A Few Critical Climate Technology Breakthroughs Multiplied by "Instigators" is Desperately Needed

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A few Critical Climate Technology Breakthroughs Multiplied by "Instigators" is desperately needed 12–15 entrepreneurs, driven by entrepreneurial energy and passion for a vision, and a little bit of luck, could change the climate crisis into societal transformation.

A dozen or so key technologies/entrepreneurs will make a substantial difference, far more than the next hundred efforts. Entrepreneurs will solve these key markets and technologies leading the industries in these areas to a new transition state. They will be the "instigators" that cause others in each industry to follow their lead. Whether these early entrepreneurs, driven by the power of ideas driven by entrepreneurial energy, are successful or they fail, they will affect change by changing conventional wisdom and making the seemingly impossible possible in each of these segments critical to climate and sustainability. Traditional players may come in to scale these approaches. If we are to affect change by 2040 through the mass adoption of these technologies, they will need to be somewhat "proven" by 2025. That is the set of technologies I am immediately concerned with.

Let me demonstrate with a few stories:

1. In 2010 few in the automotive sector took EVs seriously in their planning for the next decade or two. The US Department of Energy forecast almost no fully electric cars by 2035, based on consultation with automotive experts! But this startup with little automotive experience or credibility, Tesla, packaged enough existing technology into a consumer experience that caught the consumer's imagination and made the whole industry pay attention. A few years later, as their market capitalization climbed and Tesla violated expectations of "not doing it properly per automotive standards" and "going bankrupt", every major automaker has changed their goals. The change to electric automobiles feels inevitable now as Tesla becomes the most valuable automaker in the world, just a few years past expectations of bankruptcy. The "instigation" worked and is now independent of the fate of the instigator. One person like Elon Musk can change the technology direction, even if it requires no major technology breakthrough. It was a lot of very good engineering, out of the "experts" box thinking and vision for the future.
2. In 2011, a lone academic, Pat Brown, another instigator, decided to try and eliminate all animal husbandry given its use of 30–50% of the planet's land area and its horrendous greenhouse gas (GHG) and water footprint. Many laughed at the idea that a plant protein, even with a roughly 90% lower GHG and water footprint, could be as tasty to non-vegetarians as beef. Today, less than a decade later this is widely accepted and proven in taste tests, and beef may be slowly on its way out starting with the environmentally-conscious millennial generation because they don't have to give up any "taste" to be so conscientious. Beef, and animal products in general, are

large GHG emitters and will slowly be replaced by products like Impossible Foods. Niche technologies exist to reduce its emission (like grass-fed beef or regenerative agriculture) but they are unlikely to scale globally, cost-effectively, to meet rapidly growing demand as the developing world develops. But the world's view of plant proteins to replace animal proteins is changing rapidly. It helps because most of the IPCC scenarios for carbon reduction require us to free up land area with new carbon-absorbing planting and plant proteins take substantially less land per pound of product.

3. Lithium-ion batteries for EV's have been improving at very slow rates. Jagdeep Singh, an EIR at Khosla Ventures, teamed up with a research team at Stanford University to start Quantumscape, a ten-year effort to develop a solid-state battery with a 100% jump in performance at a dramatically lower cost, instead of the myriad of component technologies and incremental performance improvements being attempted by others. This bold attempt at doubling the end-product performance, extending battery lifetime, enhanced safety, and making fast charging at "gas stations" routine, is more of what is needed. It could dramatically accelerate and make cost-effective the trend towards EVs that Tesla started. The field is rich with efforts but it takes a concentrated push by entrepreneurs like Jagdeep Singh to change the world's trajectory in EVs. I'd guess it is the only 2x better performance battery likely to be in real cars in volume in the next five years. And it is likely sufficient to make EV's economic enough to accelerate their adoption and the one-two punch for the gas engine. I suspect, beyond Quantumscape, all major battery makers will have to adopt such a bold direction if they are to survive, creating a herd effect towards 2x universal performance.
4. Electric cars and electric trucks powered by renewable electricity are likely solutions, but air transportation by passenger jets needs a liquid fuel compatible with today's jet fleet if the change is to happen in the next 15–30 years. LanzaJet (a subsidiary of Lanzatech), started in New Zealand a decade ago and partnered by Sean Simpson and Jennifer Holmgren, is building its first pilot plant to produce 100% renewable jet biofuel using gas fermentation technology. The technology is likely to be cost-competitive at scale with today's jet fuel prices, especially with a little bit of starting help (given the variability of oil prices) as they scale just as solar and wind did before becoming competitive unsubsidized. Though these subsidies for solar and wind still exist, they should not as they are not needed today. There are other jet fuel efforts but it is hard to tell if they will scale and be cost-competitive with LanzaJet. To the best of my knowledge, few are fully operational beyond pilot plants by 2025 or have the scalability of feedstock (old cooking oils don't scale for example) to achieve global replacement of fossil jet fuel. But we need only one technology to transform air travel, though more competition will help accelerate it.

So what does it take to make a material difference in carbon emissions? A hundred or thousand of these technology/entrepreneur combinations? Surprisingly, even though the GHG problem is hard, a dozen such efforts could accelerate society's transformation, especially if we think critically about the "right dozen". Here is my list of these dozen innovation/innovator

combinations that we will need to make a large dent in a substantial portion of the emissions in each segment (plenty of niche solutions exist which though good, won't when scaled and if scaled, will make a material difference): (1) Electric vehicles & Automotive batteries (2) Food & Agriculture, especially meat (3) Low carbon Transportation: Air transportation (jet fuel), shipping (electrofuels, biofuels?) (4) Cement or substitute construction material (5) Low carbon dispatchable electricity generation (fusion, geothermal, nuclear) (6) Public transit (7) Grid storage (long duration battery storage) (8) HVAC (9) Industrial processes (hydrogen?) (10) Fertilizer (Hydrogen) (11) Water (12) Steel. The path to the first third is clearly visible though still subject to risk, as described above. The second third of this dozen seems like we will find plausible solutions though the winning technology is not clearly visible and the last third is not yet clearly visible, at least to me. So here is a quick review of some of the efforts by entrepreneurs trying to make societal transformation happen in the areas beyond EV's, plant proteins, EV batteries, and jet fuel:

1. Cement — Fortera's (formerly Calera) cement can reduce cement's carbon footprint by 60% with a path to 100% (with a switch to electric kilns, something they do because of their lower calcining temperature). But more importantly, this lower carbon cement is actually cheaper to produce in today's cement factories because it captures the pollutant CO2 and turns it into a valuable product as carbonates, hence lowering the cost of production for a ton of cement. And it can be used as both cementitious materials or as cement as it can match the properties and costs of today's cement. On the same front of building materials, there are entrepreneurs experimenting with photopolymers as substitutes for cement because they have 7x the strength of cement and hence use far less material and when combined with 3D printed construction technologies can dramatically reduce materials tonnage in construction. And others making residential space 2x more efficient making 300square foot apartments feasible.
2. Low carbon DISPATCHABLE electricity: There are very good attempts at fusion energy, a limitless source that will potentially (if cost-effective) also solve the water, hydrogen, and fertilizer problems. Geothermal is hugely underinvested and it depends upon deep drilling with linear cost per foot as the depth of drilling increases. At ten miles depth, we can get geothermal energy for renewable electricity and renewable heat in most parts of the planet. Unfortunately, there are very few efforts in this critical field to drill very deep. We have a small effort at Quaise Energy. I am particularly excited about a new fusion energy effort we helped start out of the Plasma Fusion Lab at MIT. And Commonwealth Fusion is trying to make it real in the current decade! Though there are other good efforts in fusion energy, I do assign this very risky project a material probability of being a world changer.
3. Public transit could dramatically reduce the need for cars. I am excited about how this could be hugely beneficial for carbon reduction, making public transit substantially more attractive than automobiles, and increasing the quality of life in cities through an effort we are backing. But it is too early to tell if this effort can fundamentally change most assumptions we have about automobiles and public transit and making public transit much more attractive and cost-effective than

automobiles. It could cause a dramatic reduction in the number of automobiles produced.

4. Long term grid storage is needed to make solar and wind broadly scalable. Through Breakthrough Energy Ventures I see some high-risk efforts that have the potential to bear fruit.

And that leaves a few technologies I have not seen great efforts at though they may exist in some entrepreneur's laboratory or their head:

1. Hydrogen for industrial processes: cost is paramount and it may be "mined" potentially but it could help many industrial processes.
2. Beyond animal husbandry, agriculture, and fertilizer in specific need addressing: cheap clean energy may solve this problem; soil microbes to produce nitrogen are also being attempted but I don't see scale technologies to solve this problem yet. Clean hydrogen may also help. Dairy products, a significant source of GHG at approximately 6.5% of global emissions, are being addressed similarly to plant proteins' approach to replacing animal husbandry.
3. HVAC: This is #1 on the Drawdown list of opportunities and a hard area. For at least one approach that may hold promise, we likely need dramatically better thermoelectrics. Maybe AI approaches combined with quantum computing for radical materials design will help design better thermoelectrics, thermionics, or something completely new. But we need a very large improvement in efficiency.
4. Water: There is a thermodynamics limit to energy efficiency for desalinating saltwater but cheap renewable energy could solve this problem.
5. Steel: Clever technologies to remove oxygen bound to the iron is needed. What seems more promising to me is using 90% less steel by having each pound of steel go 10x further in cars (120k miles per year instead of today's 12k miles) or to need 90% less steel through cars that don't crash or new materials like stronger polymers for construction or cheaper composites.
6. Carbon capture including direct air capture is being worked on and it is too early to exercise judgment on feasibility at less than $30–50/ton capture price.
7. Other material contributors: Plastics, fibers, recycling are all candidates and have domain-specific solutions but likely not global, rapid solutions from one entrepreneur-driven company. In these areas, there may be multiple solutions with multiple entrepreneurs. I don't consider wind and solar as they are already cost-effective and have scaled beyond most expectations. But they need long term grid storage to be broadly scalable, in my view.

There are many other very good business efforts on environmental technologies like View Glass or LED lighting for building efficiency or microbes or regenerative agriculture to reduce nitrogen need, perennial crops, microgrids/grid technology, or net-zero buildings, etc. There are too many to recount. They make business sense and environmental sense but won't make a big

enough dent in global emissions in the next twenty-five years, at least at a few % or more of global emissions level. The book Drawdown covers many of the most important areas to affect climate risk but only a few can make a big enough (in my view) difference and change our societal trajectory. I may even be wrong on some of these judgment calls as they are hard to predict and orthogonal solutions that may emerge to replace current needs as we envision them with surprising substitutes. For example, the kind of need for EV's may go down dramatically with the on-demand, point to point public transit I envision. Shipping's explosion may decline because of localized manufacturing enabled by new robotic AI technology and other technologies like 3D printing. There are others that are possible candidates but hard to forecast today. I am sure I have missed a few others but my main point is it takes only a few entrepreneurs to change the world.

I invite you to join this group. It only needs a handful of instigators and technologists to make the changes society needs, not a little bit of effort by everybody. In my paper Reinventing Societal Infrastructure, I talk about the technology soup that allows for greater levels of innovation by mixing different axes of innovation, potentially allowing for more progress on sustainability. Everybody can help by being part of the cultural change of values that will enhance our path and accelerate solutions by creating demand. Willingness to pay the green premium as these technologies get to scale (as solar and wind have done already; but they need long term grid storage to make them scale sufficiently) also helps tremendously. I am hopeful for the millennial generation that has a much stronger commitment to climate risk and sustainability and a propensity for "movements" to affect change.

If technology gets these solutions to unsubsidized market competitiveness we will have a solution. Even if these technologies start with a need for a "green premium" to enter the market because of a lack of unsubsidized market competitiveness, at least four other factors could help progress in very significant ways: (1) accelerate the progress of technologies through increased incentives. (2) Technology is likely necessary but not sufficient. Policy creates huge incentives for the right or wrong path to reduce GHG emissions. Everybody can affect policy through the right actions or activism. (3) And more Greta Thunberg's of the world is "every person" multiplied. And the cultural change in values helps tremendously. Movements matter. (4) Creating perceived financial or climate risk through future potential legislation and selective takeaways of the economics of the asset also help. Coal plants stopped receiving investment because of the risk of any new investments in coal with 40–50 years life and "time of day pricing" letting solar steal some of the most profitable intraday prices away from coal and hurt coal plant economics. It is possible, even likely over the next 15–30 years the same might happen to natural gas-based power and any investor in those asset owners ends up with stranded assets. Lesson: business models are also subject to innovation. But most of all it takes a few entrepreneurs with passion for a vision and a government willing to help get new options across the valley of death through policy.

A word on research: A few technology-based entrepreneurs are instigators, but they are not likely to become instigators without much of the research that goes on in our research laboratories. We need a lot more of both fundamental and applied research for this and other

reasons. And coupling breakthrough research with “instigator” entrepreneurs (researcher and instigators can be the same person) can make this research truly effective.

Conventional wisdom believes that most such change is done by entities with power and knowledge in their industries. Unfortunately, I have not seen one large technology-driven societal change in my forty-year career driven by “experts who know” or “larger, non-founder driven” entities because of their reliance on studies, consulting reports, projections to “extrapolate the past instead of inventing the future they want”. GE, Siemens, the oil companies, the automotive companies or cement companies or food companies will not instigate the future we want but they can follow and help scale it and adopt it. Hence I am calling all entrepreneurs and instigators to come join the effort to solve this urgent problem! Global Shipping is currently 2–3% global emissions, but projections have it getting to 10–17% by 2050. Air conditioning is 10% global electricity use but is projected to triple by 2050 so we need more than 3x GHG reduction per unit to stay even and a 100% reduction to save the planet from potentially severe consequences. Good is not good enough. Great is barely acceptable in this arena. It takes those who have the fire to impact these issues, to think differently about problem-solving, and those who take improbable risks.