

The Great Simplification

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[00:00:00] **Zeke Hausfather:** There's really three big uncertainties that future warming comes down to. The first is what we do as humans. There's how the Earth's biogeochemistry responds to our warming, and then the final piece is this question of climate sensitivity. And if we put all of them together, we get a pretty wide range of future warming possibilities.

[00:00:19] But in an El Nino year, like what we're experiencing right now, is in some ways a sneak peek of what the new normal will be a decade from now. We add about point two degrees from human emissions every eight years, and so we're essentially adding a permanent super El Nino worth of heat every eight years just by burning coal, oil, and gas

[00:00:42] **Nate Hagens:** Today I'm joined by Zeke Hausfather, a climate scientist and systems analyst, for a deep dive into what the various numbers and models and acronyms in climate science are actually telling us about our rapidly changing biosphere. Zeke is a lead author of the IPCC Seventh Assessment report. He also has authored the climate trends chapter of the Fifth US National Climate Assessment, and has testified as an expert witness before the US House Committee on Science, Space and Technology.

[00:01:17] At Berkeley Earth, Zeke helps produce one of the world's primary global surface temperature records. He is also a climate science contributor at Carbon Brief, as well as the lead climate researcher at Frontier. In this conversation, Zeke shares where we're currently at compared to the prior IPCC models, what that actually means, and how the IPCC is updating its models for the upcoming seventh report in order to understand the biggest climate questions of recent years, including, is global heating accelerating?

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[00:01:55] Beyond that, we also discuss what the current Super El Nino means for warming in twenty twenty-seven and beyond, as well as Zeke's recent analysis on the surprising energy requirements of using AI and large language models for environmental research. If you enjoy digging into the weeds of climate science and getting a better understanding of what climate research is based on and how reliable it is, this one is for you.

[00:02:21] With that, please welcome Zeke Hausfather, welcome.

[00:02:27] **Zeke Hausfather:** Thanks, Nate. Great to be on.

[00:02:29] **Nate Hagens:** So you have had a unique path for a climate scientist. you founded a clean tech company, when you were in grad school and ran it for about a decade before going back, to get a PhD in energy and resources, which rhymes with my past a bit.

[00:02:46] But now you're wearing several hats at the same time: scientist at Berkeley Earth, climate research, that you do at, companies Stripe and Frontier, climate reporter, for The Climate Brink and Carbon Brief, and, and this one I imagine takes up a lot of your time, lead author of chapter two of the IPCC's seventh assessment.

[00:03:13] That is a pretty unique mix of expertise. So, let's start by asking how might your perspective differ from a typical climate scientist, if there's such a thing, who has stayed in academia, and what do you think is the biggest insight that you've gained from your background?

[00:03:33] **Zeke Hausfather:** So I think working in both the startup world and now in, in Silicon Valley with, Stripe and, Frontier, I've come to realize that there's a lot of things that we, you know, discuss in the academic literature that are often abstract or, not necessarily that practical and that, you know, when it comes to

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building things in the real world, there's a lot of challenges that aren't necessarily reflected in, peer-reviewed papers.

[00:03:58] this is probably a bit more on the solution side than the climate science side itself. But just getting a recognition of how messy the real world is, how friction full it is, and how our simple models, you know, often, you know, fail once they meet the reality of the real world.

[00:04:16] So, I think of all the things, understanding and recognizing that complexity.

[00:04:21] **Nate Hagens:** Well, I, I think there's climate science and then there's technology and innovation, but then there's-- that all sits within the broader backdrop of human macroecology. And so there's different lenses with which to view this whole situation.

[00:04:41] And, I do think the climate science and tech lens is interesting, and nestled in there.

[00:04:50] **Zeke Hausfather:** So my first company was helping utilities reduce their customers' energy use. and so a lot of it was focused on helping people change their behaviors. And one really interesting thing that stuck with me from that work is just how hard it is to get sustained behavior change, particularly if it involves a sacrifice on behalf of people.

[00:05:10] You know, the only things that were ultimately successful in the energy efficiency work I was doing were the solutions that were to set it and forget it. You know, replace your light bulb, then you don't have to worry about it. You know-- Yeah ... buy an efficient appliance or an electric car that does the same thing that your current appliance or car does, and then you don't have to worry about it.

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[00:05:27] When I think about solutions now, I'm much more confident in succeeding with solutions that improve people's lives rather than solutions that require a significant change in people's lives.

[00:05:38] **Nate Hagens:** Or, which probably wasn't, one of the options when you were doing that, is having everyone else in your neighborhood do things differently and then try to meet their lower level of throughput, 'cause we don't have that experiment happening in, too many places.

[00:05:55] **Zeke Hausfather:** No. I mean, real social pressures can change behavior in important ways. It's just hard to engineer those, Yeah ... in the real world.

[00:06:02] **Nate Hagens:** Agreed. So let's jump to the number that most of our listeners certainly are familiar with, which is temperature. so you host a very detailed piece of technology and science called the Climate Dashboard, that has global heating updates and histories and scenarios and projections.

[00:06:25] and before we get into those, how do you actually come to arrive at temperature numbers that you publish, and why do different institutions often arrive at, at, at different results?

[00:06:39] **Zeke Hausfather:** So calculating the Earth's temperature is somewhat non-trivial, right? You know, we-- at least until the satellite era, we don't measure every square meter of the Earth's surface.

[00:06:49] and the ways we've measured things have changed a lot over time. You know, back in the 1800s and even into the mid-1900s, we used to throw buckets over the side of ships and pull them up and stick a thermometer in them and measure ocean temperatures that way. And it turns out how high the deck of the ship is creates a bias in the measurements because there's more evaporative

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cooling the longer between when you pull the bucket out of the ocean and when you actually stick the thermometer into it.

[00:07:13] **Nate Hagens:** Sounds like a Richard Feynman experiment.

[00:07:17] **Zeke Hausfather:** But just understanding, like, all the ways that, how we've measured things have changed over time is challenging, and then how to combine all these measurements and deal with gaps. You know, we didn't have anything in Antar-Antarctica until 1950, so how do you deal with that?

[00:07:30] Do you just ignore it and sort of implicitly assign it the global average? Do you do some fancy s- geospatial statistics like Kriging? So there's a lot of different choices the different groups have to make when they're trying to turn these, you know, tens of thousands of weather stations and millions of ocean measurements into a single global estimate of temperature change.

[00:07:50] That being said, the results that different groups around the world get are pretty similar. There's now 14 different groups of researchers that have put together global temperature records, and they're based all around the world. There's a couple Chinese ones, Japanese ones, you know, European ones, UK-based ones, a number of US groups, including Berkeley Earth that I work for as a research scientist, producing one of the main temperature records.

[00:08:14] and if you plot them all together, you know, the differences are particularly in the last 50 years, they're quite minor. If you go back into the, you know, early 1900s or into the 1800s, they start getting bigger and, part of that is that we have more sparse measurements. There's bigger, you know, variations in how things were measured back then, and so the choices the individual research groups make of how to put these records together matter more.

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[00:08:37] But there's not much overall uncertainty that the world has warmed by about 1.4 degrees, since pre-industrial times. And in fact, one of the big things we're doing for the next IPCC report is instead of showing 14 different lines from 14 different research groups, which is a bit of a nightmare to maintain, we're trying to put together sort of a, a canonical ensemble that's going to incorporate all these different data sets, and robustly show uncertainties across all them.

[00:09:02] So it'll be like a 10,000-member ensemble of global mean surface temperatures. This comes out of some work that we-- there's a preprint out on it now, but it hopefully will be published later this year, a big community paper led by Peter Thorne, that I'm on as well that's doing this.

[00:09:18] **Nate Hagens:** Not to put you on the spot, but is managing the writing and approving and science and the cat herding that I can only imagine, is happening with a global group of climate scientists with pedigrees and status and opinions, is that a microcosm for the broader, human cultural challenge we face?

[00:09:49] **Zeke Hausfather:** I mean, whenever you get a big enough group together, there's going to be some drama. But, you know, I think at this point, the Intergovernmental Panel on Climate Change, the IPCC, where I'm a lead author of the, the upcoming Seventh Assessment Report, is a pretty well-oiled machine. You know, this is going to be the seventh time they've gone through this big assessment cycle.

[00:10:06] You know, we ultimately come up with, you know, three different working groups, each of which produces about a 2,000-page report. So it's a, a pile of reports, you know, half as tall as I am. and It's, I don't know, it's been a surprisingly positive experience. It's... Everyone is very motivated to, like, understand science.

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[00:10:26] There's very little discussion of policy or politics. In fact, the IPCC is sort of designed to be politically neutral, and not policy prescriptive. You know, everyone is a scientist. You know, there, there's a lot of agreement on the basics. The world is warming, human emissions are accumulating in the atmosphere, CO2's a greenhouse gas.

[00:10:43] You know, that's basic physics. But you know, what everyone is really trying to do is sort through the tens of thousands of studies that have come out since the last IPCC report and assess them together to see how they refine our understanding of some of these big, important questions like, is global warming accelerated, accelerating?

[00:11:02] Have we passed 1.5 degrees? How sensitive is the climate to our emissions? What are plausible future warming pathways that the world might take? You know, all of these big questions that the community tries to answer in, assessments like the IPCC. But in a world that's so polarized and fragmented, it actually makes me a bit more optimistic to be able to have scientists from so many different countries come together and work together on a big collective project like this.

[00:11:26] **Nate Hagens:** And at some level, it's gotta give you faith in humanity. We're all on this spinning blue-green orb, and you're working with people that have different presidents and prime ministers and cultures and food and habits and whatever, and you're all collaborating towards measuring the temperature of our home and other things.

[00:11:48] **Zeke Hausfather:** Yeah. I mean, it's nice to have everyone so aligned on, you know, a mission to understand the planet, to understand the science, and to provide the best summary we can of it.

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[00:11:58] **Nate Hagens:** At some point, and I don't know why these questions are popping into my head, but, does the IPCC report presently and in the future become a bearing witness and more of an adaptation document as opposed to a mitigation, hopefully mitigation document?

[00:12:21] Do you feel that changing already?

[00:12:23] **Zeke Hausfather:** I mean, certainly some of the focus of working groups two and three have changed over time. So to back up a little bit, the IPCC is broken up into three different sorts of reports, for each assessment cycle. The working group one, the– that I'm participating in, is physical science.

[00:12:40] So it's, you know, just understanding the physics of the climate system and all the observations. Working group two is on impacts of climate change, so, you know, what are gonna be the impacts on ecosystems, on humans, on our economy. and then working group three is on mitigation, how do we reduce emissions?

[00:12:59] And both working group two and working group three cover questions of adaptation, and that's become an increasingly important part of the report because we're already seeing many of the effects of climate change, you know, start to show up in our daily lives.

[00:13:11] **Nate Hagens:** Thank you for that. That was very clear. I recently did a, a frankly presentation series where I ran through, some complex scenario planning of earth social systems as a way to think about different plausible paths of the future, and climate science does something similar, but at much larger scale with the RCPs and the SSPs Can you maybe briefly walk us through what those scenarios actually are, including what each one describes and what the numbers and the names, mean?

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[00:13:45] And then I have a follow-up question to that.

[00:13:47] **Zeke Hausfather:** Yeah. So one of the questions the climate scientists often get is what is gonna happen in the future to the climate, and how should governments and societies prepare? And to determine the answer to that requires two things. One is a good physical understanding of the climate system itself.

[00:14:03] You know, how do different greenhouse gases trap heat? How does that trapped heat interact with all these other things and feedback processes that determine temperature? But you could have the perfect climate model that completely understood the climate system and still get the wrong answer if you didn't know what humans were going to do.

[00:14:21] So half of the uncertainty is on the climate side, and we could dive into that a bit more, but half the uncertainty is us. You know, how much coal do we decide to burn in 2100 compared to today? How cheap do renewables and solar get? You know, how big a price, if any, do we put on carbon? What sort of policies do countries enact?

[00:14:39] Those are things that are not physics questions. You cannot answer with physics-based models. And for that you need scenarios. And so climate scientists, ever since the early 1990s, have been developing in parallel with the climate modeling community, a set of future emission scenarios. These went through a number of different generations.

[00:15:01] They were originally the IS92 scenarios that came out in 1992, then the SRES scenarios that came out in the year 2000. and then the more modern iterations are the representative concentration pathways, or RCPs, that came out in the early 2010s, and more recently, the SSPs, or shared socioeconomic pathways, that came out in the early 2020s, or late 2010s.

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[00:15:24] and now as of a few months ago, we've released a new set of emission scenarios built on top of the SSPs called the CMIP7 scenarios. and CMIP7 here refers to the, the current, set of coordinated modeling, being done in the, in conjunction with the IPCC's seventh assessment report. And so these scenarios try to do a couple different things.

[00:15:45] they try to look at what might happen in a world, both, you know, with policies in place today. You know, what is a current policy type scenario? Where are we headed today? what a world might look like where current policies weaken, and on the flip side, what might a world that takes mitigation more seriously than we do today look like?

[00:16:05] You know, what is a world that really tries to cut emissions quickly? And for those latter scenarios, they're often designed around picking an end of century target that we would like to ideally hit or that global policy makers have at least in principle agreed to hit, and then working backwards to see what types of and speed of emission reductions and energy policy, or energy technology changes might be needed to get there.

[00:16:32] And so in the, both the RCPs, the SSPs, and these new CMIP7 scenarios, the community took that approach of creating a number of different possible trajectories reflecting, you know, those different types of outcomes. Those scenarios historically have had a sort of wonky name. So in the RCPs we had RCP8.5, RCP6.0, RCP4.5, RCP2.6.

[00:16:59] Those numbers don't actually refer to temperature even though they probably should. They refer to the radiative forcing in 2100, and radiative forcing is essentially a measure of the amount of heat trapped by greenhouse gases and human influence more broadly in the atmosphere. And so, RCP4.5 refers to a world where there's 4.5 watts per meter squared of energy, being trapped by human activity in the year 2100.

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[00:17:27] thankfully in the new generation of scenarios, which again we published a few months back, we have moved toward more reasonable names. Now they're just called high, medium, low, and very low. because no one really knew what, you know, SSP24.5 actually meant. and we love acronyms a bit too much in this field.

[00:17:46] **Nate Hagens:** Well, if you write the way you speak, I think that chapter two is gonna be really helpful, for people to understand. You mentioned just briefly double-clicking on human forcings, but what about biological forcings, which increasingly could be as much as humans? Does it measure that too or, is that separate?

[00:18:08] **Zeke Hausfather:** When we talk about forcings, versus feedbacks, which is the other term I used earlier, the distinction between the two is that forcings are external. Okay. So there's something that is happening from, say, humans digging up coal and burning it or the sun changing its output. You know, there's, they're not a response of the planet to something else.

[00:18:31] Ah. That's what we would call feedback. So when we try to go from what humans might do to climate futures, there's a few different steps we have to take. First, we create these emission scenarios of, you know, how much coal, oil, and gas we burn for the rest of the century or, now actually through 2150 because 2100 isn't as far away as it used to be.

[00:18:52] then those get translated by models into concentrations of greenhouse gas in the atmosphere and radiative forcing, and that step includes a number of different feedbacks relating to the carbon cycle itself. So, you know, as the world warms and as CO₂ increases in the atmosphere, a number of different things happen.

[00:19:13] the ocean absorbs a bunch of that CO₂ and becomes more acidic, which results in it being able to absorb less CO₂ than it otherwise would, because

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the pH of the surface waters affect the partitioning into different, sort of carbonates and bicarbonates. The biosphere changes in a bunch of different ways.

[00:19:31] So more CO₂ in the atmosphere leads to some plants growing more robustly, which can actually absorb more carbon. But at the same time, you know, changing precipitation patterns and increasing temperatures can cause, you know, more wildfires, can cause drier soils and plant death, can cause droughts in some regions.

[00:19:46] And so the biosphere in particular is really, complicated and really hard to predict how it's going to respond to both increasing CO₂ in the atmosphere and temperatures. and so there's a pretty big uncertainty in how much carbon you end up with in the atmosphere as a result of human emissions because of all of these carbon cycle feedbacks.

[00:20:04] And this is actually something that has been a little underappreciated by the climate science community until recently. and until recently, a lot of climate models didn't have biogeochemical cycles built into them. They were primarily atmospheric physics models. And so For that reason, the IPCC decided in previous assessment reports to turn emissions into concentrations beforehand and just give all the climate models the same set of concentrations to run, so that all the different models could participate, even the models that didn't have a dynamic carbon cycle built into them.

[00:20:39] That's changing this time around. So in the upcoming seventh assessment report, we've essentially said, "Okay, it's the year, you know, 2026. If your earth system model doesn't have a dynamic carbon cycle, you're out. You can't participate in the main future projections." And so now we're gonna have a much more robust representation of the uncertainties in these carbon cycle feedbacks in the next assessment report.

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[00:21:01] But the final step, once we get to the amount of, you know, CO₂ in the atmosphere and other forces, is to then translate those into the actual warming. And when you do that, there's a whole bunch of additional feedback that comes into play. So how does, you know, how do clouds respond to increasing temperatures?

[00:21:15] How does water vapor in the atmosphere respond to increased evaporation? How do snow and ice cover respond? And how do the changes in snow and ice cover affect the reflectivity of surfaces, what we call albedo? And so, you know, even going from knowing how much CO₂ into the atmosphere to warming introduces its own wide uncertainties, and that's what we call climate sensitivity.

[00:21:34] And so in the last IPCC report, we said, "If you double the amount of CO₂ in the atmosphere, you get somewhere between two degrees and five degrees of warming, a very likely range." and that's a pretty big range, and that's just-- that's not even including the carbon cycle feedback uncertainties. That's just how the climate system itself responds to warming.

[00:21:52] **Nate Hagens:** And, that wasn't even the whole range. That was like the midpoint of the range. There were some, like, there were nine or 10, I think.

[00:21:57] **Zeke Hausfather:** Well, two to five is the 90th percentile. Okay. So there's about a 10%-ish chance that it's outside of that, probably with more uncertainty on the high end than the low end.

[00:22:06] **Nate Hagens:** And is that, I mean, there's three, three kinds of sensitivity, right? The equilibrium climate sensitivity, which is near term and transient TCR, which is 100 years or so, and then Earth's system sensitivity, which is the one we really should care about, which is the long term after everything is equilibrated.

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[00:22:27] The two to the five, is that the first one, the equilibrium climate sensitivity?

[00:22:31] **Zeke Hausfather:** Yeah. So, so transient climate response, TCR, is even shorter than 100 years. It's more like 20-ish year response times– Oh, okay ... to the climate system. But you can run it out to 2100. Their equilibrium climate sensitivity is on the timescale of three to 500 years, so when the fast climate processes and sort of ocean responses mostly equilibrate.

[00:22:53] And then Earth system sensitivity is the much longer term. The challenge with Earth system sensitivity, and to be honest, even equilibrium climate sensitivity, is that they represent a sort of weird experiment. and this actually also goes back to a bit of a weird quirk in climate modeling. So as I mentioned, a lot of climate models until recent decades didn't include biogeochemistry, and didn't have a dynamic carbon cycle.

[00:23:17] And so the experiment that people ran, instead of saying, "What if we double emissions?" Was, "What if we double concentrations and hold it constant?" And so they say, if you keep CO₂ in the atmosphere at, say, 560 parts per million, which is doubling the pre-industrial level of 280, and hold that steady for 300 years or 3,000 years, what happens to the climate system?

[00:23:40] But holding the amount of CO₂ in the atmosphere steady for thousands of years itself requires some very weird assumptions, right? You know, you'd have to have some emissions continuing. '

[00:23:52] **Nate Hagens:** Cause that never happens historically usually. Yeah. Yeah.

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[00:23:55] **Zeke Hausfather:** Well, so if we could actually get emissions all the way down to zero, atmospheric CO₂ would fall pretty quickly, because the biosphere in the ocean would take up more than is being emitted.

[00:24:04] it'd eventually level off at a new equilibrium, but it doesn't sort of stay at a fixed level. And so if you keep CO₂ fixed in the atmosphere at, say, 560 parts per million, what ends up happening is you end up having immediate warming, you know, and then a long tail of additional warming as these processes equilibrate.

[00:24:26] And over thousands of years, that ends up being very significant. You know, ice sheets melt, exposing darker surfaces underneath. You know, ecosystems dramatically change, and that's this Earth system sensitivity question. But if instead of holding atmospheric concentrations constant, we get our emissions down to zero, then a very different set of things happens.

[00:24:44] So as I mentioned, CO₂ in the atmosphere falls up to a point, but the oceans continue to warm up, because they're out of equilibrium today. Like, the oceans have been our friend historically because they've absorbed 90% of the heat trapped by greenhouse gases. They are buffering the rest of the climate system and making it so we don't experience the full sort of heat of climate change immediately.

[00:25:05] And so falling CO₂ would cause cooling, warming oceans causes warming. Those two things largely cancel each other out. And so if we can get emissions down to zero, warming more or less stops, at least over multi-century to millennial timescales, which in some ways is good news. It means there's not a huge amount of warming in the pipeline, but at the same time, it's bad news because it means that even if we get our emissions all the way down to zero, we're stuck with what warming we have.

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[00:25:30] The Earth is not going to cool back down barring, you know, removing more CO₂ than we're adding or doing other sort of more out of, out there climate engineering approaches.

[00:25:40] **Nate Hagens:** I'm gonna jump around here 'cause, n- this-- I knew this was gonna happen. I have, like, 30 times more questions than I started with.

[00:25:49] A phrase that I've heard lately, and I've actually used it myself, is because of the Super El Niño, that this year, and maybe next year, and we can talk about that, will be the warmest year of my life and your life. But statistically speaking likely the coolest year of the rest of our lives. Is that an accurate scientific statement?

[00:26:14] **Zeke Hausfather:** So I might flip that around. This year might be the warmest. Next year will definitely be the warmest.

[00:26:19] **Nate Hagens:** Oh, really? So 2027 will be warmer than- Yeah.

[00:26:23] **Zeke Hausfather:** 2027 will be much warmer than 2026. And the reason for that is that there's a lag of about three to five months between when El Niño conditions peak in the tropical Pacific and when we see the biggest global temperature response.

[00:26:36] And this is a pretty consistent pattern we've seen in other big El Niño years. So for example, 1997 was like 2026, where there's a very strong El Niño developing. It peaked around December 1997. 1997 was quite a warm year. I don't think it was quite the warmest year on record at the time, but it was close.

[00:26:53] And then 1998 just blew everything out of the water. It was the warmest year, you know, by a huge margin. 2015 and 2016 were the exact same story. 2015 was, you know, in the top three warmest years, and 2016 was the

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warmest year by a big margin. 2023 and 2024, similar. 2023 actually was the warmest year on record at the time, and then 2023 was considerably warmer than it.

[00:27:13] And so we expect to see something very similar this time around, where 2026 is either the warmest year or the second warmest year, but if it is the warmest year, it's gonna be by, you know, not by a huge margin. But 2027 is gonna be stunning, particularly if the models are right that we're gonna see an El Niño, you know, beyond anything we've seen in history.

[00:27:30] And my latest estimate is that 2027 will be about 1.8 degrees above pre-industrial levels, which is a huge jump from the previous record, which was only 1.5 degrees. Is it gonna be the warmest year or the, sorry, coolest year you'll experience in the rest of your life?

[00:27:47] **Nate Hagens:** Well, well, with the-- Of course it'll retreat after that for a few years.

[00:27:51] Yeah. But that, including that.

[00:27:54] **Zeke Hausfather:** Yeah, I mean, the line keeps going up, right? You know, u- until we get emissions all the way down to zero, which isn't gonna happen anytime soon- No ... the world will continue to warm. And so, you know, an El Niño year like what we're ex- experiencing right now is in some ways a sneak peek of what the new normal will be a decade from now, right?

[00:28:11] **Nate Hagens:** Right. Oh, that's a way to look at it. When you have a strong El Niño, it's a glimpse at what it would be 10 years out, the average.

[00:28:18] **Zeke Hausfather:** Yeah. Strong El Niños add about 0.2 degrees to annual temperatures the year after they peak. You know, this year might be 0.3

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because this El Niño is crazy. But we add about 0.2 degrees from human emissions every eight years, and so we're essentially adding a permanent super El Niño worth of heat to the climate system every eight years just by burning coal, oil, and gas.

[00:28:39] **Nate Hagens:** I wanna get into the El Niño, but one more question on the scenarios. So on another podcast recently, you said the SSP3 scenario felt a little close to home for you these days. Why does that specific scenario hit home, and what does it do to the emissions picture?

[00:28:56] **Zeke Hausfather:** The SSPs are an attempt to look at different potential socioeconomic futures.

[00:29:03] So there's five different SSPs. SSP1, which is a sort of a world that very much embraces sustainability and, you know, more modest resource use. There's SSP2, which is sort of current trends broadly continuing as they are today. I'll get back to SSP3 in a second. SSP4 is a world of very high inequality.

[00:29:22] You know, the rich get very rich, the poor stay relatively poor. And then SSP5 is a world where everyone gets quite rich, but, you know, continues to burn fossil fuels willy-nilly. So SSP3 is the worst world from an adaptive capacity standpoint, it's a world that is relatively poor overall, that is characterized by resurgent nationalism, a lack of international cooperation, you know, lots of regional conflicts.

[00:29:47] Countries turn more back to domestic resources because there's not a robust trade in things. You know, many things that seem to be very much, you know, characterizing the last decade or so, with what we're seeing in, you know, Ukraine and the Middle East and all these other conflicts. I hope that's a blip.

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[00:30:04] I hope that it doesn't become the dominant mode of the 21st century because it would also just be a really bad future for humanity. But that's a world that because of a lack of cooperation, because of slow growth, because of persistent poverty in places like Sub-Saharan Africa, the world is in a very bad position to adapt to the impacts of climate change.

[00:30:24] And we're seeing slower technological growth, we're seeing slower technological transfer and deployment, and so emissions remain high for quite some time. and so in the new set of scenarios, the ones that we published for the upcoming IPCC report, the high scenario is associated with an SSP3 world.

[00:30:42] And so it's one where global emissions continue to increase. You know, they're about 50% higher by 2100 than they are today. So not crazy. You know, we're burning 50% more fossil fuels in 75 years than we are today.

[00:30:55] **Nate Hagens:** Zero chance of that.

[00:30:57] **Zeke Hausfather:** The world burned 30% more fossil fuels in a single decade between 2000 and 2010.

[00:31:01] **Nate Hagens:** Yeah. Yeah. Well–

[00:31:03] **Zeke Hausfather:** But, that reflects the fact that even in a poor, conflict-ridden world, you know, solar is quite cheap, right? You know, we're gonna be using less coal in 2100 than today because alternatives are cheaper and in people's self-interest, even excluding concerns around climate change.

[00:31:18] And I think that's what really has changed in the scenario literature. So one thing we didn't really touch on scenarios is how the high end has changed. So in previous generations of scenarios, we had outcomes like RCP8.5 or SSP5, 8.5,

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where the world was, you know, tripled global emissions by 2100, and was burning five times more coal by 2100.

[00:31:38] And those reflected, you know, assumptions in energy system models at the time that clean energy would remain expensive and that fossil fuels would remain cheap, particularly coal. And so that the 21st century would be dominated by, you know, increasing coal use, and that seems a lot less likely today, which I think is some good news.

[00:31:57] **Nate Hagens:** I have to disagree with you on that. Clearly we need to have a larger percentage of our energy mix be renewable, but we're using the engine of coal to build those rebuildable, technologies, solar panels and wind turbines. In the last 10 years, from 2015 through the end of tw- 2025, we grew solar globally, 4,400 terawatt hours worth because it got 90-some percent cheaper.

[00:32:32] But in that same 10 years, we grew coal and natural gas and oil 14,000 terawatt hours. So we're building-- we're growing the whole thing, and solar keeps getting cheaper, and we keep having more emissions. So I don't know how solar getting cheaper is good news for the climate unless our entire economic system and our values and aspirations and governance also changes.

[00:32:56] **Zeke Hausfather:** I mean- It's certainly not gonna solve the problem by itself, but coal use globally has been relatively or has, has plateaued more or less since twenty fifteen, so over the last decade, which, you know, isn't what we need. We're still setting records by a small margin, but it's been relatively flat.

[00:33:15] Gas use has increased pretty dramatically. Oil use is a bit more complicated. It increased, though has flattened in the last few years, as EV adoption has taken off. You know, thirty percent of all cars sold globally this year

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are electric. The US is only five percent. We're the laggards here. and that's pushing down oil demand or starting to really eat into oil demand.

[00:33:37] And, you know, obviously, the current situation in the Middle East is accelerating that by driving up oil prices and making alternatives cheaper. But I do think there's some truth in that coal hasn't declined, and it's still slightly increasing, and gas has increased pretty rapidly. That being said, you know, clean energy from wind and solar is going to generate more than natural gas globally this year for the first time.

[00:33:59] you know, and if that weren't the case, if it hadn't increased exponentially, the world would be burning a lot more coal, oil, and gas today. So we haven't quite reached the point where we have peaked global emissions and seen them decline. You know, fossil fuel use is still growing, albeit, you know, at less, well less than one percent a year compared to, you know, more than three percent a year a few decades ago.

[00:34:21] I'm hopeful we'll reach that point in the next few years. You know, China is about to have its third year of falling CO2 emissions or flat to falling CO2 emissions. You know, the US has reduced its emissions by twenty percent. Europe has also reduced its emissions by about twenty percent. The UK is down forty percent.

[00:34:38] You know, there are some success stories out there. The UK today burns no coal. The place where the Industrial Revolution started that used to be, you know, all coal-powered is now one of the first countries to fully phase out coal. So there are some good s-stories out there, but they need to happen a lot faster because a world where we continue down this track where we're heading today is still one where, you know, global emissions flatline But we end up close to three degrees warming by the end of the century, which would be pretty catastrophic.

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[00:35:05] **Nate Hagens:** How many parts per million are we right now? Or I know there's a range depending on what type of time of the year you measure it.

[00:35:12] **Zeke Hausfather:** Let's say 430, slightly below 430 parts per million today.

[00:35:15] **Nate Hagens:** Okay. And has that pace slowed at all, or has it stabilized?

[00:35:20] **Zeke Hausfather:** It's been increasing pretty linearly in recent years.

[00:35:23] So again, if emissions stay flat, the amount of CO₂ in the atmosphere increases linearly. If emissions increase, the amount of CO₂ in the atmosphere, or the increase in CO₂ in the atmosphere accelerates, 'cause the atmosphere is cumulative emissions, right?

[00:35:35] **Nate Hagens:** And if emissions slow, will it become sub-linearly?

[00:35:39] **Zeke Hausfather:** Yeah. So if emissions slow, we still increase CO₂ in the atmosphere, but at a slower rate, at least until emissions fall enough that sinks from the ocean and the land are taking up more than they're emitting. When that actually happens depends on how quickly we reduce emissions. but you could say if we call it cut emissions roughly more than in half, we'll start seeing atmospheric CO₂ concentrations start to slowly fall.

[00:36:02] **Nate Hagens:** Not increasing at a lower rate, but actually falling.

[00:36:06] **Zeke Hausfather:** If we get emissions down far enough. and again, it'll eventually reach a new equilibrium with sinks, so it's not gonna fall forever. But certainly if we get emissions all the way down to zero, then atmospheric CO₂ will fall, you know, by maybe 80 parts per million from where it is today.

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[00:36:21] If we're lucky. Yeah. Yeah. I mean, it depends on how the land and the ocean sinks actually behave, and as I mentioned earlier, there's some pretty big uncertainties there. But again, that's balanced by the oceans continuing to warm up, so that's why temperatures roughly flat line at zero emissions.

[00:36:35] **Nate Hagens:** Well, that's where I wanted to go next. I knew this was gonna happen, that I haven't even begun my prepared questions yet. But you mentioned earlier that the ocean has been our friend in the sense– Yeah ... that it's masking or, removing the warming that we would have on land. Under what scenario does the ocean start to not be our friend?

[00:36:56] **Zeke Hausfather:** So the ocean will n– not be our friend if we want to cool the planet back down. So the ocean is always gonna warm more slowly than the land. Like, water has an immense amount of heat capacity. You know, it's almost unique among molecules out there. It's what makes the Earth so habitable, is that we have these giant oceans to balance out our climate.

[00:37:15] The ocean's surface has warmed about one degree centigrade. The world as a whole has warmed about 1.4 degrees. The land, where we all live, on average has warmed about two degrees. But the deep ocean, if you go down 3,000 feet, has warmed maybe .1, .2 degrees.

[00:37:31] So heat is slowly making its way down from the surface to the deeper layers of the ocean, and that's been slowing down.

[00:37:37] **Nate Hagens:** So the deep ocean is really our friend.

[00:37:40] **Zeke Hausfather:** Yeah. The deep ocean hasn't warmed much at all. Like, if you go down th– three th– or 5,000 meters, you know– Yeah ... the changes are really tiny. And so that will continue to slowly warm up. However, if we try to cool down the atmosphere in the future, again, by getting emissions to

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zero, making CO₂ concentrations start to fall, then the ocean is going to work the opposite way, right?

[00:38:00] It's still absorbing heat. The ocean surface will continue to warm up as the deeper ocean warms up. Yeah ... and so those two s- the things largely counter each other, which is why, again, you get flat warming at zero emissions.

[00:38:11] **Nate Hagens:** Thank you. Okay. Let's move on to your current topic of expertise, though you have many.

[00:38:19] we mentioned El Niño, and I had just naively assumed that it's happening now. When will the Super El Niño peak, I-later this year? And, maybe you can just explain what, what factors are causing this and what your scientific assessment is of, what this means.

[00:38:44] **Zeke Hausfather:** So there's been a number of, y- a handful, you know, let's say eight or nine strong El Niño events, or very strong El Niño events, in the last 150 years.

[00:38:53] And in those events, they almost all peaked near the end of the year. So the most common- Okay ... months of El Niño peaks are November or December. It happened as early as October. It happened as late as February. but the general expectation is events peak right around the end of the year.

[00:39:12] **Nate Hagens:** What is peaking at that point?

[00:39:14] **Zeke Hausfather:** So El Niño, the primary way we measure it, because again, El Niño is a warm water pool at the surface of the tropical Pacific that's driven, you know, by a combination of upwelling on the coast of Peru and westerly wind bursts, across the, the Pacific that drives warm water, over there, on the subsurface.

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[00:39:34] And so that is generally measured in a particular region of the tropical Pacific, say a third of the way across the Pacific off the coast of Peru on the equator, called the Niño 3.4 region, and that, you know, El Niño is a pretty big sort of tongue of warm water in that tropical Pacific region, and the Niño 3.4 region is pretty much the middle of that tongue.

[00:39:57] and so it gives you the best measure of it.

[00:39:59] **Nate Hagens:** So it's not that global temperature is peaking at that point. It's— No ... the size of this, this warm water tongue.

[00:40:05] **Zeke Hausfather:** The size of this, this an— anomalous event,

[00:40:07] **Nate Hagens:** right? Got it. Got it. And this is a big one. You said maybe, three-tenths of a degree Celsius. So what does an event like this actually mean for different parts of the world, and, where might it hit the hardest?

[00:40:18] **Zeke Hausfather:** So three-tenths of a degree Celsius is the global impact of this in terms of global— Okay ... temperatures. The anomaly i— we're seeing in the tropical Pacific is much, much, larger than that. So as of today, it's actually above 3C, more than normal in the Niño 3.4 region, which is, you know, m— more than a gr— degree higher than any previous El Niño event was at this point in time in mid-September.

[00:40:40] So it's blowing every previous event out of the water. And we expect this event to peak at about 4C, in that region, which again, will be more than a full degree higher than the previous strongest El Niño event, which was about 2.75C. again, that's a rough tie between the 1877–1878 event and the 2015–2016 event.

[00:40:59] So we're really in, you know, uncharted waters when it comes to this El Niño. and it has a lot of really big impacts. So that 1877–1878 event was

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associated with massive famines that killed an estimated 50 million people worldwide.

[00:41:13] **Nate Hagens:** Because of heat waves and droughts and deluges?

[00:41:19] **Zeke Hausfather:** So primarily droughts.

[00:41:20] Okay. there are certainly much higher ocean temperatures and those have a bunch of different effects. But El Niño also screws up weather patterns in a really big way. So it leads to a huge amount of rain falling over the tropical Pacific and a huge amount less rain falling in the regions around the tropical Pacific.

[00:41:34] So like Southern Africa, India, Indonesia, Br- northern Brazil, all of these re- Australia, all these regions tend to have much drier years than normal during El Niño.

[00:41:45] **Nate Hagens:** Like you, I'm covering many different topics at once, and last night I was on a chat group with a bunch of scientists and m- macro observers, and they are predicting massive caloric shortages and regional famines in 2028.

[00:42:03] Nothing to do with El Niño, only to do with the fertilizer and shortfalls from the Strait of Hormuz and some of the shipping, shutdowns in Ukraine and, and, in Russia. So I mean, if you add on what you're saying, y- you, this is not good.

[00:42:24] **Zeke Hausfather:** Yeah, it's not a good time to have this record-breaking El Niño event on top of everything else going on in the world right now, particularly with fertilizer shortages.

[00:42:31] Yeah. I mean, the good news is people do seem to be taking it seriously this time. You know, the WMO has done the largest mobilization in the

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history of the organization, the World Meteorological Organization around this El Niño. countries are starting to, you know, prepare. Kenya's distributing livestock vaccines for, You know, diseases that tend to be prominent there 'cause they have much heavier rain than normal.

[00:42:53] south- southern parts of Africa are starting to set up systems of food stocks and distributing drought-tolerant seeds to farmers. So the world is beginning to prepare a little bit. At the same time, you know, a lot of global aid funding has been cut. USAID was, you know, fed through the wood chipper.

[00:43:10] More or less. Yeah. Even some European countries have cut back, so there is a real worry of what's gonna happen this year, particularly in Africa.

[00:43:16] **Nate Hagens:** So many climate scientists that I've read have said that they're worried that this super El Niño marks a turning point of things getting really bad.

[00:43:27] do you feel this way, and what type of event or numbers would you look for, to get to that point, the really bad point?

[00:43:36] **Zeke Hausfather:** So I think it's important to be a little careful when we talk about El Niño. So El Niño itself is primarily a natural phenomenon coming from internal climate variability. There is some evidence that climate change has started making El Niño events more extreme.

[00:43:53] there's a pretty prominent paper published in Nature a couple weeks back looking at a thousand-year coral record in the Galapagos and finding that El Niños in the last fifty years or so seem much stronger than anything in that thousand-year history. But there's not necessarily a super clear mechanism for climate change making it worse, and the models themselves, the climate models don't necessarily have...

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[00:44:14] They're a bit mixed on whether or not El Niño becomes more intense, so we should be a little careful in over attributing the impacts of this El Niño to climate change. That being said, this El Niño is happening on top of a huge amount of climate change, and that climate change itself has been accelerating in recent years, not because of El Niño, but and this is a whole separate topic of conversation, but primarily because we keep putting more CO2 in the atmosphere at the same time that we're cutting air pollution– that has been masking about a third of historical warming, particularly sulfur dioxide emissions. And so I think the combination of those two things, this record-setting El Niño occurring on top of accelerated warming, certainly makes the impacts and many of the impacts much worse, and much harder to respond to.

[00:44:58] and so I think that, you know, this event is certainly going to focus the world's attention on climate change in a big way. You know, if we actually end up at 1.8 degrees in 2027, like that will be smashing the previous record by a large amount, and we'll see, you know, a huge amount of damage worldwide, associated both with the El Niño and the high temperatures.

[00:45:17] and hopefully will make people realize that we don't want that to become the new normal, right? We don't want a world of, 1.7, 1.8 degrees.

[00:45:23] **Nate Hagens:** Well, in, in the same way that, the day after the nuclear, movie kind of galvanized people's attention, you as a climate scientist who have been very much in the public domain this year, and many others talking about this issue, next year you're gonna be proved right or not.

[00:45:44] and I would think that, I expect you will be proven right, and then maybe more government and philanthropy and hyper agents and society and politicians and young people who will be future leaders will prioritize, Earth's ecology and regenerating, working towards, better future outcomes

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[00:46:11] **Zeke Hausfather:** Yeah.

[00:46:11] I mean, I think that, like our politics, interest in climate is thermostatic. You know, we saw a big focus on climate in 2020, 2021, 2022. I feel like the last four years since then, it's been a little diminished as an issue, particularly in the US, in part because climate as a long-term problem ends up being a bit of a political luxury good.

[00:46:36] You know, if things are going well, if people feel like their lives are reasonably okay, they tend to focus more on long-term problems. Yeah. Whereas if the world is literally on fire, from wars or economic crises, they tend to focus a lot more on those. And so, you know, I think that we are coming into a period of time when the climate will be get- be getting a lot more attention, in part because of these extreme events that we're seeing, both associated with this El Niño and, just the acceleration of warming in recent years.

[00:47:06] **Nate Hagens:** You mentioned aerosol de-masking. I had Leon Simons on a couple- years ago to talk about that, that it's, removing some of the global cooling impact from, bunker fuels and things like that. c- can you give an update on that, and do you think that's gonna continue to be a big story in the coming decade, and, affecting the rate of warming in the future?

[00:47:35] **Zeke Hausfather:** Aerosols, particularly sulfur dioxide, cool the planet but in two ways. One is that they are very reflective particles. They directly scatter sunlight back to space. That's called the direct aerosol effect. but they also serve as cloud condensation nuclei for low-lying clouds. So if the air is too clean, it's harder for clouds to form, and so having a certain level of air pollution actually makes it a little cloudier.

[00:47:58] And those low-lying clouds are themselves reflective. You know, they're white and billowy. and so that has a cooling effect as well. And so in our

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models, we estimate that aerosols have contributed to somewhere between 0.2C and 1.2C cooling, compared to pre-industrial levels, and that's a huge range.

[00:48:21] **Nate Hagens:** If it's 1.2C, that means that climate would be 2.5C without the aerosols?

[00:48:27] **Zeke Hausfather:** It does, yeah

[00:48:28] **Nate Hagens:** Wow

[00:48:28] **Zeke Hausfather:** And that would be a really bad outcome. And so some of the very high climate sensitivity scenarios have very high aerosol masking 'cause the two are correlated, right?

[00:48:37] **Nate Hagens:** Okay, I didn't know that.

[00:48:39] **Zeke Hausfather:** Because if you have really high climate sensitivity, you kinda need high aerosols, otherwise, you know, your model is going to say we should already be at two degrees, or close to two degrees.

[00:48:49] So that itself is a big uncertainty, and a reason to be a little worried about what's gonna happen in the future. and we've seen a pretty big change. You know, global emissions of sulfur dioxide have fallen by 40%, since their peak in around 1980, and most of that decline has happened since 2005 or so.

[00:49:08] China, which is one of the biggest emitters historically of sulfur, you know, you remember these, these old videos of Beijing with sky like pea soup, they've reduced their emissions by 75% just since 2008. It's a huge and a little underappreciated public health success story, where they've, you know, mandated the use of scrubbers in coal-fired power plants and transitioned to electric vehicles and put strict standards on diesel, which tends to have high sulfur emissions.

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[00:49:34] And the combination of those has just led to this huge dramatic cut in their emissions. And then finally in 20, '20, we changed regulations for ships, mandating the use of low diesel-- sorry, low sulfur diesel fuel or low sulfur bulk-bunker fuel, I should say, for shipping, which itself has, you know, led to about an 80% reduction in s- sulfur emissions from shipping.

[00:49:57] And shipping is, you know, only about 10% or so of global sulfur emissions, so it by itself isn't huge, but the location where ships are emitting sulfur is particularly impactful on the climate because it tends to be areas where the air is, relatively cleaner, and so those cloud formation effects are, correspondingly bigger there.

[00:50:15] And so the combination of all these things has contributed to some additional warming. In my estimate, pretty much all of the acceleration we've seen in the rate of warming in recent years has been attri- due to reductions in aerosol emissions. If it were just CO₂ and greenhouse gases, the rate of warming-- the world would still be warming, but it would only be at, you know, .2 C per decade roughly.

[00:50:40] now we're seeing warming of closer to .3 C per decade, and that appears to be due to these aerosol cuts on top of continued emissions.

[00:50:48] **Nate Hagens:** So in, in a weird sort of way, pollution was our friend, for a little while.

[00:50:53] **Zeke Hausfather:** I mean, yes and no, right? There's something like five to eight million people dying prematurely a year from outdoor air pollution.

[00:51:00] No, you're right. You're right. Yeah Like, i-i- in terms of the pure human health impact and damages, I'd much rather take the climate warming than the air pollution. Yeah. So we need to clean it up

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[00:51:07] **Nate Hagens:** So two Berkeley colleagues, Tad Patzek was on the show recently and shared that Earth's energy imbalance is roughly 20 times the entire human economy and growing.

[00:51:20] But maybe briefly, just to kind of connect all these dots, can you explain what the Earth's energy imbalance is, what it represents, and why it's so significant in understanding the current state of Earth's climate?

[00:51:33] **Zeke Hausfather:** So if you recall when we were talking about scenarios, I mentioned that the numbers associated with the scenarios, refer to this thing called radiative forcing, which is a measure of heat trapped in the climate system in sort of watts per meter squared.

[00:51:44] And so Earth energy imbalance is another way of measuring that quantity. So how much heat is entering the planet from the sun and how much is leaving the planet through the atmosphere. And the difference between those two tells you how much heat is being trapped. It tells you the radiative forcing value.

[00:52:01] And so we previously could only model Earth energy imbalance, but starting in the early 2010s, we launched a satellite called CERES that actually directly measures Earth energy balance. What that satellite does show is that Earth's energy balance has been steadily increasing and, you know, recently it's been increasing considerably more quickly.

[00:52:26] this again is probably driven by reductions in sulfur emissions on top of continued emissions of greenhouse gases. There's also some concern that there might be feedback in the climate system as well at work here. So one of the big changes that we see in climate models as the world warms is that we get less low-lying clouds.

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[00:52:48] Similar mechanism to what happens with sulfur, but n- as a result of warming itself, just a warmer climate tends to have a bit less low-lying clouds, and that itself represents a feedback in the climate system, leading to more warming. But how m- big a change in clouds there is varies enormously by the model, and models with very high climate sensitivity that show, you know, a much higher amount of future warming tend to have a much bigger reduction in low-lying clouds.

[00:53:14] and so if what we're seeing in satellite measurements of Earth energy imbalance and of cloud behaviors is... How much of that is reflecting aerosol reductions and how much is reflecting potential temperature-mediated feedback is a huge question, and one that a lot of my colleagues are focusing a lot of time on right now.

[00:53:32] Because in some ways, if it's just sulfur, it's good news, right? You know, that's the devil we know, somewhat. There's still big uncertainties there, but eventually we'll get sulfur to zero, and that's not gonna contribute to more warming after that point. If it's feedback, then it's something that is driven by climate change itself, and that's gonna continue to happen as the world continues to warm.

[00:53:53] **Nate Hagens:** So one of those feedbacks, presumably would be methane, and that is the second biggest contributor to warming, and my understanding is it behaves quite differently. And based on your res- research, where do things stand with methane or permafrost or any of that right now, and, how should we be focused on it, as a priority relative to carbon?

[00:54:16] **Zeke Hausfather:** Yeah. So methane is responsible for about .4 C of historical warming, so a sizable chunk given that we're at 1.4 C today. Sure. and methane Most of that warming actually happened earlier in the century. The rate

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of warming from methane has actually slowed down pretty substantially, and part of that is that unlike CO₂, methane doesn't accumulate in the atmosphere.

[00:54:39] It has a natural chemical sink. So CO₂ is an incredibly stable molecule. CO₂ just doesn't break down naturally, which means that if we emit CO₂ to the atmosphere, it either stays in the atmosphere or it has to go somewhere, like into a tree or into the ocean. Methane is very chemically unstable. That's why it burns.

[00:54:56] You can't burn CO₂, you can burn methane. and methane naturally oxidizes in the atmosphere and inter-interacts with OH radicals, hydroxyl radicals, and breaks down through a complicated series of chemical interactions, but eventually forms carbon dioxide and water vapor. And so because of that, it's fairly short-lived.

[00:55:12] You know, CO₂ is forever. It takes thousands of years for the warming from CO₂ to dissipate, whereas the warming from methane dissipates in a decade or so, which also makes methane a very powerful level to-- lever to cool the planet quickly. If we could actually cut methane emissions, we could have cooling, whereas if we cut CO₂ emissions, we just slow down the rate the planet is warming.

[00:55:31] But what's happening with methane feedback is an important question as well. And so here there's a number of different systems that we're concerned about. You know, one that you mentioned is permafrost. There we're seeing some regional fluxes of methane that are concerning, but on a global basis, methane emissions from permafrost are still relatively minor.

[00:55:51] we expect that to potentially change as permafrost continues to thaw at an accelerating rate, and it's something we're keeping an eye on. What we've seen more recently, though, is methane from wetlands appears to have increased

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substantially, and much of the growth of methane in the atmosphere we've seen in the last decade appears to be coming from wetland systems.

[00:56:10] We're not entirely sure why. It might be a temperature-mediated feedback where higher temperatures are leading to more methanogenesis in swamps and wetlands in the tropics in particular. There's obviously also some contribution to increasing methane concentrations from fossil fuels. but it seems like actually natural methane emissions, or natural being a slightly misleading term because these are being triggered by feedbacks to, to temperature, are the dominant driver of increases in atmospheric methane concentrations recently.

[00:56:42] **Nate Hagens:** I hope you'll take this as a compliment, Zeke, but in listening to you, I just had a recognition that it's kind of like talking to Claude or an AI because your answers are almost like a large language model. They're pure signal-to-noise science. it's, it's interesting. So, that, that's meant as a compliment and also a segue into talking about AI.

[00:57:09] Two questions about AI. Has anyone used one of the most powerful models, and just fed in all of the climate data and had some new inferences? I mean, can AI help us make sense of IPCC-type work?

[00:57:27] **Zeke Hausfather:** So historically, using AI for physics-based processes has been a little challenging, or even stepping aside from AI for a little bit, using machine learning models for physics-based processes has been challenging because physics likes linear or nonlinear relationships.

[00:57:42] It likes relationships that are characterized by a smooth function. Machine learning often forms inferences in ways that are not necessarily linear. And so trying to create physics-based simulations from pure machine learning approaches have historically not always worked out that well. Now, there are some exceptions to that.

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[00:58:02] You know, AI-based weather models are actually quite phenomenal, but that's largely a sort of pattern and state inference based on a large training data of previous weather models. We don't have, you know, a huge, you know, set of experiments of the planet as a whole, particularly out of sample into the future that we can feed into AI models to learn from in the same way.

[00:58:23] And so, you know, I think there are a lot of ways that AI can improve our modeling, particularly on, you know, the coding side to make models run faster, to potentially better downscale them, to better parameterize some of these complicated processes like cloud formation. I don't think we're just gonna be able to feed all our climate data to an AI and say solve it for us.

[00:58:43] **Nate Hagens:** Probably a good thing because, I mean, then people are gonna say, "Well, this is your projection. That's just AI slop." So it's good that we have real scientists doing it.

[00:58:53] **Zeke Hausfather:** The one thing I will mention with AI is that at least in my experience, AI is quite good at answering questions about climate science.

[00:59:01] Like even Grok, which I think is not necessarily the most balanced model.

[00:59:04] **Nate Hagens:** I know. That was one of my hopes too is that you could, like, a- actually I'm thinking about doing this, about recording a Frankly with several different untrained climate models, just the generic thing at a internet cafe, and asking it a series of basic climate questions or ecology questions or energy questions that then anyone in the world could do themselves.

[00:59:28] So do you think that, AI, and I'm gonna ask you some, some environmental ecological impacts from, Yeah ... use of AI in a second in data

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centers, but do you think AI could be a beneficial, information tool for humanity to understand the natural world and our ecosphere?

[00:59:47] **Zeke Hausfather:** So I think there's a hopeful story that one could tell, which is that in modern times, our information ecosystem has become increasingly fragmented.

[00:59:56] and it became far too easy for people to Google what they want to hear– Right ... rather than what is true. You know? Yes. If I wanna find something that says climate change is a Chinese hoax, that's, you know, a Google search away to find something that sounds very compelling that makes that case.

[01:00:11] **Nate Hagens:** Right.

[01:00:11] **Zeke Hausfather:** You know, there's not the Walter Cronkite that the whole nation is listening to anymore. There's not the same sort of information sources that everyone holds with high respect. There is a world where AI changes that. There's a world where it doesn't. But to the extent that AI is effectively a consensus machine, it's trying to give the single best answer to questions.

[01:00:31] You know, whether or not you're a conservative Republican or a liberal progressive Democrat or, you know, a liberal Democrat in the UK, you know, if you ask AI a question about climate change, you're gonna get pretty much the same answer. And so– Yeah,

[01:00:46] **Nate Hagens:** as you

[01:00:46] **Zeke Hausfather:** should ... one thing I'm cautiously optimistic about is it might, in some ways, almost recenter expertise by pointing people to the actual scientific literature and, the scientific consensus on these questions.

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[01:00:57] Because it's really hard to train an AI that gives you climate denial but also answers physics-based questions about another field

[01:01:04] **Nate Hagens:** accurately. Yeah, exactly. So, you recently wrote a piece, Zeke, tracking the energy intensiveness and environmental impact of large language models and AI, a subject that many climate activists and people watching this show have become very vocal about recently.

[01:01:26] Can you walk us through the different types of AI use from web search overviews to AI agents and how they differ in energy use?

[01:01:36] **Zeke Hausfather:** In our modern society, everything or almost everything uses energy. and everything digital uses electricity. and so how we track that is itself challenging, in part because a lot of the AI labs have not been very transparent about how much energy their models use.

[01:01:55] but last year, in 2025, both Google and ChatGPT published figures on their energy use per prompt or per query.

[01:02:06] **Nate Hagens:** Mm-hmm.

[01:02:07] **Zeke Hausfather:** Google said that a typical Gemini prompt uses about 0.24 watt hours, which is quite a small amount. You know, if you think of your lamp as, your LED lamp as 13 watts, that means that every hour it uses 13 watts of electricity.

[01:02:24] so 0.24 watt hours is a small fraction of that, for a single prompt. ChatGPT said theirs was 0.34 watt hours, so not that different. a traditional Google search, at least the last time they published, an estimate of it, which was a bit more than a decade ago, was also about 0.3 watt hours, so it's probably maybe a tenth of that now because of improved- compute processing

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efficiencies. So for a while, people were essentially saying, "Oh, these numbers are so small." Right? 0.24 watts per prompt. I can prompt Gemini all day, and it's not actually gonna use any energy or affect my sort of energy or carbon footprint at all. The problem is that it refers to a prompt in a textbook, like an online chatbot, interaction with no reasoning turned on, which is not the way that AI is being primarily used today.

[01:03:14] So most of the AI use is reasoning models, which themselves use maybe five X more or ten X more energy than a non-reasoning model, 'cause they're doing a whole bunch more work behind the scenes and a bunch of queries to sort of work through a process of determining the best answer. But increasingly, we're also using AI agents.

[01:03:33] And so these AI agents themselves might be given a single prompt, like, "Do this thing," but then they do a whole bunch more research. They spawn 10 separate sub-agents that go off and do things. They, you know, they might run for 10 minutes or even 30 minutes or, in some cases multiple hours, to accomplish a task.

[01:03:52] And so that's calling, you know, the equivalent of thousands of individual prompts or individual queries. and so I used four months of my own personal cloud code, data, 'cause, you know, as a, a scientist and someone who does a lot of coding and a lot of data analysis, I, like almost everyone else these days, you know, use these AI tools to, help me with data analysis and, coding.

[01:04:19] and I found that, you know, a typical, session of using cloud code, you know, was somewhere between point two and one point two kilowatt hours, so two hundred to one thousand two hundred watt hours, compared to, you know, point two watt hours for a single prompt. That's, you know, much more energy use.

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[01:04:39] And then a--an average day of AI agent use, you know, was somewhere between one point two and six kilowatt hours. And so to put that in perspective, that's, you know, roughly the equivalent of running two fridges a day, to power my AI energy use, which is a lot. It's, you know, adding two fridges to your house is a non-trivial amount of additional energy use.

[01:05:00] Now, I'm probably, you know, ninetieth, ninety-fifth percentile in the curve of users. I work for a tech company in Silicon Valley. I've been drinking from the AI fire hose in terms of the tools. But that's, you know, where things are going. You know, these tools are becoming more ubiquitous in our daily lives.

[01:05:15] They're being embedded in more processes. You know, they're becoming more autonomous. Agents are doing their own things. And so there is a worry that, you know, the energy use of this is really just going exponential.

[01:05:25] **Nate Hagens:** I am very worried about that. Having said that, though I don't-- I expect you couldn't have been as productive and had the science and the multiple things that you're trying to juggle by just using Google the way it was five, 10 years ago.

[01:05:43] **Zeke Hausfather:** Yeah. I mean, these tools enable a lot more productivity. Yeah. And so you could say, "Well, if I were using my laptop for the amount of hours it would've taken to write all that code or create all those dashboards and visualizations without AI coding tools helping, you know, maybe it would've used that much energy use anyway."

[01:05:59] **Nate Hagens:** Right, and six months.

[01:06:01] **Zeke Hausfather:** Yeah. But I think that's a bit of an unfair comparison, right? 'Cause I just wouldn't have done it. Like-- Right ... There's this idea called

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Jevons paradox, which comes from the energy efficiency literature among other places. The idea is that as the cost of something declines, we use it more.

[01:06:16] So lighting is a classic case here, right? You know, we co- cut the cost of lighting, you know, by 1,000% or by 10X when we switched from incandescent bulbs to LED bulbs. And you'd think that means we'd be paying 10 times less for lighting today. But the problem is LEDs are so cheap, they're now everywhere and everything.

[01:06:35] So we use, you know, maybe three times more lighting on average in terms of lumen output, even as the cost of lighting has gone down by 10X. So it's still reduced, but it's reduced a lot less than it otherwise would. And I think there's a very similar thing at play with computers, where as these tools get more powerful and cheaper, you know, the amount I can do, you know, for the cost now is very different than it was three years ago.

[01:06:59] We're gonna be using them a lot more, and they're just gonna be embedded in a lot more processes that we interact with in our daily lives, even if we're not making a decision to use them.

[01:07:08] **Nate Hagens:** I agree. And that paradox applies to solar and all kinds of things in our world, in our current system that is.

[01:07:18] So getting back to global heating, You're probably the 40th or 50th climate scientist that I know personally, and you're all completely in agreement that the world is warming and headed to north of two degrees Celsius, and some, of them have much higher, midpoints in their, ranges. But there's dif-- like with every topic, that's important to our future, there's quite a standard deviation.

[01:07:51] What do we really not know yet? And, what, is the remaining uncertainty in the whole climate ecological, planetary boundary space? And what is your

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midpoint currently, and what, do we not know, do you think? I suppose there are always unknown unknowns as well.

[01:08:13] **Zeke Hausfather:** I guess there's really three big uncertainties that future warming comes down to.

[01:08:19] A--and we covered some of these a little earlier when we were talking about scenarios, but the first is what we do as humans, right? How-- do we increase emissions? Do we decrease emissions? Do they stay flat? How quickly? That's maybe half the uncertainty in future warming at this point. There's how the Earth's biogeochemistry responds to our warming, and how that affects greenhouse gas concentrations, so carbon cycle feedback that we've talked about a fair bit.

[01:08:44] And then the final piece is this question of climate sensitivity. How do all the feedbacks in the climate system around water vapor and clouds and albedo, et cetera, respond to that warming? And if we put all of them together, you know, we get a pretty wide range of future warming possibilities. I'll give sort of my estimates for where we might end up in 2100, but obviously 2100 is just an arbitrary point in time, and the world keeps warming after that if emissions haven't gotten all the way down to zero.

[01:09:16] So in 2100, if we, you know, keep on a trajectory we roughly are today, so emissions are roughly flat for the rest of the century, which you could argue might be a little optimistic, but, you know, I think is reasonable.

[01:09:30] **Nate Hagens:** So the emissions from human activities stay at roughly the level of 2026. They don't increase, but they stay up here.

[01:09:37] **Zeke Hausfather:** Yeah. So we're emitting about forty gigatons of CO₂ a year today, about sixty gigatons of CO₂ equivalent if you add in methane and nit-

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nitrous oxide and all these other things. If you just keep that at today's levels. Okay. So we don't cut emissions at all– Right ... but we also don't increase them globally.

[01:09:49] **Nate Hagens:** Right.

[01:09:50] **Zeke Hausfather:** In that world, we end up at about three degrees, by 2100, but with a pretty big uncertainty range. Right ... you know, it could be as little as two degrees, could be as much as four degrees. Right. And that really depends on these questions of how the climate responds to our emissions. Two degrees would be really lucky that we'd end up only that low.

[01:10:10] **Nate Hagens:** Well, especially since next year we might see one point eight temporarily already in 2027

[01:10:16] **Zeke Hausfather:** And, two are rounding a little bit. I think the– Yeah ... the low end of the models is like 2.2 in that scenario. Okay. so it's a bit higher. But the four degree one would be particularly catastrophic, and I think that we don't have a good way to reduce that uncertainty.

[01:10:28] And so, you know, we shouldn't just plan for that central outcome. We shouldn't plan for three degrees. We should, you know, try to calibrate, how we can reduce those tail risks, how can re– we reduce the risk of, four degrees. And, even that four degrees is, again, let's call it a 90th percentile confidence, right?

[01:10:44] And so there's tail risks well beyond that, particularly if we start talking about some of the potential tipping points in the climate system.

[01:10:50] **Nate Hagens:** And, again, that's a global average, which means the land is almost double that, right? 50%

[01:10:55] **Zeke Hausvater:** faster,

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[01:10:55] **Nate Hagens:** yeah. Okay. And o- on the other hand?

[01:11:00] **Zeke Hausfather:** So I think if we roll back climate policy, if we end up, you know, in a higher emissions world, you know, we could get to closer to 3.5 degrees by 2100, say two and a half to four and a half degrees is the range there.

[01:11:13] And again, that continues warming after 2100. So if you go out to, you know, 2150, there's a, a non-trivial, say a, a one in four chance of even five degrees warming in that high scenario.

[01:11:25] **Nate Hagens:** Yeah. Like, why, do we even-- I mean, I can understand why we look at 2050, because your baby's gonna be 27 then or so.

[01:11:33] Mm-hmm. But from an ethical standpoint, 2500 Common Era is equivalent to 2100 because it shows the living systems for all the other descendants of ours and other species into the future. So does it-- do we keep warming after 2150 then?

[01:11:56] **Zeke Hausfather:** I mean, if emissions stay above zero, we do. I mean, one of the big challenges going out further than that is that the human dimension becomes so uncertain.

[01:12:06] Like, are we still burning coal in 2150? I hope not. I hope humans are smarter than that. Yeah, I, don't,

[01:12:13] **Nate Hagens:** I think so.

[01:12:14] **Zeke Hausfather:** But, yeah. but it becomes harder and harder. But if we do end up getting emissions, you know, close to or at zero, you know, the world will hopefully stop warming.

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[01:12:24] **Nate Hagens:** Tell me the scientific mechanism of one day, that human emissions are zero, they've gone from 40 gigatons a year down to zero.

[01:12:40] What, what is actually happening then in the biosphere?

[01:12:43] **Zeke Hausfather:** Sure. So for a while, for a couple hundred years after that point, the biosphere is going to be absorbing more carbon than it is releasing. But, you know, we also are continually increasing emissions. Once we get our emissions to zero, there'll still be some CO₂, net CO₂ that's taken out by the biosphere up to a point.

[01:13:04] Eventually, it'll reach an equilibrium, and the oceans are similarly responding. How good the biosphere is at taking up carbon depends on how warm the planet is, how other human influences on the biosphere have affected things. Like, if we're still deforesting the Amazon, it's gonna be a lot worse at that.

[01:13:22] and those things interact with each other. The higher the temperature gets, the bigger the uncertainties get on the biosphere response.

[01:13:28] **Nate Hagens:** Just out of curiosity, how important are Earth's forests as a sink, to stay at least the size they are today in the coming century?

[01:13:36] **Zeke Hausfather:** They're pretty important. You know, land use emissions, which are primarily deforestation, are about 10% of global emissions today, so let's say about four gigatons of carbon.

[01:13:47] you know, that's a substantial amount, and if we're actually going to stop the world from warming, we don't-- we need to not just cut fossil fuels and, replace them with cleaner alternatives, we also need to eliminate deforestation and ideally transform that, you know, four giga-gigatons a year loss into a couple gigatons a year net growth of trees globally.

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[01:14:07] **Nate Hagens:** Yeah. No, that was where I was going. Well, no, where I was going is, if we deforest at a higher amount because we have fuel shortages or whatever, like in 2008, the Greek army had to have guards in the northern forests in Greece to help avoid people cutting down the forest for heat.

[01:14:34] So the standing forest is what percent of Earth's sink capacity for carbon, or don't you know that?

[01:14:43] **Zeke Hausfather:** I don't know forests specifically. The biosphere as a whole is, a little less than half of the, the net carbon sink. The oceans are slightly more than half.

[01:14:53] **Nate Hagens:** I didn't expect you to know it, but you've been such, like a large language model that I thought you might just instantly know that.

[01:14:59] So, as a climate scientist and as a United States citizen, let me ask you this. Our nation pulled out of the IPCC this year, and at the same time, we've been dismantling a lot of the scientific measuring apparatus, climate.gov, the billion-dollar disasters database, ocean sensors, the 40-year satellite sea ice record that ended, I think last July.

[01:15:31] How is all that gonna affect the data and, what are the risks? And are there other nations then that can pick up the reins and take a lead?

[01:15:41] **Zeke Hausfather:** Yeah. I mean, thankfully, the ocean sensors appeared to have been saved by congressional action, but- Okay ... many of those other things have been cut. so I divide it into two categories.

[01:15:52] You know, one big service the US does, particularly NOAA, the National Oceanic and Atmospheric Administration, is data aggregation and analysis, and I think that definitely is being cut in many ways, and particularly the public

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presentation of that is being toned back. I think that can more easily be replaced by others.

[01:16:13] So Copernicus, which is the, big, EU, scientific group, is very much trying to rebuild many of the functions that NOAA currently does around climate data aggregation, and for, to provide sort of a, a separate independent set of tools, so we're not just reliant on the US government to keep these projects going.

[01:16:34] That said, the measurement side is the harder to replace bit. You know, satellites in particular, if they're not replaced at the end of their life, produce a gap that can never be filled. You know, you can't go back in time and launch a satellite. And so I know there's a lot of discussion in Europe in particular, among the Chinese, others, of like what are the critical earth observation satellites, which ones are at risk of having big gaps because there's not funding for replacements, when they fall out of orbit or malfunction, and, you know, what can we launch to replace those.

[01:17:09] I don't think there's been huge gaps in most cases yet, but that may well change. And even if there is a change in political priorities of the US, it may take time to get new missions together to replace instruments that have degraded. So, I think that we are in- increasingly worried about data gaps and what that's going to mean.

[01:17:30] **Nate Hagens:** As an American, how do you feel about this, as a scientist who is working with scientists from all over the world?

[01:17:38] **Zeke Hausfather:** I mean, it's a little embarrassing, right? Yeah, right. Having your president refer to your entire field as a Chinese hoax. explaining that to my Chinese colleagues is at least to some very funny conversations.

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[01:17:50] Yeah. 'Cause they're like, "We don't think it's a hoax." "Our government sent us here to help write this report." Yeah. They're taking it seriously, even if your government is not.

[01:17:59] **Nate Hagens:** We've seen science fiction movies about this where scientists from around the world were the ones kind of holding together the collaboration o- of the world.

[01:18:11] and what, what better topics than for, for scientists from all the countries to collaborate on is the biosphere and where we're headed. I mean, it just seems like a hopeful path that brings us together, but I may be naive.

[01:18:27] **Zeke Hausfather:** I'm hopeful that people will see it that way. I mean, it's... Politics seems to corrupt everything it touches, and, you know, a lot of the things like the biosphere, like the climate that really shouldn't be partisan issues have become partisan issues in a way that I think is deeply challenging for our ability to actually address these problems.

[01:18:46] **Nate Hagens:** So, we talked earlier about next year's likely record-setting temperatures- Mm-hmm ... and maybe people will start to pay attention. But on the flip side, do you think our culture is beginning to experience alarm fatigue after hearing and seeing similar headlines for years now? And how do you think we cont- continue to motivate people, especially young people, even with the constant stream of this type of news?

[01:19:17] **Zeke Hausfather:** It's a tough question. You know, I certainly think there are people out there who go too far on the alarm side. You know, there's a, a legendary and, now deceased unfortunately climate scientist named Stephen Schneider, once said that when it comes to climate change, the end of the world and good for us are the two least likely outcomes.

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[01:19:37] **Nate Hagens:** Yeah.

[01:19:38] **Zeke Hausfather:** and I think there's an incentive to try to portray problems as existential because people think that if they're not existential, people aren't gonna try to solve them. You know? I feel like there's a lot of parallels right now with a lot of the AI risk discussion happening– Mm–hmm ... in the public domain.

[01:19:52] But most of the problems we face as a society, almost all the problems we face as a society are not existential. You know, poverty, hunger, traditional environmental pollution, all these things make our lives worse, but we still have managed historically to address them. And so I think we need to treat, in some ways, climate as a normal problem, just like AI as a normal technology.

[01:20:18] And be better at addressing those sorts of normal problems rather than portraying it as the ur–problem that all other problems are subservient to. but I feel like our politics are also just not good at addressing normal problems anymore. They need a crisis to respond.

[01:20:33] **Nate Hagens:** Yeah, I agree with both of those.

[01:20:34] **Zeke Hausfather:** But that then leads to people being very fatigued about the constant cr– state of crisis.

[01:20:39] **Nate Hagens:** And it's not just climate, as you're aware. I wanna be respectful of your time, knowing your schedule and that you have a young human in your household. So I will ask you some, some closing questions if you have a few more minutes.

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[01:20:54] What can someone listening to this episode do now, today, this week, this month, to help address some of the challenges in our world, or is it all up to politicians and leaders?

[01:21:06] **Zeke Hausfather:** I mean, I think there's some things that people can definitely do. You know, for one thing, we in democracies at least have some say in our policies and leaders.

[01:21:16] so being more politically engaged, voting, making-- writing to your policymakers, calling your policymakers, you'd be surprised at how few actual contacts they get from their constituents, at least in the US. and so, you know, that, that can actually matter. But beyond that, you know, I'm not one to say that if we just reduce our carbon footprint, it's gonna solve this problem, but at the same time, taking action in your personal life can move the needle on certain things.

[01:21:42] So as someone who works, you know, in Silicon Valley, I am ultimately a bit of a technological optimist, but I think the way that technology becomes cheap enough that it gets deployed widely and that it gets, you know, able to, drive more meaningful policy is adoption. You know, being someone who's an early adopter to rooftop solar or electric vehicles or heat pumps is not only going to reduce your own emissions, but it's also gonna play a role in driving down the cost of those technologies so that other people can adopt them.

[01:22:14] And as those technologies become cheaper, other countries are going to be able to structure policies around getting them more widespread. So I think there's a bit of a, you know, mutually beneficial relationship between behavior in terms of what we choose to do, what we choose to buy, how much we choose to pay for minimizing our climate impact, technology, you know, adoption, economies of scale, driving down costs, and policy, you know, mitigation being

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not prohibitively expensive, enabling more political ambition on policy that we underappreciate.

[01:22:45] And so I do think that there's an important role people can play in their own personal decisions. Not that they're gonna solve the problem by themselves, but that they're gonna support many of the solutions that are needed at scale to solve those problems.

[01:22:57] **Nate Hagens:** What advice do you have for young humans in their teens and twenties who are becoming aware of all this?

[01:23:03] **Zeke Hausfather:** I'd say to stay focused on these issues, to keep abreast of what's happening with the climate and the environment, but also to put things in context. You know, this is a big problem. This is a problem that we're going to need to solve, and that many of us are devoting our life to solving. And we should avoid giving up hope.

[01:23:22] You know, we're not gonna get to the best case. We're not gonna limit warming to one point five degrees. But we still have time to limit warming to a manageable amount that is not gonna leave our planet a ruin. And I feel like there is a risk, particularly for young people, that we do give in to doom, that we do say, "Oh, the world is going to hell in a handbasket, and I'm gonna check out."

[01:23:41] And I feel like apathy when it comes to these problems is our worst enemy.

[01:23:45] **Nate Hagens:** Yeah. I agree with that. What do you care most about in the world, Zeke?

[01:23:50] **Zeke Hausfather:** Oof, that's a big question. Well, you know, as a parent of two small kids, I care about them more than almost everything else, and

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making sure that they have a future where they can be happy, I think is critically important, and I think a lot of the work that I do is guided by that.

[01:24:13] but I think I also just want us to live in a world where we can have conversations with each other about hard and important topics, where we have political systems that actually are functional at addressing the challenges we face. you know, it-- I'm sure it-- looking back, you know, it had its problems, but in some ways I, you know, pine for the days of, like, the nineteen nineties to the early two thousands, in the US in particular, when we had political systems that spent plenty of time fighting but could ultimately work together when there were big challenges that needed to be addressed.

[01:24:52] And I think if we don't figure out how to do that, and it's not just the US, we see growing polarization all around the world, like we're gonna be in a much worse place to address the big crises we face today.

[01:25:02] **Nate Hagens:** Agree on that. I don't know how often you, if at all, you watch my podcast, but one question I ask all my guests is, if you could wave a magic wand, and there was no personal recourse to your decision, what is one thing you would do to improve the future for humanity and the biosphere?

[01:25:22] **Zeke Hausfather:** I think I'll give the boring, economist answer here 'cause I think ultimately it's right. You know, I think that- We're not gonna overthrow capitalism anytime soon, that a lot of decisions people make are still gonna be driven by prices and incentives. And so I think ultimately solving environmental problems writ large requires internalizing social costs into private costs.

[01:25:46] You know, take the damages of climate change-

[01:25:48] **Nate Hagens:** So change, change the prices.

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[01:25:50] **Zeke Hausfather:** Change the prices, yeah. Yeah. Take, put the cost of species habitat loss into our activities, put the price of CO2 emissions into our activities. You know, put a price on carbon. It's kind of a boring thing, but at the end of the day, it's going...

[01:26:03] If I could make it happen, it probably would be the most effective thing we could do– Yeah ... to actually solve the problem at

[01:26:07] **Nate Hagens:** scale. it would actually work. I worked on that for a long time and got nowhere. But–

[01:26:13] **Zeke Hausfather:** I did too, and I'm not optimistic we're going to do it. Yeah. But if I had a magic wand

[01:26:16] **Nate Hagens:** No, fair answer.

[01:26:18] So, real quick, give me some insight and an overview of what sort of hopeful products and directions the companies you work at, Stripe and Frontier are working on?

[01:26:34] **Zeke Hausfather:** As I mentioned earlier, solving climate change, stopping the world from warming ultimately requires getting our emissions all the way down to zero.

[01:26:41] And if we end up in a world warmer than we'd like, you know, two degrees, two and a half degrees, the only way to cool the planet back down in the long term is to suck out some of that carbon that we've previously emitted. And so what I'm doing with Stripe and Frontier is working on that side of the problem, trying to figure out which of the technologies out there could actually reduce the amount of carbon in the atmosphere.

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[01:27:02] Not that they're a silver bullet by any stretch of the imagination. They're probably like ten percent of the solution, and ninety percent is reducing our emissions. But for a problem as big as climate change, you know, working on ten percent of the problem still actually matters. And so there's a couple exciting technologies we're working on that front, and I'll highlight a few of them.

[01:27:19] One that I've done in particular a lot of work on myself over the last couple years is something called enhanced rock weathering. So over geologic time, over millions or tens of millions of years, the temperature of the planet is largely governed by the balance between volcanism and silicate weathering.

[01:27:36] So volcanoes put out CO₂. If you have a huge amount of volcanic eruptions like the Deccan Traps, the Siberian Traps, you get a huge amount of CO₂ in the atmosphere. It's actually driven by some previous mass extinctions. But those volcanoes emit the seeds of their own destruction, so to speak. You know, volcanoes emit basalt and other alkaline rocks that over long periods of time, rain and water weather away, and those alkaline rocks bind with CO₂ and form carbonates.

[01:28:05] And those carbonates then form limestone. They eventually get subducted, and they come back out of volcanoes hundreds of millions of years later. So that's sort of the long-term carbon cycle of the planet. And so the idea with enhanced rock weathering is how can we speed that up? In particular, can we speed it up in a way that gives some pretty big benefits?

[01:28:20] And it turns out that one of the systems that is the best at binding carbon into ground up rock is farmlands. And it also turns out that farmlands are often too acidic and can get a lot of benefit from spreading rock dust. And so enhanced rock weathering is spreading rock dust in croplands or rice paddies, which can boost yields, and also suck up carbon from the atmosphere.

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[01:28:39] And so we've been doing projects in Brazil and India and in the US, to that end, and Africa, that have all seen some successes in recent years. Another interesting one is, this idea of river liming. So similarly, a lot of rivers are too acidic, in part due to a legacy of acid rain, of sulfur emissions.

[01:28:58] and you know, if you put alkaline materials like limestone into those rivers, you can absorb additional carbon from bicarbonate and also restore those ecosystems. So there's a company in Canada called Carbon Run that we're working with that does this. They started out restoring salmon fisheries, then realized that the thing they were doing to restore salmon fisheries also captured carbon in the process, and now we're trying to use that to really scale up what they're doing to rivers all around the world.

[01:29:25] so there's a whole bunch of other technologies. There's ocean alkalinity enhancement, there's various biomass-based carbon capture approaches. There's, you know, direct air capture that we're all trying to work on. and our goal with the work at Stripping Frontier is essentially to use this decade to figure out what works and what can scale, and if we figure out something can't work, to discover that quickly.

[01:29:43] so we have the technologies we're going to need in the twenty-forties and twenty-fifties to really get all the way to, to zero emissions.

[01:29:49] **Nate Hagens:** Yeah. It has to start somewhere. I mean, under the, the thin scenarios that, in my opinion, get us there, we need people like you working on that stuff now to see what-

[01:29:59] **Zeke Hausfather:** Yeah

[01:30:00] **Nate Hagens:** what's possible.

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[01:30:01] **Zeke Hausfather:** And it's not the only thing we should work on. Like I, I get that there's real worries that this distracts us from the need to reduce emissions near term, which is the most important thing. Yeah. But I think today we're spending, you know, ninety-nine percent of our money globally, you know, that two point three trillion dollars on reducing emissions and well less than one percent on figuring out ways to remove it from the atmosphere.

[01:30:20] And so I think both are important. Just need to, you know, be proportionately used.

[01:30:25] **Nate Hagens:** Well, so far the two point three trillion dollars spent on renewables has not reduced global emissions. global, I will say.

[01:30:34] **Zeke Hausfather:** Well, they've reduced emissions compared to what would've happened if we didn't spend it. They haven't absolutely- Okay

[01:30:38] reduced

[01:30:38] **Nate Hagens:** emissions yet. Yeah, that's true. Yeah. That's true. Zeke Hausfather, thank you so much for your work and your time today and, I look forward to reading the executive summary of chapter two of the next IPCC report.

[01:30:54] **Zeke Hausfather:** Yeah. Thanks, Nate. It's been a pleasure and a pretty wide-ranging conversation.

[01:30:58] **Nate Hagens:** To be continued, my friend. If you'd like to learn more about this episode, please visit thegreatsimplification.com for references and show notes. From there, you can also join our Hilo community and subscribe to our Substack newsletter. This show is hosted by me, Nate Hagens, edited by No Troublemakers Media, and produced by Misty Stinnett and Lizzy Sirianni.

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[01:31:22] Our production team also includes Leslie Batt-Lutz, Brady Heyen, Julia Maxwell, Gabriela Sleiman, and Grace Brunfelt. Thank you for listening, and we'll see you on the next episode.