voltage-direct-current-hvdc-transmission
[8] Paul Werbos, Reviewing Space Solar Power policy, Ad Astra, Vol. 26, No.2, 2014,
http://www.nss.org/adastra/volume26/ssppolicy.html
[9] Paul J. Werbos, Computational intelligence for the smart grid-history, challenges, and opportunities, *Computational Intelligence Magazine, IEEE* 6.3 (2011): 14-21.
[10] Deloitte, *2016 oil and gas industry survey: Optimism emerges in the aftermath of a long downturn*
http://finance.yahoo.com/news/deloitte-survey-oil-gas-executives-140000839.html
[11] Purkey, Sarah G., and Gregory C. Johnson. "Global contraction of Antarctic Bottom Water between the 1980s and 2000s*." *Journal of Climate* 25.17 (2012): 5830-5844.
http://journals.ametsoc.org/doi/full/10.1175/JCLI-D-11-00612.1
[12] Paulmier, Aurélien, and Diana Ruiz-Pino. "Oxygen minimum zones (OMZs) in the modern ocean." *Progress in Oceanography* 80.3 (2009): 113-128. http://www.sciencedirect.com/science/article/pii/S0079661108001468
[13] Paul J. Werbos, Update *on H2S threat of human extinction: news keeps getting worse*,
http://drpauljohn.blogspot.com/2015/11/update-on-h2s-threat-of-human.html
[14] James Montgomery, Calculating Solar Energy's Land Use Footprint, *Renewable Energy World*, August 8, 2013
http://www.renewableenergyworld.com/articles/2013/08/calculating-solar-energys-land-use-footprint.html
[15] Woodhouse, Shayla, and Peter Meisen. "Renewable Energy Potential of Chile."*Global Energy Network Institute: San Diego, CA, USA*(2011).
https://www.geni.org/globalenergy/research/renewable-energy-potential-of-chile/Chile 2020 Report II PBM final.pdf
[16] https://en.wikipedia.org/wiki/Ivanpah_Solar_Power_Facility
[17] Michael Woodhouse , Rebecca Jones-Albertus , David Feldman1 , Ran Fu , Kelsey Horowitz , Donald Chung, Dirk Jordan and Sarah Kurtz, On the Path to Sunshot: The Role of Advancements in Solar Photovoltaic Efficiency, Reliability, and Costs National Renewable Energy Laboratory, May 2016 NREL/TP-6A20-65872
http://www.nrel.gov/docs/fy16osti/65872.pdf
[18] L. Johnson, *INSPIRE: Novel Ceramic Membrane Electrode Assemblies for High Efficiency ThermoElectrochemical Converter*, 2012,
http://www.nsf.gov/awardsearch/showAward?AWD_ID=1248040&HistoricalAwards=false
[19] www.excellatron.com
[20] Yager, Joseph A., and Eleanor B. Steinberg. *Energy and US foreign policy: a report to the Energy Policy Project of the Ford Foundation*. Brookings Institution, 1974.
[21] P.Werbos, Rational approaches to identifying policy objectives *Energy: The International Journal*,15 (3/4), 1990, p.171-185
[22] US Senate Committee on Environment and Public Works, Full Committee hearing entitled, "Update on the Latest Global Warming Science.", February 25, 2009. Video posted at
http://www.epw.senate.gov/public/index.cfm/hearings?ID=864D3319-802A-23AD-46A0-15D3B819178D
(If you look behind Senator Specter, you can even see me in the video, and later see Senator Boxer's comments on us.)
[23] Peter D. Ward, *Under a Green Sky*, Harper Collins, 2008
[24] Werbos, P.J. and Dolmatova, L., 2016. Analog quantum computing (AQC) and the need for time-symmetric physics. *Quantum Information Processing*, *15*(3), pp.1273-1287.
[25] Kump, Lee R., Alexander Pavlov, and Michael A. Arthur. "Massive release of hydrogen sulfide to the surface ocean and atmosphere during intervals of oceanic anoxia."*Geology* 33.5 (2005): 397-400.
[26] National Oceanic and Atmospheric Administration, *Amount of coldest Antarctic water near ocean floor decreasing for decades,* March 20, 2012
http://www.noaanews.noaa.gov/stories2012/20120320_antarcticbottomwater.html

[27] Hager, Thomas. *The alchemy of air: a Jewish genius, a doomed tycoon, and the scientific discovery that fed the world but fueled the rise of Hitler*. Broadway Books, 2009.
[28] https://en.wikipedia.org/wiki/Hydrogen_sulfide (accurate on toxicity issues but not updated in all aspects)
[29] Paul J. Werbos, New Technology Options and Threats To Detect and Combat Terrorism. In Sharan, Gordon and Florescu eds, Proc. of NATO Workshop on Predetection of Terrorism, NATO/IOS, 2016 (in press, approximate citation)_