

ToughTech

A publication by The Engine, built by MIT



FALL 2020

We

The founders,
investors, corporations,
and policies helping solve
climate change.

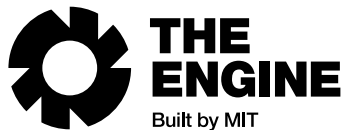
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A home for Tough Tech founders.

The Engine, built by MIT, is a venture firm that invests in early-stage companies solving the world's biggest problems through the convergence of breakthrough science, engineering, and leadership. Our mission is to accelerate the path to market for Tough Tech companies by providing access to a unique combination of investment, infrastructure, and a vibrant ecosystem.

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Tough Tech's New Home

A Climate of Hope

In an era of great uncertainty, I remain optimistic. For every group of founders in which we invest, dozens of others are also pursuing solutions to challenges like climate change.

Last month, as multiple hurricanes barreled toward the Gulf Coast and wildfire spread unchecked through the West, the threat of climate change became tangible for many Americans.

While the problem seems ever more complex, we have understood for many years what the solution set should include: policy that enables the deployment of clean technology and catalyzes further innovation in critical fields. Such policy is a patchwork of technology, investment, and regulation that depends on a diverse and motivated group of researchers, innovators, entrepreneurs, policy makers, and business leaders across the world that have dedicated their lives to fighting climate change. As we embark on a critical decade, this group and its bold actions give me hope.

This publication acknowledges the scale of its subject matter and strives to provide readers with an impactful summary of the technology and investment landscape for the current generation of cleantech — while reflecting on the developments that made the technologies of today possible.

Community is at the core of The Engine — the open exchange of ideas that drive us all forward. In that spirit, we've spoken to a broad group of

those at the forefront of the cleantech revolution, recording their perspectives on the present and future of sustainable technologies, climate policy, and investment. I suspect you will find their perspectives encouraging regarding the technology at our disposal and, simultaneously, demanding of additional innovative breakthroughs to move us toward decarbonization.

Of course, innovation will play a critical role in our response to climate change. While electric power systems possess the technologies to drive decarbonization within the next decade, a number of carbon-intensive industries require scientific and engineering breakthroughs to move us toward deep decarbonization of the entire economy.

As investors, we see great opportunity in supporting those innovative breakthroughs, but we recognize that systemic change is necessary for these technologies to reach commercial impact. Beyond strenuous technical journeys, climate solutions often have common challenges. How do you deploy meaningful first-of-a-kind projects at scale, while competing against economically stable incumbents? How do you establish financing pathways to avoid “valleys of death” during early-stage growth? Investors of all types understand the

existential imperative of deploying capital in cleantech startups as well as the necessity of an infrastructure to support technology and business development as efficiently as possible.

In an era of great uncertainty, I remain optimistic. For every group of founders in which we invest, dozens of others are also pursuing solutions to challenges like climate change. These founders are made of incredible stuff — intelligent, focused, and dedicated to building a sustainable future. +

Katie Rae
CEO & Managing Partner
The Engine





Cleantech's Comeback.

What we learned from the collapse of investment in Cleantech 1.0 and how we can ensure the success of Cleantech 2.0.

By Michael Kearney, Senior Associate, *The Engine*

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umerous accounts have documented the collapse of venture investment in the clean-technology sector during the first fifteen years of the 21st century. Retrospectively known as

Cleantech 1.0, investors piled \$25 billion into cleantech startups from 2006-2011, funds that resulted in little return on capital.¹

The subsequent flight of capital from cleantech increased commercialization challenges for the struggling sector. In the latter part of the 2010s, however, the tide turned once again for cleantech startups. With \$4 billion invested in the space since 2017, investors clearly have renewed interest in supporting cleantech companies.

So, what have we learned from Cleantech 1.0? What are investment firms doing differently to account for this newfound knowledge? What problems may still exist, and what can be done to solve them? In short, the investment community has moved to account for the deep technical risk, long development timelines, and capital intensity associated with cleantech investing. However, while energy markets, including electricity, fuels, and transportation infrastructure,

seem large, the paths to market are arduous, and value capture in those markets is challenging. For Cleantech 2.0 to be a resounding success for venture investors, a series of structural reforms and government interventions are necessary.

The climate challenges facing the planet are numerous — emissions are tightly tied to global economic growth and, despite progress in reducing emissions in the electricity sector through deployment of carbon-free electricity and efficiency gains in end usage, achieving the Paris Climate Accord goals of limiting global temperature increase to 2°C will require both an extraordinary build-out of existing renewable resources and rapid invention and diffusion of new technologies.

¹ <https://energy.mit.edu/wp-content/uploads/2016/07/MITEI-WP-2016-06.pdf>

There is an emerging body of evidence that in the energy sector, startups are more likely to fund high-risk, high-impact technical projects² compared to large incumbents with incentives to show growth on a quarterly-returns basis that is not aligned with the longer timelines associated with innovative projects. As a result, these startup projects are vital.

Society must approach the existential challenges of climate change from every angle — every tenth of a degree increase in global temperature that we are able to mitigate has meaningful implications for the future of our planet. That the investment community is stepping up to this challenge is a resoundingly positive step in the right direction.

/2/ Nanda R, Younge K, Fleming L. 2015. Innovation and entrepreneurship in renewable energy. In *The Changing Frontier: Rethinking Science and Innovation Policy*, ed. A Jaffe, B Jones, pp. 199-232. Chicago, IL: Univ. Chic. Press

Lessons from Cleantech 1.0

In a thoughtful review of financial returns during Cleantech 1.0, Gaddy, Sivaram, and O’Sullivan (2016) evaluate the returns to cleantech venture capital investments relative to those in other sectors. Of the \$25 billion that investors placed in cleantech firms from 2006-2011, they lost more than \$12.5 billion (over 50%).

Moreover, whereas successful cleantech investments returned 8.6 times the initial investment to VC firms, similarly successful investments in software companies returned 11.6 times the initial investment, and this likely understates the overall differ-

ence as cleantech companies in the sample were more likely to fail.

As we reflect on the Cleantech 1.0 period, it is important to reflect on areas where the investment community has evolved in response to the challenges that hindered returns. Today’s investor community has internalized these lessons, shifted focus, and launched a variety of experiments that offer hope that the returns for Cleantech 2.0 will be different.

Technical Risk: Investors did not fully appreciate the technology risks inherent in clean technologies. Complete understanding of the technolog-

ical advance at the root of a cleantech innovation requires accessing the frontier of a specific scientific field. Rarely do investment teams retain in-house talent able to adequately evaluate these types of technologies. During the Cleantech 1.0 period, the venture capital industry self-assembled around software-driven business innovations, with VC funds recruiting primarily from MBA programs rather than PhD programs.

In response to this challenge, two divergent pathways have emerged. On the one hand, many firms have eschewed technology risk altogether and found ways to use parallel innovations

BOOM AND BUST IN CLEANTECH VENTURE CAPITAL

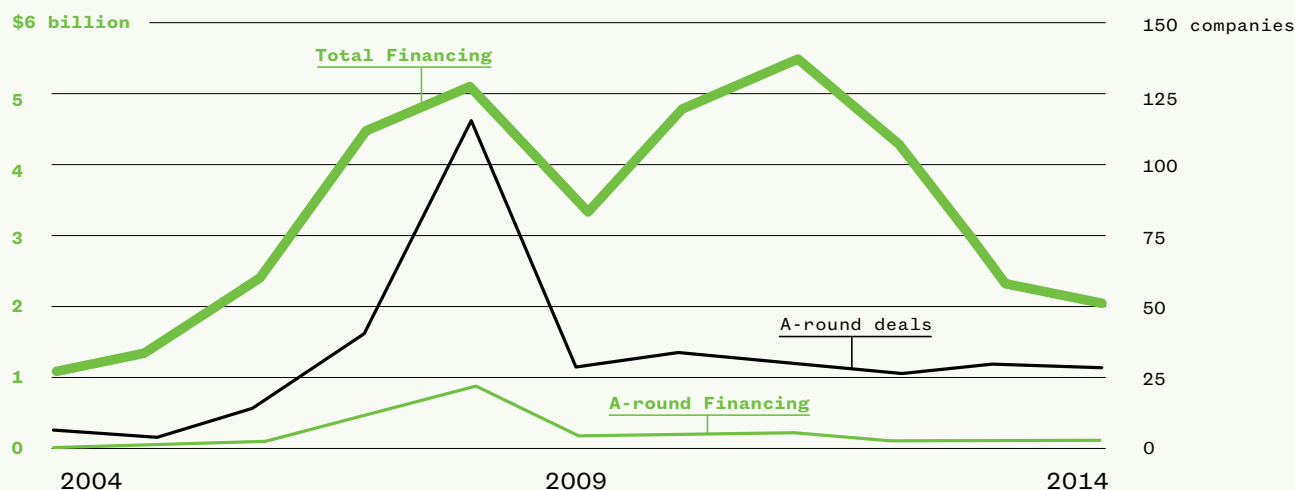


Chart from: *Venture Capital and Cleantech: The Wrong Model for Clean Energy Innovation, An MIT Energy Initiative Working Paper: July 2016*

in software, connectivity, and analytics to build large, impactful businesses in the energy sector. These investors look to high-profile exits like EnerNOC, Nest, and Opower as inspirational endeavors that both provide VC-quality returns and have significant potential impact in the energy sector. On the other hand, cleantech-specific firms have arisen, staffed with the internal technical and sector-specific experts needed to adequately assess industry-specific risks. (Take a moment to check out the work being done at Clean Energy Ventures and Energy Impact Partners, among others.)

Technology Development

Timelines: A different feature than pure technical risk, the timeline to maturity for a given technology can adversely affect investor return. There is a mismatch between a typical 10-year close-ended fund, along with the return requirements thereof, and the plausibly five-to-ten-year time

horizons for technology development, scale up, and manufacturing.

New funds and financially engineered structures have arisen to abate some of the more vexing realities related to the long development timelines. Prime Coalition creatively brings philanthropic capital into the capital stack by blending that capital with traditional LP dollars to shift the return profile of the fund as a whole. Breakthrough Energy Ventures and The Engine have extended fund lives to provide game-changing technologies the time to mature.

Capital intensity: In addition to the time it takes to develop technology, cleantech firms require significant capital investment throughout a company's life cycle.³ Importantly, though, it isn't just that it takes a lot of capital to bring the technology to market but also that even in the early days of a company's life, the necessary technical experimentation is relatively

costly. This is key to the lower returns thresholds described above. Conditional on a comparable exit valuation, a firm that requires more money to get to scale will return less capital.

However, the capital stack is diversifying to include later-stage institutional investors that play a critical role in managing the capital intensity of the cleantech sector as firms scale into commercial readiness. Large institutional investors, such as Softbank, Temasek, Fidelity, and others, are now active players, as are large corporates like ENI.

/3/ For more information, see here: <https://davidmytton.blog/the-data-behind-49bn-of-cleantech-investment/>

More change is necessary

These developments are exciting, but they could be largely immaterial if the commercialization path for cleantech companies is not streamlined. There remain significant barriers to the scale-up of clean technologies, barriers that stem not from the inherent technical challenges of innovation, but rather from the market dynamics within which these technologies have to compete.

Across industry verticals, energy technologies face an uphill climb to commercialization. Consider, for example, the electricity industry. In electricity, end users of innovative products, mostly electric utilities, are highly regulated organizations — their return profile on an investment in an innovative technology looks exactly

the same as their return profile on a traditional technology, resulting in a system lacking incentives for change. Similarly, in fuels and any sectors currently dependent on fuels for transportation or high-quality process heat, carbon-free alternatives have to compete with traditional fossil fuels at cost in many cases because economies have not appropriately priced carbon emissions. Moreover, the market price for oil and gas can ebb and flow in response to competitive pressures, which is an existential threat to commodity competitors.

To generalize across end-use applications, cleantech companies face a few specific hurdles getting to market: access capital to scale up production or deploy first-of-a-kind commercial projects, entering highly regulated markets, and working with risk-averse incumbents. These barriers result

in reduced market opportunities for energy companies across commercialization stages, in particular at any potential exit point, resulting in reduced valuations and exit multiples. Specifically, companies face four distinct but related barriers:

Funding of early-stage

prototypes: Companies have to balance achieving meaningful technical progress at a relevant scale while demonstrating market traction, even though, at this scale, a prototype has little market value.

Funding of first-of-a-kind

commercial projects: A critical barrier to commercializing clean technologies is asymmetry between project risk for first-of-a-kind deployments and risk tolerance of capital providers for project

finance. In non-commodity fields, a financier would be able to internalize the increased project-level risks by increasing the interest rate on the capital to be provided for a project. However, because cleantech firms often operate in a commodity market, increasing the interest rate on provided capital decreases the economic viability of those projects. In cleantech, this challenge extends beyond the “first of a kind” as well because even after the first deployment, it can take months or years to demonstrate the lifespan and reliability of an infrastructure asset.

Fractured, convoluted regulatory regimes: Regulatory environments remain particularly stubborn to new technologies. This is acute across energy subsectors but perhaps most acute in electricity. For example, 10 years after the first battery storage projects tied into the grid, wholesale electricity markets are still debating how to value energy storage in capacity markets. Regulations within the electricity sector prohibit the primary end users of new technologies, namely electric utilities, from efficiently working with the new technologies on a research or commercial basis.

One game with different rules: The reality is that today, cleantech firms are competing with conventional energy sources in an economy that does not appropriately price greenhouse gas externalities. This limits the market opportunities for cleantech startups, with associated downstream effects on the investment community that reduce incentives for investment across the innovation pipeline. Innovation scholars across fields have articulated the important role of efficient commercial markets for technology as a key element of a functioning innovation system.⁴ Critical to the commercialization of a new idea or product is a startup firm’s engagement in the market with customers, regulators, and larger established firms as strategic partners, exit opportunities, or both.

The fluidity of these engagements is critical to building a cleantech financial system. The path forward here is not complicated — there is no shortage of good ideas about how to solve these challenges. The first and most obvious response is a nationwide price on carbon. However, moving beyond the obvious, focus must reside on pathways to reframe the regulation of energy technology and a national deployment effort.

/4/ Gans and Stern (2003); Teece (1986); Hellmann and Perotti (2011); Jaffe, Trajtenberg, and Henderson (1993); Saxenian (1994); Porter (1998); Carlino and Kerr (2015).

There remain significant barriers to the scale-up of clean technologies, barriers that stem not from the inherent technical challenges of innovation, but rather from the market dynamics within which these technologies have to compete.

Considering New Regulatory Frameworks

Unlike drug development, where there is a federally regulated but clear path to commercialization that delineates appropriate value inflection points across the life of technology development, the energy sector in the U.S. is regulated within each state, across collections of multi-state actors, and at the federal level. It is an opaque framework that encourages incumbents to be risk-averse and limits those incumbents’ ability to experiment with new technology.

Consider the regulatory framework for electric power. The challenging role of electric utilities is to deliver power on a sub-second basis across vast distances with high reliability. Downtime is measured in the magnitude of dollars lost in the economy, often on the order of billions of dollars, as we have seen recently in the rolling blackouts in California. As a result, the industry is tightly regulated to preserve reliability and protect consumers — technology innovation and diffusion become casualties of a system that prioritizes reliability.

We must move beyond the false choice of reliability or innovation by

creating frameworks that enable both. New rules are needed that empower electricity providers to experiment with new technologies. The federal government could assist with this through the creation of a technology certification office that approves specific technologies for experimentation in risk-averse settings at initially modest investment levels that increase with the technology’s maturity. Moreover, a staged process provides investors with tangible value-inflection points as a company approaches commercialization, value-inflection points that draw more follow-on capital into a company.

A National Deployment Effort

Barriers to cleantech commercialization exist across stages of deployment for clean technologies from pilot projects to broad-scale commercialization. A National Deployment Effort that nurtures technologies from pilot projects to massive impact is necessary. Historically, the U.S. government has played an active role in later-stage commercialization efforts of foundational technologies, and that same effort is required for cleantech going forward.

Consider, for example, the development of the U.S. semiconductor industry in the 1950s and 1960s.⁵ Government procurement efforts were as or more fundamental to the growth of the sector as government R&D efforts. In fact, from 1955 to 1977, government procurement accounted for an average of 38% of all semiconductors produced in the U.S. In 1962, the first year that integrated circuits shipped, the government purchased all of them (100%). At the time, the U.S. government was one of the largest consumers of transistors in the world, just as today, the U.S. government is the largest individual consumer of energy in the world.

A critical barrier to commercializing clean technologies is asymmetry between project risk for first-of-a-kind deployments and the risk tolerance of capital providers for project finance. The government has played a productive role in bridging this gap in the past through tax credits and the DOE Loan Guarantee Program, among other mechanisms. To capitalize on the recent growth in cleantech innovations, however, a codified national deployment effort is necessary that adjusts existing programs and offers new ones that meet the scope of the climate crisis.

The Loan Guarantee Program has supported the deployment of energy projects with significant capital expenses. While it continues to support

large-scale efforts, it is an imprecise tool for supporting more modular, distributed, early-stage projects. Potential improvements to the program include expanding the set of technologies that can be supported to a broad umbrella of clean technologies and reducing barriers to entry for all smaller, more distributed, and higher-risk endeavors.

Recently, the Clean Future Act included language for a National Climate Bank. This would be an effective tool for launching new clean technology products and projects into the market. Importantly, the Bank is structured to leverage private sector capital to cover the majority of project costs but only public capital to support the difference between the market value of the project and the ultimate project costs. This is a critical intervention because it is rare for novel clean technologies to be competitive for early projects — often, components/products are not yet being manufactured at scale, and the corresponding projects have to compete in commodity markets.

Finally, as the largest consumer of energy in the world, the U.S. government could serve as a test bed for early-stage commercial energy projects. Procurement and testing mandates for government facilities could do for cleantech what government procurement of early computing technologies did for that hardware market.

The efforts to align capital to the realities of technology development and the needs of financial markets at all stages will remain undervalued without commensurate attempts to tackle the daunting challenges on the commercialization side for cleantech startups.

⁵/ For more information, see here: <https://fedtechmagazine.com/article/2018/09/how-government-helped-spur-microchip-industry>

Moving Forward

The data is clear: the investment community is currently rising to the challenge of supporting the next generation of clean technologies. It is doing so with new approaches and coalitions that address long-standing asymmetries between cleantech innovation and investment structures.

The efforts to align capital to the realities of technology development and the needs of financial markets at all stages will remain undervalued without commensurate attempts to tackle the daunting challenges on the commercialization side for cleantech startups.

Investors, collectively and alongside their portfolio companies, must participate in the national conversation about how best to seed the commercial landscape of our energy future. In response to a depression-like contraction of the economy, the success of the cleantech industry is critical. We must redouble our efforts to ensure that the story of Cleantech 2.0 is one of sustained growth, new industries, and new opportunities for the American people. +



Thoughts Changing

And what we can do





on a Climate. about it.

We asked seven leaders in their fields the same six questions about climate change, sustainable technology, and how we can create a lasting impact. You'll find their answers on the following pages.

Interviews by Nathaniel Brewster / Illustrations by Alejandra Acosta & Andrés Rodríguez

(Answers have been lightly edited for clarity and brevity.)

Meet the interviewees.



Barbara Burger

Vice President, Innovation and President, Technology Ventures, Chevron

Barbara is president of Chevron Technology Ventures (CTV). She joined Chevron in 1987 and has had a long career with a number of technical and management positions in International Marketing, Chemicals, Technology Marketing, and Lubricants. Barbara is an active alumna of the University of Rochester, joined its Board of Trustees in 2015, established the Barbara J. Burger Endowed Scholarship in the Sciences in 2012, and, in 2015, founded the Barbara J. Burger iZone, a center where students go to generate, refine, and communicate ideas for social, cultural, community, and economic impact. Barbara holds a bachelor's degree in chemistry from the University of Rochester, a doctoral degree in chemistry from the California Institute of Technology, and an academic honor MBA in finance from the University of California, Berkeley.



Jeremy Grantham

Co-Founder & Chief Investment Strategist, Grantham, Mayo, & van Otterloo Co-Founder, The Grantham Foundation

Mr. Grantham co-founded GMO in 1977 and is a member of GMO's Asset Allocation team, serving as the firm's long-term investment strategist. He is a member of the GMO Board of Directors and has also served on the investment boards of several non-profit organizations. Prior to GMO's founding, Mr. Grantham was co-founder of Batterymarch Financial Management in 1969, where he recommended commercial indexing in 1971, one of several "firsts" to his credit. He began his investment career as an economist with Royal Dutch Shell. Mr. Grantham earned his undergraduate degree from the University of Sheffield (UK) and an MBA from Harvard Business School. He is a member of the Academy of Arts and Sciences, holds a CBE from the UK, and is a recipient of the Carnegie Medal for Philanthropy.



Jennifer Holmgren **CEO, LanzaTech**

Jennifer is the Chief Executive Officer of LanzaTech. Prior to joining LanzaTech, she was Vice President and General Manager of the Renewable Energy and Chemicals business unit at UOP LLC, a Honeywell Company. In that role, she led UOP's renewable business from its inception through to the achievement of significant revenues from the commercialization of multiple novel biofuel technologies. Jennifer is a member of the National Academy of Engineering and holds a BSc degree from Harvey Mudd College, a PhD from the University of Illinois at Urbana-Champaign and an MBA from the University of Chicago.



Bob Mumgaard
CEO & Co-Founder,
Commonwealth
Fusion Systems

Bob leads the strategic vision for CFS. He also serves as a key member of the technical team, leading the SPARC design process and determining how it interfaces with the business strategy. Bob performed his PhD work at MIT on Alcator C-Mod, developing techniques to measure the magnetic field inside tokamak plasmas by utilizing precise polarization techniques, robotics, and novel optical instruments. During this time, he contributed to the design of several small superconducting tokamaks for a variety of physics missions using high-temperature superconductors (HTS).



Carmichael Roberts
Founder and Managing
Partner, Material Impact
Senior Member, Investment
Committee, Breakthrough
Energy

Carmichael is a founding partner of Material Impact, a fund that builds resilient technology companies that develop products to solve real-world problems using innovative materials. Material Impact companies collectively have a mission to keep the world healthy, safe, fed, warm, powered, and secure. Carmichael is also a senior member of Breakthrough Energy. Prior to venture, as an entrepreneur Carmichael built several successful companies that create innovative products by applying material science. Carmichael received his B.S. and Ph.D. from Duke University and was a National Science Foundation Fellow at Harvard University's Departments of Chemistry and Chemical Biology. He earned his M.B.A. from the MIT Sloan School of Management.



Dipender Saluja
Managing Partner,
Technology Impact Fund
Managing Director,
Capricorn Investment
Group

Dipender is Managing Partner of the Technology Impact Fund, and Managing Director of Capricorn Investment Group, an investment firm founded to invest profitably while driving sustainable positive change. Prior to Capricorn, Dipender was Chief of Staff at Cadence, where he built and managed businesses that worked closely with electronics companies around the world. Prior to that he was at Data General (EMC), Honeywell, ROLM (IBM), and GF Energy Research Center. He's an electrical engineer by training, attending UND, Univ of Minnesota and Stanford. Dipender is a Commissioner of the Global Commission to End Energy Poverty, serves on the boards of AST, Automatiks, Encell, Innovium, Insyte, Joby Aviation, Kinestral, Navitas, NuVia, QuantumScape, Raxium, Saildrone, and SummerBio, the Leadership Council of Cyclotron Road and the investment committee of PRIME.

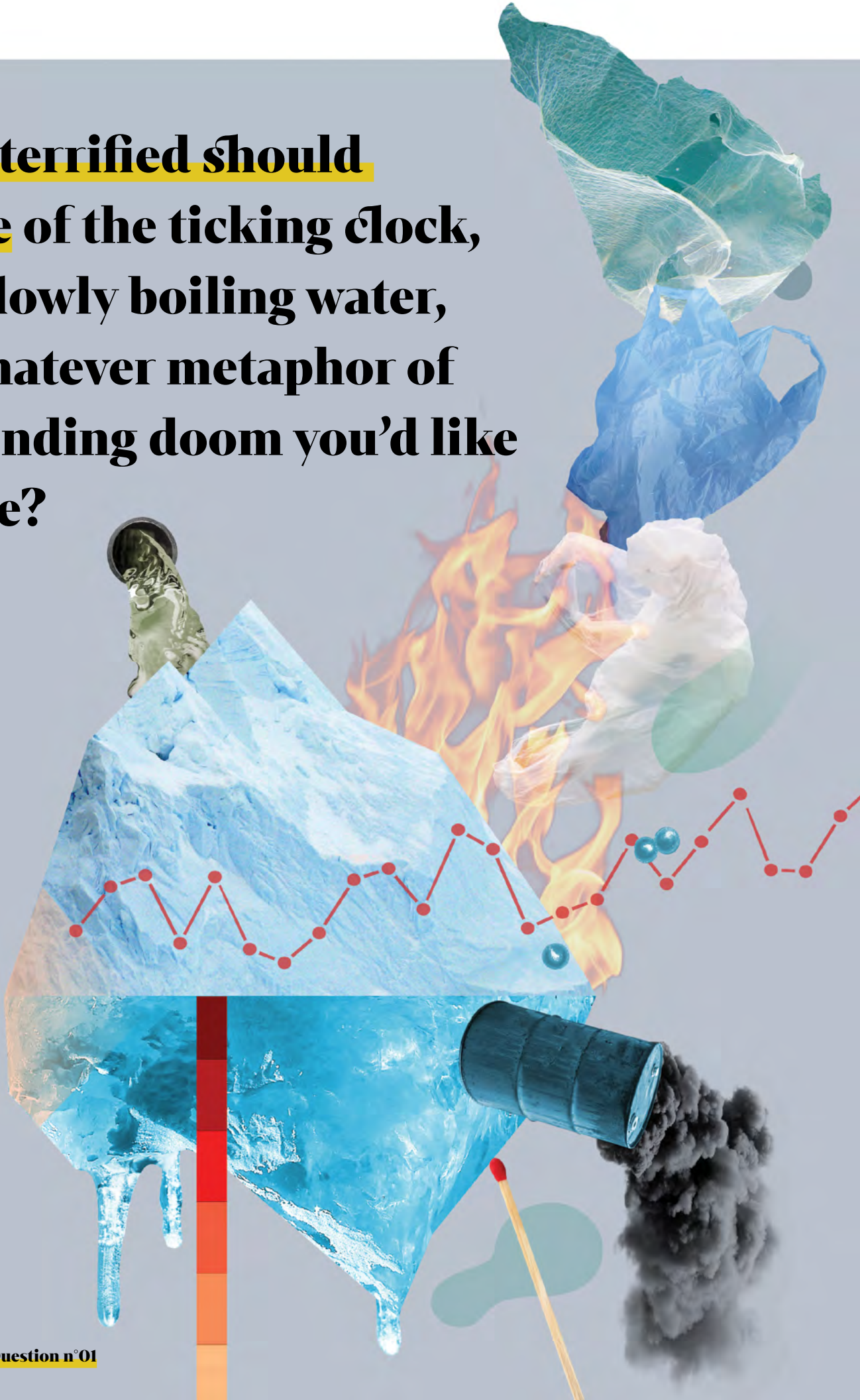


Dave Snyder
CEO & Co-Founder,
Lilac Solutions

Dave founded Lilac in 2016. He is a materials engineer and an expert in battery technology, with experience spanning multiple battery startups developing next-generation materials and manufacturing processes. Dave holds a PhD from Northwestern University and a BA from Wesleyan University.



**How terrified should
we be of the ticking clock,
the slowly boiling water,
or whatever metaphor of
impending doom you'd like
to use?**



Question n°01



Jeremy Grantham

As terrified as we can bear to be. Even with the progress we're making, the world is certainly going to be over two degrees warmer than it used to be by 2100. And swathes of it — including highly populated parts of Africa, India, and more — will be simply too hot for humans to survive in.

And the ticking clock or slowly boiling water is exactly the right kind of metaphor. If changes like this, or even the changes we've already seen over past decades, were to happen over one or two years, they would drive public outrage and a massive reaction. But, because they occur over generations, we're completely underreacting to them.



Barbara Burger

We prefer optimism over pessimism because it more accurately reflects today's reality. The fact is that the prospects for humanity have never been brighter. People today are living longer, healthier, more prosperous lives than at any time in human history. This doesn't mean we don't face challenges, and addressing the challenge of climate change is a critical one. But we have confidence in the power of human ingenuity, creativity, and innovation to deliver the breakthroughs we need.

Affordable, reliable, cleaner energy is essential to achieving a more prosperous and sustainable world. Because billions of people around the world depend on it, oil and gas will play an important role in any transition to a low-carbon economy. Chevron sees a great opportunity to produce these vital resources with a lower carbon footprint and will play a leading role in this transition.



Jennifer Holmgren

Honestly, I think we should be scared shitless. That's my answer. We should be scared completely out of our minds.

I find it offensive when people say that if you're scared out of your mind, you're paralyzed. Being scared is the first step in a call to action — it's the moment you take before making the decision to fight or flee. At the end of the day, you can freeze for a second, but then you must decide to take action. I don't think anybody is willing to accept how bad this problem is except for a few people (like climatologist Michael Mann and others that have been doing climate science for decades and telling us we should be very concerned).



Bob Mumgaard

Climate change is the biggest issue of our generation, but we can't let fear paralyze us into preserving the status quo. We must use it as a motivator to develop the solutions to fix it. Instead of looking at this as impending doom, we should look at this as an opportunity to leverage human ingenuity and innovation to make meaningful change. The majority of emissions have happened in a single generation; that means we—the people here now—can fix it.



Carmichael Roberts

The climate used to be one of those topics that would make people, especially people in power, duck and dodge. But they don't do that anymore. Take a look at when people are running for the Senate, or the House, or governor, or president — there's no more talk about whether climate change is real or not. They don't argue as to whether they should address it; they talk about *how* they are addressing it and how they will address it.

So, yes, we should be worried, but also incredibly optimistic.



Dipender Saluja

The world is not acting as it should because, like you said, we are frogs in slowly heating water. Climate change has gotten very politicized. I've been in Silicon Valley for three decades and have never seen such resistance to new technologies — such resistance to the new, better options. Why is that?

Take the smartphone as an example. People could have raised their hands and said, "That's a war on landlines." But people didn't do that. They adopted it as a wonderful thing. Instead of embracing technologies that could help cut emissions and add jobs, we've politicized climate change — that's why we need to be worried.



Dave Snyder

In California, the water is already boiling. We are being hit with heat waves and devastating wildfires casting smoke so thick it blacks out the sun. Other parts of the world are suffering from droughts so severe they drive mass migrations and civil war. Climate is an urgent public health and national security crisis. Certain pockets of America remain insulated from the crisis, but there is increasing pressure for people to come off the fence and take action in their personal and public lives.



Emissions are rising, climate disasters are becoming more frequent, and major world powers are choosing nationalist politics over climate action — in spite of all this (and more), how do you remain hopeful?



Jeremy Grantham

There's a lot to be worried about, but there's a lot to be hopeful about too. The hope is technology. There's been incredible progress in electrification and in renewable energy in the last two decades. Today, renewable power is cheaper at the margin than fossil power, and electric cars are more economical than gasoline cars. All of that was unimaginable a few years ago. As progress continues, climate action is going to be increasingly painless; in fact it will be inevitable.



Barbara Burger

We're not just hopeful; we have confidence due to the power of human ingenuity, creativity, and innovation — what we call human energy — to address the greatest challenges. No single company, industry, or country will have all the answers, and we will need to work together. Market incentives, particularly those set by well-designed carbon pricing policies, are the most effective, efficient way to focus the energies of all stakeholders on finding lower-carbon solutions and bringing them to the marketplace.

At Chevron, we seek to provide the affordable, reliable, and ever-cleaner energy that billions of people rely on worldwide. We are building and strengthening partnerships with those who have shared aspirations and where our combined strengths can have a tangible impact on delivering a lower-carbon future.



Jennifer Holmgren

I stay hopeful because I know we can solve the problem. I know there are technologies that will allow us to solve the problem. And I know there are people that are committed to making the policy environment fit the problem.

We can change how we do things. The question is: how fast are we willing to change how we do things? That's what it's going to come down to.

We're going to pay for this one way or another — whether it's carbon taxes or because we clean up after hurricane after hurricane. The difference between those scenarios is not the amount of money we spend: it's the amount of suffering that we are willing to endure.



Bob Mumgaard

People fundamentally want a world they can live in, and, right now, the effects of climate change are becoming more and more difficult to ignore. I remain hopeful in our ability to turn it around. We are seeing growing coalitions dominated by young people who are concerned about the future of this planet, and they are making a strong moral movement to get this right. Importantly, a comprehensive approach to combating climate change is not a net-zero problem. This is also the greatest market opportunity in history. An effective approach to combating climate change will bolster the world's economies, and I see an undercurrent moving in this direction beneath all the bad news.



Carmichael Roberts

The conviction of people of all ages, shapes, sizes, and backgrounds. There are so many issues that have divided us today, but climate change is unique — it's a topic about which 10-year-olds and 40-year-olds see eye to eye. It is a topic that cuts across socioeconomic standing: poor folks and some of the wealthiest people on the planet are equally concerned. The momentum of change and action behind such a diverse group of people is undeniable.



Dipender Saluja

There is no such thing as choosing hope in this case, because this is not a binary situation. It's not like there's a tipping point and the world disappears the next day. It's just the question of how bad are we willing to let it get before we stop causing more harm. And the answer to that question varies from location to location, socioeconomic group to socioeconomic group.

I have a cartoon that I use in my slide decks where there's a guy giving a talk on climate change. And another guy says, you know, this is all bogus, you're going to mess up our lives. And the one giving the talk says, well, the worst — the worst — that can happen, if somehow climate change were not real, is that we would have created a bunch of new technologies that employed a bunch of people and created a bunch of wealth.



Dave Snyder

Governments can help support new industries, but, ultimately, private enterprise and consumer choice play a central role in the battle against climate change. Transportation is now the largest source of emissions, and Tesla has been both a wonderful inspiration and an existential threat for other automakers around the world. Deployment of wind, solar, and batteries on the grid is also a continuing success story. Meat alternatives are positioned to make a major impact as well. All this needs to be accelerated and ramped up by orders of magnitude, but we can now see a pathway toward significant decarbonization.



Which is the larger hurdle in the fight against climate change: policy or technology?



Question n°03



Jeremy Grantham

Out of those two, the larger hurdle is policy. Policy needs to let markets price in the climate externality — by taxing emissions. That’s the only real hurdle as far as policy, and technology has gotten over many of its hurdles already.

The largest hurdle, of course, is the brute physical fact that fossil fuels make a great power source. If only they didn’t emit greenhouse gases when you use them! So, getting off them was always going to be hard. But our technology has advanced to the point where we can do it now. All we need is policy to help give us a push.



Barbara Burger

Frankly, both technology breakthroughs and sound public policies are critical to society’s ambition to achieve a lower-carbon future. At Chevron, we’re taking action on both fronts.

We’re actively investing in breakthrough technologies and working collaboratively with many partners to scale them. We’ve built and operate one of the world’s largest integrated carbon capture and storage projects in Australia, capable of capturing and storing approximately four million tons of CO₂ every year. We are working with the U.S. Department of Energy as well as one of our venture-backed startups on an engineering-scale carbon capture plant in California, which will help advance commercial deployment.

At the same time, we’re working to shape smart, inclusive public policy and support emerging technologies that can help more stakeholders participate in a lower-carbon economy.



Jennifer Holmgren

Policy — it’s policy that sets the environment for new disruptive technologies to thrive.

Policy is the thing that changes everything. Our legislation can choose to incentivize new approaches and to disincentivize old approaches. And until that happens, we will not address climate change fast enough.



Bob Mumgaard

We are not going to do this without both. However, historically policy has lagged and that makes it feel like the bigger hurdle. The distributed nature of innovation has pushed technology harder and faster than policy can match. Ultimately, we’ll put it in the hands of the people, both the innovators in technology, the mobilizers for policy change, the consumers who demand sustainable options, and the board rooms who allocate capital. That whole system will need to — and I believe is starting to — work together.



Carmichael Roberts

There are certain solutions that are bottlenecked by policy. Then there are problems that can be solved without policy playing a role. And then there are those that require a balance of the two. It is incredibly dependent on the problem. Look at COVID vaccine development, for example. There is equal importance on science creating the vaccine and policymakers approving it and deciding how it will be distributed.

I don’t want the general public to think that there’s no way to make progress unless we have significant policy changes. At the same time, I don’t want people to think policy is somehow unimportant. It’s all about context.



Dipender Saluja

There is no upper limit of either of those right now. Climate change is happening — every day is worse than the day prior. We are so far away from the bare minimum on the policy front that any positive action is good action.

Some say cleantech is too expensive now. I have friends that say, “I haven’t bought solar this year because it will be cheaper next year.” And I tell them that you’ll lose more financially if you delay buying solar by a year than you gain by the cost reduction of the product — it makes no sense.

We need to have everybody in technology doing all they can. Because this is not just about climate — if we have 100 new technologies that come out that are better than a “good enough” technology, then we’ll have that much better everything.



Dave Snyder

Within transportation, which is the largest source of emissions, the technology mostly exists, state incentives already exist, and federal incentives are unlikely to make a major difference. In my view, the largest hurdle in this sector is neither technology nor policy but is consumer choice. We need more car buyers to vote with their wallets. Young people who are passionate about climate have a role to play in educating older drivers about electric vehicles and about the environmental impact of gasoline to help shift this decision-making. Policy is the big hurdle for electricity generation and land use. Policy and technology are both hurdles for chemicals and materials.



Looking back to the cleantech bubble of a decade ago, what's changed? Why and how will Cleantech 2.0 be different?

Question n°04



Jeremy Grantham

What's changed is that "cleantech" is much better now than it was then. Solar power is now cheaper than coal power; electric cars are better than traditional cars. The bubble of a decade ago was required to will these innovations into existence. Now that they exist, they're much easier to profit from.

If you consider the internet bubble: all the things 90s dotcom boosters predicted, in terms of how the internet would change our lives, have come to pass. It was just the companies of the time that didn't make it. But those ideas, now successfully commercialized, are producing much more lasting returns for investors in the current FAANG boom. Cleantech 2.0 could be much the same.



Barbara Burger

Cleantech 2.0 is very different. Investors now have a deeper understanding of the time horizons needed to develop and scale the technologies that will be vital to the energy transition.

The pace of innovation has increased, and there is more support across the ecosystem to fund, guide, and grow technologies that are increasingly more capital efficient. Cleantech 2.0 has also changed as companies across numerous sectors have made significant commitments to sustainability, climate change, and a lower-carbon future.



Jennifer Holmgren

A decade ago, there was a lack of a realization of what it really took to commercialize clean technologies. If you're only familiar with investing in software, you don't realize that you have to invest half-a-billion dollars and 15 years to bring a "tough technology" to market.

I resent the way people criticize those original investors. If they hadn't been bold enough to take those risks, we would have never learned from them. My hat's off to the Vinod Khosla's of the world, who dare to say, "I want to build a non-fossil supply chain to make fuels."

As far as "Cleantech 2.0" is concerned, the industry still needs to build a bunch of "first ones," and we need people to be willing to fail. We will succeed when we're really, really prepared to fail. And I don't mean fail at the million-dollar lab scale, but at the hundred-million-dollar commercial scale.



Bob Mumgaard

People forget that cleantech goes back to the 70s. We've learned a lot. Most importantly, it's now become existential to the world. And the result is a completely different ecosystem that's poised to make significant change. We now have interest from large broad-based coalitions that have the capital, the policy, the network, and the technology at a completely different magnitude focused on sustainability more than ever before. It's no longer cleantech. It's not even tech. It's just business. Look at everything from Tesla to the positions of the European oil majors to BlackRock.



Carmichael Roberts

A supermajority of the companies in the first wave of cleantech were focused on how to provide energy in a cleaner fashion. It was a very direct approach. But if you look at today, the approach is less direct — more top down. We're seeing more companies focusing on negative-emissions or emissions-free outcome, and as such, we're seeing a broader spectrum of technologies and companies than we did a decade ago.

Along with the accomplished scientist and engineer founders, we're also seeing a different class of entrepreneur — those who have started in other industries and then come to cleantech later. They may have sold a consumer technology startup, for example, so they have the business savvy. Couple this with being committed to making a positive impact, and you have incredible potential for success.



Dipender Saluja

It's not 1.0 versus 2.0 — within our firm, we are on version 3.0. Think of the past decades: the 80s, 90s, 2000s, 2010s, and then just entering the next one. Each one of those has brought an amazing wave of entrepreneurship and growth and innovation.

When you add it all up, the failure of Cleantech 1.0 or 2.0 or 1.5 — whatever you call it — that failure is a tiny pimple on the dimple of another small thing compared to the total innovation that is going to happen in cleantech. Take the dot com bubble, for example: imagine if everyone had thrown up their arms in the year 2001 and said, "That was a disaster. Let's stop while we're ahead." The losses in that era, just like the losses in cleantech, were necessary failures of fast, fearless innovation.

I would argue that if you don't see a certain degree of failure, you're not innovating fast enough. And you become the automotive industry of the 80s or the aerospace industry of the last decade.



Dave Snyder

Cleantech 2.0 has the benefit of a rapidly growing EV market and a maturing solar/wind market. There is real money changing hands today in clean energy, and startups can now sell into those markets.



What are the most impactful ways the free market can help solve our biggest climate challenges? And, in a related question, how can the government do the same?



Question n°05



Jeremy Grantham

The free market is very flawed but also very powerful. The advances we've seen in battery technology, in solar, and in wind, in the past several years show just how powerful it can be. The market can do crazy things in the short run, but it will do the right thing in the long run, as long as it's provided the right incentives.

There are two major things governments can do. Some kinds of very large-scale research can only be effectively run by the government, as seen in WW2 and the postwar era. Today, research into nuclear fusion power might fall into that category. The other thing they can do — in fact the thing they must do — is set up the right incentives to get out of the free market's way: by instituting a carbon tax.



Barbara Burger

Market incentives are the most effective, most efficient way to advance to a lower-carbon future. That's why we advocate for well-designed carbon pricing policies that create markets where lower-carbon solutions are rewarded, which helps ensure all stakeholders are focusing their energies on achieving society's global goals.



Jennifer Holmgren

First, we have to do everything faster. We must be willing to fail faster, invest faster, and build faster. Funding should be at least 50/50 government and private investment, with, potentially, government funding taking the lead. And government funding must exist beyond early-stage and pilot work. Perhaps there should be some type of matching investment — a public/private partnership is vital. And while governments must step up, they should never develop 100% of a new technology. These technologies must have independent validation and vetting, which is best done by the market.



Bob Mumgaard

The free market has an opportunity to support and benefit from the many innovations and companies that are tackling climate challenges. The scale of this problem and the need to solve it will create large, high-growth companies that will be pillars of our future economy. These technologies will go from impossible to inevitable, and I think we'll see it happen really fast, much faster than the doubters predict. Innovation and the free market are really amazing things to watch.

Governments also have an opportunity to support broad, forward-thinking policies that will enable bold change. We need a significant increase in public funding for technology research and development that will enable private companies to bring innovative solutions to market on a timeline that impacts climate change.



Carmichael Roberts

Aside from funding early-stage technologies in universities or other research institutions, the government can play a massive role in communication to its citizens. It can help spread awareness and advocacy. It can be a steward of new technologies and the potential they hold.

Private industry will naturally take care of the bulk of the innovation once these technologies leave the labs. We know how to build technologically-driven companies that manufacture at massive scales. Bringing back the COVID example for a minute — if you look at the production of PPE, policy takes a backseat to making and distributing the product, which private industry can do very well.



Dipender Saluja

We must have an intelligent free market — a free market doesn't mean blocking everything that doesn't pay off on day one. You cannot ignore what a certain cost today delivers in value tomorrow and what that does to the total cost of adoption. If we have to invest in an industry ahead of its elbow, then so be it, as long as we know that the elbow will more than make up for that investment.



Dave Snyder

Free enterprise is the driving force behind climate solutions. I've been privileged to be in a position to raise VC financing to build climate solutions and would highly encourage other technologists with a clear vision of success to do the same. State governments should deregulate electric utilities that still own coal plants and allow clean energy developers to compete fairly. The federal government should pass new tax credits or rebates for EVs.



**How will the
sustainable technology
revolution reshape the
United States' economy?**



Jeremy Grantham

Sustainable technology will entirely reshape the world economy. Renewable infrastructure investment will be hundreds of billions, peaking in trillions, of dollars every year for this century — and non-renewable industries will disappear. But unless the U.S. takes a leadership role in developing sustainable technology, it'll get much less of the economic benefit in terms of jobs and wealth.



Barbara Burger

Technology innovation — aided by market incentives — has the potential to bring significant value to nearly all industries, helping us to achieve our economic goals while using limited resources more wisely.

Chevron is actively applying innovation to our business and our operations. We have invested in a range of technologies to support our core business as well as in renewable power, biofuels, hydrogen, energy storage, and carbon capture and storage. Chevron Technology Ventures has more than two decades of experience investing in energy innovations and then integrating them into use at scale. Technology breakthroughs are required for a cleaner and more sustainable future, and Chevron will play a leading role in getting to that future.



Jennifer Holmgren

What is a big company about? Efficiency. They are forced to become better and better at yields and costs. Therefore, it is the startup companies that create a massive number of jobs. New ideas create new opportunities.

At the learning stage, you need more people. You are focused on building something. And in cleantech, you're going to have jobs at every level — construction jobs because you're building new infrastructure, engineering jobs, chemistry jobs, science jobs — you're going to have jobs across the whole spectrum. That's how you stimulate an economy.



Bob Mumgaard

The U.S. has an opportunity to capitalize on our strengths and be a leader in this revolution. If we have the right policies and the right products, we can build defensible industries that capitalize on innovation, technology, and advanced manufacturing. This will mean long-term job creation and massive economic development in cleantech. We will also see companies that did not get on board and anticipate this revolution disappear. If the U.S. wants to be important in the future, it is going to have to win the battle for the climate, and, historically, the U.S. has shown it has the tools and spirit to do that.



Carmichael Roberts

One of the things that's made our country great is the ability to take a nascent technology and to turn it into something prominent. And that goes beyond job creation. Look at today's group of companies with the highest market caps in the world. Their prominence, for the most part, was impossible to predict 15 years ago.

So, if you push out 15 more years, knowing how transformative technologies can take hold, we can be assured that some of the early-stage technologies that we are investing in will fall into that list of those companies with the highest market caps in the world. We'll see even more in the top 200 market caps — we will see a fundamental shift in where commerce is coming from and how business is being done.



Dipender Saluja

We have so many technologies sitting under our noses that we can deploy and stimulate the economy. I can't imagine a better way to build back better.

If COVID has taught us anything, it is that when our collective backs are up against the wall, we can mobilize. Our government can mobilize quickly and disperse trillions of dollars for its citizens in need. Putting a dent in climate change requires just a tiny fraction of the trillions of dollars we've spent during the pandemic. For example, if we were to harness the wind from the wind spine of our country, we could provide 20% of our energy needs. And the total price tag to retool our grid to make use of such renewables is in the tens of billions of dollars. And that retooling creates jobs up and down the line — that investment goes straight into the economy. I don't know a single thing that is bad about a situation like that.



Dave Snyder

Oil companies used to be dominant players on the national stage and large employers, and now they are fighting for survival. Retraining engineers and technicians to thrive in new cleantech sectors will be essential. PhDs in materials and chemical engineering have an important role to play: many will have opportunities to help retrain the workforce and reshape the economy.

Next starts *now.*

A survey of companies and technologies at the forefront of the latest cleantech revolution

Written and Researched by: Nathaniel Brewster, Sophie Sponder Levin, and Eric Lehnhardt

The math's been done. The equations written and rewritten to accommodate an ever more volatile status quo. We know what's causing climate change and we know the numbers we must hit to prevent its permanent, disastrous effects.

In light of this volatility, we remain optimistic. As Bob Mumgaard, CEO & Co-Founder of Commonwealth Fusion Systems, notes in an interview within this publication, "The majority of emissions have happened in a single generation, that means we — the people here now — can fix it."

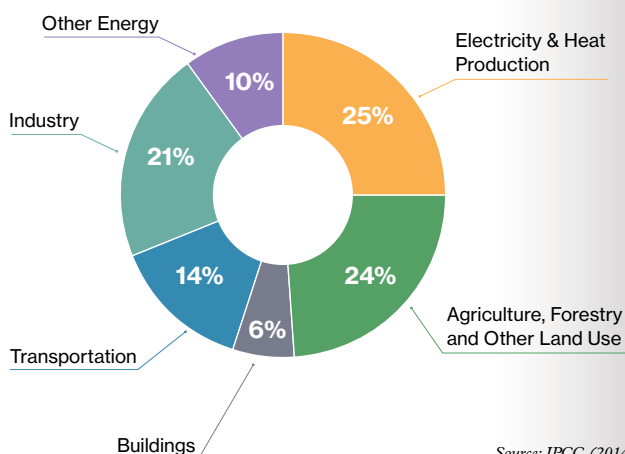
The following survey is not exhaustive of all emerging clean technologies, approaches, and companies. The Global Greenhouse Gas Emissions data compiled in the 2014 IPCC report on climate change served as a guide in identifying the broad sectors on the following pages. These sectors have some of the greatest potential for contributing to a decarbonized world. The sub-sectors we identify are of particular interest as they feature dynamic Tough Tech innovation.

Our goal is to provide a succinct overview of some of the most promising emerging technologies, the companies commercializing those technologies, and a high-level picture of the investment landscape.

"The majority of emissions have happened in a single generation, that means we — the people here now — can fix it."

Bob Mumgaard, CEO & Co-Founder of CFS

Global Greenhouse Gas Emissions by Economic Sector



Source: IPCC (2014)

Electricity

p . 30

Carbon-Free Power Generation

Solutions like fusion, next-generation solar, and geothermal energy are highlights of the latest wave of emissions-free power generation.

Load Following Resources

Typically a significant source of CO₂ emissions, innovations in load following energy (also known as dispatchable energy) can help ensure emissions-free grid resiliency.

Carbon Capture Utilization & Sequestration

p . 34

Capture

We must find reliable, inexpensive, and safe ways to capture greenhouse gases.

Utilization & Storage

Companies are using CO₂ to create useful materials and products, as well as sequestering it in the Earth.

Food & Agriculture

p . 38

Alternative Proteins

Raising animals for meat produces huge amounts of CO₂ – we need better options for omnivores.

Plant Genetics

Our food production needs to double by 2050. We can edit plant genomes to be more efficient and productive.

Waste Reduction

Harvesting, packing, and shipping food is massively energy intensive, yet a third of our food doesn't make it from farm to fork.

Transportation

p . 44

Electric Vehicles

We need clean energy to run all the vehicles we can – that means better, cheaper batteries and more efficient motors.

Autonomous Vehicles

Self-driving cars can move faster, more safely, and more efficiently, which decreases traffic congestion and saves energy.

Alternative Fuels

There are applications that will always demand a clean alternative to batteries.

Materials & Buildings

p . 50

Materials

Steel, cement, and chemicals make the modern world possible, but their ubiquity comes at a cost. Together, these materials account for approximately 20% of total global CO₂ emissions.

Buildings

There are more than 230 billion square meters of building space in the world. Ensuring that this space, and the platforms used in it, are optimized for efficiency is a critical to combating climate change.

Carbon-Free Power Generation

If you were to ask the average person what they imagined when they heard the words “clean technology,” the answer would most likely be some derivation of clean electricity. Carbon-free power generation, at the scale to replace fossil fuels, is one of the (if not the most significant) goals of the current cleantech revolution. Electricity production alone produces approximately 25% of the emissions responsible for climate change. Decarbonizing electricity at the grid scale would represent a monumental human achievement.

Fusion power represents an emissions-free source of energy so vast, so easily deployable, and so resilient, that it has remained a holy grail of clean technology for over 70 years. Despite painstaking, groundbreaking, science-oriented research at academic and government research labs, no one has yet achieved a net-positive fusion reaction that produces more power than it consumes.

However, a new dynamic is afoot in the fusion community, as evidenced by increasingly vibrant private sector activity. Roughly 20 fusion companies are now in operation, backed by some \$1 billion in capital. Notably, The Engine portfolio company Commonwealth Fusion Systems announced in September 2020 a series of seven peer-reviewed papers¹ that validated their approach to commercial fusion energy. The papers are significant public predictions of the company’s ability to produce net energy from the plasma within its reactor.

Solar power remains one of the most commercially mature sources of clean energy on the planet. The sector has seen incremental improvements in efficiency in the past decades, but a new breed of technically innovative companies hopes to provide step changes in both performance and manufacturing efficiency. There is tremendous

interest in the potential of perovskite solar cells, but while the material promises increased efficiency and power delivery, it is less stable than other photovoltaic technologies. There are notable challenges with the commercialization of perovskite solar cells. However, there is a sizable opportunity for the first companies to successfully bring the technology to market.

Geothermal energy is routinely harnessed for small-scale applications as a complement to grid power. A new generation of geothermal companies looks to utilize the unlimited carbon-free source of power beneath the Earth’s crust for grid-scale energy generation.

Partially adapted from "Knowledge, Capital, and a Growing Sense of Mission: Fusion Energy Development Enters a New Era" by Peter Dunn

For further reading, download Tough Tech N.1 @ www.engine.xyz

^{1/} <https://www.cambridge.org/core/journals/journal-of-plasma-physics/collections/status-of-the-sparc-physics-basis>

Fusion

These highlights are diverse in technical maturity, approach, and investment. Despite this, they face similar challenges in bringing fusion power to life and then to commercial scale. If they are to succeed, each company must also address the significant policy and social hurdles incumbent upon any new nuclear power source.

Examples

- + Bruker
- + Commonwealth Fusion Systems
- + CTFusion
- + Helion Energy
- + General Fusion
- + Tokamak Energy
- + TAE Technologies
- + Zap Energy

Solar

Solar power is one of the most established sources of renewable energy on the planet. It is a mature industry with consistent incremental improvements in panel efficiency and production cost. The next generation of solar energy providers will make use of unique manufacturing techniques and materials like perovskite.

Examples

- + 1366 Technologies
- + Array Technologies
- + Bluedot Photonics
- + First Solar
- + Leading Edge Equipment Technologies
- + Heliogen
- + Maxeon
- + Nexwafe
- + Osazda Energy
- + Oxford PV
- + Sun Co. Tracking
- + Sunfolding
- + SunHydrogen

Geothermal

If we dig deep enough, we can take advantage of thermal energy with power densities consistent with fossil fuels. Geothermal energy companies are attempting to capture this unlimited, carbon-free power source at various depths and with various approaches. Quaise, for example, will bore over 10km deep to achieve its goal of harnessing “supercritical” geothermal energy.

Examples

- + Climeon
- + Eavor Technologies
- + Fervo Energy
- + Quaise

Investment Notes

Venture Investment in Private Fusion Companies – 2017-2019:

\$281M

<https://www.cleantech.com/fusion-energy-innovation-accelerated-progress-in-2020/>

U.S. VC & PE Investment in Solar – 2017-2019:

\$1.1B

https://data.bloomberglp.com/professional/sites/24/BNEF-BCSE-2020-Sustainable-Energy-in-America-Factbook_FINAL.pdf

Timeline

Technology Development

1975 | The Princeton Large Torus (PLT) proved that neutral beam injection could be used to achieve temperatures over the 50 million K (that Enrico Fermi estimated would be) needed to maintain fusion

1986 | IBM researchers discovered high-temperature superconductors

1991 | The Joint European Torus (JET), a large tokamak completed in 1983, achieved between 1.5 and 2 megawatts of fusion power, the first fusion reactor to create a “significant amount of power”

1994 | Princeton's Tokamak Fusion Test Reactor (TFTR) set a world record when it achieved a record-setting 510-million-degree plasma

1997 | The TFTR tokamak reached a 0.7 ratio of fusion power to input power

2003 | The Tore Supra, the first superconducting tokamak, achieved a six-and-a-half-minute-long plasma discharge

2016 | MIT's Plasma Science and Fusion Center set a new record for plasma pressure with its Alcator C-Mod tokamak nuclear fusion reactor (2.05 atmospheres, a 15% increase)

Public Policy and Awareness

1985 | President Reagan and Secretary General Gorbachev agreed on an international effort to develop fusion energy “as an inexhaustible source of energy for the benefit of mankind”; this led to the creation of the International Thermonuclear Experimental Reactor (ITER) project

1998 | The U.S. (temporarily) withdrew from ITER; rejoined in 2003

2015 | The DOE awarded \$30 million in funding to nine projects under the new Accelerating Low-Cost Plasma Heating and Assembly (ALPHA) program

2019 | The DOE announced up to \$30 million in funding for a new ARPA-E program, Breakthroughs Enabling Thermonuclear-Fusion Energy (BETHE)

2020 | NuScale's small modular reactor was the first new nuclear reactor design in decades to get approval from the Nuclear Regulatory Commission

2020 | DOE and ARPA-E announced a joint program, Galvanizing Advances in Market-Aligned Fusion for an Overabundance of Watts (GAMOW) with up to \$30 million in funding over three years; the objective of GAMOW is to fund R&D in fusion energy subsystems and cross-cutting research

Load Following Resources

For all their importance to modern life, electric grids remain sensitive and sometimes temperamental things. They exist in a constant state of flux, dynamically adjusting within milliseconds to surges in demand. If they fail to accommodate such demand, they risk leaving customers in the dark. The type of electricity that is used to meet these surges in demand is known as “load following” or dispatchable energy. Not all types of power are dispatchable; sources like nuclear, coal, or biomass are known as “baseload sources.” Baseload provides a consistent and predictable output but requires significant time to ramp up to meet demand. There is significant interest and technical innovation in alternative load following plants, which are usually significant emitters of CO₂.

Today, power systems are built around flexible, primarily natural gas generation that is able to modulate output in real-time to meet daily/weekly variations in renewable output. Successful decarbonization requires replacing this capacity with clean resources. However, in order to replace this capacity, we need to find a resource that operates similarly to natural gas power plants and dispatches power for up to 10 hours per day.

Many companies in this segment are trying to replicate the functionality of pumped hydropower energy storage — the leading source of energy storage in the world. A game-changing energy storage technology would be one that replicates the functionality of pumped hydropower across the distribution system.

The vast majority of solutions to the challenges of zero-emissions dispatchable energy have used lithium-ion batteries for short duration applications. These batteries provide the necessary reliability and resilience to the grid, but are not suited for longer duration applications.

Other technologies in this segment include fuel cells, which, when powered by hydrogen, can provide a zero-emissions solution. In July 2020, Bloom Energy, a fuel cell producer, announced its intention to produce renewable hydrogen and hydrogen fuel cells. The company already produces gas-powered fuel cells with up to 60% less CO₂

emissions than the average coal-fired power plant.

The Engine portfolio company Form Energy is designing a large-scale battery storage system that would enable a 100% renewable, carbon-free grid. The platform itself remains a trade secret, but it promises to liberate the potential of renewables by storing and deploying, the power they generate for up to 150 hours, which is far greater than the four-hour deployment window common in lithium-ion platforms. In May 2020, Form announced a partnership with Minnesota utility Great River Energy to help replace its coal power with new wind capacity. This project will be the first utility-scale test of the company’s “aqueous air” battery system.

Malta, a Boston-based energy storage company, is pioneering a system that converts electricity gathered from any source into thermal energy, which is then stored in either molten salt or chilled liquid. The temperature difference between these two storage mediums is then converted back to electrical energy and sent to the grid when needed.

Today, the global market for stationary energy storage is \$9.1 billion. Navigant Research projects that the market for medium-duration energy storage will exceed \$16 billion by 2025, and Lux Research estimates that the grid-scale battery energy storage market will exceed \$111 billion in 2035.

Battery

These companies use a variety of battery technologies, from proven lithium-ion platforms to innovative large-scale long duration systems. The overall goal is the same: to store energy from renewable sources and deploy that energy when renewables alone cannot meet the demand.

Examples

- | | | |
|---------------|---------------------------|------------|
| + Alpha ESS | + Form Energy | + Stem |
| + Coda Energy | + Invinity Energy Systems | + Sumimoto |
| + ESS | + Ionic Materials | + Tesla |
| + e-Zinc | + Primus Power | + UET |
| + EnerVault | + Sion Power | + ViZn |

Gravity Based and Flywheel

Many of these approaches use similar physics to pumped hydropower but eliminate the need for water. Like other solutions within the sector, the core offerings from these companies are not dependent on geology or topography, meaning they can be deployed where needed most.

Examples

- | | |
|----------------|-----------------|
| + Ares Power | + Gravity Power |
| + Energy Vault | + Tata Power |
| + Gravitricity | + Teraloop |
| | + OXTO Energy |

Investment Notes

Timeline

Technology Development

1973 | NASA produced the first iron-and-chromium redox flow battery to store energy at a future moon base

2002 | Sandia National Labs evaluated the application of used EV batteries in stationary applications and found that four applications (transmission support, light commercial load following, residential load following, and distributed node telecommunications backup power) were good candidates

2011 | MIT researchers developed a new battery architecture that combines the design of liquid-flow batteries with that of conventional lithium-ion batteries resulting in a 10x improvement in the energy density of liquid-flow batteries and halving the size of a battery system

2012 | GM and Duke Energy piloted the first grid-scale storage with second-life EV batteries; on average, lithium batteries from old EVs retain over two thirds of their usable energy storage

2017 | Tesla installed a 100MW/129MWh battery project in South Australia (powered by the neighboring wind farm); the battery system reduced the local grid service costs by 90% in only six months

2019 | California connected the first grid-connected flow battery

Compressed-Air and Water

These technologies promise to use the innate power of air and/or water to store grid-scale amounts of power, without being tethered to a particular geography.

Examples

- + Hydrostor
- + Highview Power
- + General Compression
- + Quidnet Energy

Hydrogen

Fuel cells powered by hydrogen promise reliable, easily deployable power with a highly adaptable form factor. Challenges remain with the economics of producing hydrogen, as well as with the emissions emitted during typical gasification, electrolysis, liquid reforming, and other commonly used production methods.

Examples

- | | |
|---------------------|-----------------------|
| + Ballard Power | + Intelligent Energy |
| + Bloom Energy | + Nel Hydrogen |
| + Ceres Power | + Plug Power |
| + Fuel Cell Energy | + Redox Power Systems |
| + Hydrogenics | + Sunfire |
| + Hydrogenious LOHC | + ZEG Power |

Energy Storage Company VC & PE Investments in the U.S.
– 2016-2018:
\$814M

<https://www.bcse.org/wp-content/uploads/2019-Sustainable-Energy-in-America-Factbook.pdf>

New Build Energy Storage Investment, Worldwide – 2017-2019:
\$8.8B

https://www.danskenergi.dk/~media/Smart_Energii/Global_Energy_Storage_Forecast_2016-24_2016_08_31.ashx

Public Policy and Awareness

1978 | Sandia National Lab launched the “Batteries for Specific Solar Applications” program, to develop battery technologies that could be integrated with photovoltaic and wind energy systems

1996 | The DOE expanded Sandia National Lab's Utility Battery Storage Program (UBS) program to include the development of innovative storage technologies, such as flywheels and compressed air energy storage (CAES)

2009 | The DOE announced \$185 million in funding for energy storage as part of a \$3.9 billion smart grid stimulus

2018 | President Trump signed the Agricultural Improvement Act of 2018 (aka the Farm Bill), which included provisions making energy storage eligible for up to \$50M/year in grants when co-located with renewable energy to support clean energy projects in rural communities, particularly farms and small businesses

2018 | The Federal Energy Regulatory Commission (FERC) issued Order 841, which directed regional grid operators to remove barriers to the participation of electric storage in wholesale markets; the order was upheld in federal appeals court in 2020

2020 | The U.S. national Energy Storage Association (ESA) has adopted as a goal the deployment of 100GW of new energy storage using a range of technologies by 2030, updating a previously set 35GW by 2025 target

Carbon Capture

How do we turn back the clock on climate change? With some amount of warming already guaranteed — and projected emissions generating quite a bit more — we need to stem the flow of carbon dioxide into the atmosphere and retrieve what has already escaped to meet internationally recognized climate goals. Carbon capture technologies can help “bridge the gap” during the hard work of economy-wide decarbonization, trapping necessary emissions at the source and filtering the atmosphere to reduce its carbon dioxide content. These technologies provide the opportunity to sequester carbon even faster than the trees.

Capturing carbon dioxide emissions — as opposed to eliminating any process that produces carbon dioxide — carries the distinct advantage of enabling a high degree of business as usual: we can keep our plastics, high density fuels, and synthetic pharmaceuticals; retrofitting existing infrastructure is often cheaper and faster than building new; enough capture from the air could halt or reverse ecologic and economic climate change impacts. What it lacks today is a cost structure that will enable scale.

The price of carbon capture depends on whether CO₂ is caught coming from a smokestack (a ‘point-source’) or pulled from the atmosphere (‘direct air capture’). Of the two, point-source capture is by far the cheaper option, for the simple reason that carbon dioxide at its source is much more concentrated and therefore easier to separate. Yet even point-source capture often requires \$50-\$100 / ton, or more. With U.S. tax credits (45Q) and international carbon prices overwhelmingly below that threshold, point-source capture today is technologically mature, but frequently requires government subsidy,

and happens at the scale of tens of millions of tons of CO₂. This is two orders of magnitude below what is needed. A major driver is the cost of energy: carbon capture systems decrease the power output of a typical natural gas energy plant by 30%; innovations that reduce that power draw are on the way.

Direct air capture technologies have innovated beyond the point-source systems that were first articulated in the 1930s, focusing on reducing the costs of air handling and on the energy required to regenerate their carbon dioxide filters (sorbents). Technical advancements in achieving low flow resistance in air contactors, using moisture or electricity instead of heat to drive the release of captured CO₂ so that the filter may be used again, and integrated coupling with renewable energy sources all promise to lower costs, which to date remain largely above the carbon price in any market. Systems capable of filtering already-emitted CO₂ will be critical both for offsetting dispersed CO₂ emissions, such as those from agriculture, and for achieving true negative emissions to reduce the overall atmospheric CO₂ concentration.

Point-Source Capture

These technologies trap concentrated carbon dioxide as it exits a flue stack (thin a natural gas peaker plant or a steel mill) using filters that can be regenerated with heat and, sometimes, pressure.

Examples

- + NRG Energy; partnership with JX Nippon
- + Equinor
- + SaskPower
- + ExxonMobil
- + Shell

Note: the companies listed here are engaged in another primary industry but have added point-source technologies to some of their facilities, including the Petra Nova coal plant, the Sleipner field in the North Sea, the Boundary Dam, and more.

Direct Air Capture

These technologies sieve the atmosphere for carbon dioxide, processing 2,500 tons of air for every ton of CO₂ captured, using high-surface area filters that can be regenerated with heat, moisture, or pressure.

Examples

- + Carbon Engineering
- + Climeworks
- + Global Thermostat
- + Silicon Kingdom Holdings

Investment Notes

Investment in carbon capture technology in the U.S. between 2007 and 2017 by sector:

+ **\$2.5B** Post combustion flue

+ **\$822M** Hydrogen production – oil production

+ **\$472M** Gas Processing

+ **\$449M** Hydrogen production – refinery

+ **\$208M** Fermentation – ethanol production

+ **\$123M** Hydrogen production – steel

+ **\$88M** Hydrogen production - fertilizer production

<https://www.iea.org/commentaries/us-budget-bill-may-help-carbon-capture-get-back-on-track>

Timeline

Technology Development

1999 | Klaus Lackner was the first person to suggest the artificial capture of CO₂ from air in the context of carbon management

2006 | Vattenfall began operating the world's first demonstration plant at the Schwarze Pumpe power station

2007 | Global Research Technologies, with Columbia University, successfully demonstrated the first technology to extract CO₂ from free-flowing air

2009 | Vattenfall announced that it was achieving nearly 100% CO₂ capture at the Schwarze Pumpe power station

2017 | Climeworks began operating the world's first commercial carbon-capture plant in Switzerland; their current systems are 90% efficient in capturing CO₂ (\$600/ton)

2018 | Carbon Engineering achieved a levelized cost of \$94 per ton of CO₂

2019 | Drax successfully captured CO₂ from the combustion of biomass (first time) using a solvent

2020 | Oak Ridge Laboratory demonstrated a prototype device (made with 3D printing) that is up to 20% efficient in absorbing CO₂ from an industrial source

Public Policy and Awareness

2002 | The federal government established the Clean Coal Power Initiative with \$2B for cleaner coal technologies

2005 | The G8 leaders pledged to accelerate the development and commercialization of CCS technology at the Gleneagles summit

2009 | Texas passed the legislation H.B. 469, which allowed projects with >70% CO₂ capture to qualify for more than \$100 million in Texas tax relief

2016 | The DOE and National Energy Technology Laboratory launched the CarbonSAFE Initiative to “address the R&D knowledge gaps and develop the technologies needed to nationally deploy commercial scale (50+ million metric tons) CO₂ storage”

2018 | The California Air Resources Board (CARB) proposed updates to the Low Carbon Fuel Standard (LCFS), which includes a CCS protocol to allow CCS projects to qualify for LCFS credits

2019 | The DOE awarded \$20M (total) in funding to four regional CCUS projects

Utilization & Storage (U.S.)

What will we do with the carbon dioxide we've captured? Carbon is a resource, not only as an energy carrier in fuels but as the chemical backbone of plastics, food, and medicine. Some will need to be stored — likely underground — but some can be upgraded into value-added products. Carbon utilization technologies offer that promise: the chance to turn a virtually limitless supply of carbon dioxide into the feedstock for the plastics, fuels, and materials that enable modern life; the chance to mine the air for carbon, and not the ground.

Carbon storage costs — they're a central reason for the existence of carbon prices and carbon tax credits. Subterranean storage, when coupled with appropriate sealing and monitoring, exists in ample capacity to store humanity's emissions for centuries to come. Enhanced oil recovery is a potentially profitable route to underground CO₂ sequestration. Importantly it is not a negative emissions technology when recovered oil and natural gas are burned. As the industry stands today, virtually all storage facilities are run by oil and gas majors, who already possess drilling and well infrastructure.

Given the magnitude of CO₂ that will need to be captured — potentially hundreds of billions of tons — humanity will need the scale of geologic storage options, but carbon utilization technologies offer an attractive method to turn a profit while keeping net carbon emissions neutral or negative.

The existing market for CO₂ as a product, excluding EOR, is relatively limited, but the market for carbon-based

products that can be made from CO₂ is estimated to top \$800M as early as 2025 (McKinsey). Concrete made with an extra injection of CO₂ is already in use at 170+ mixing facilities in North America. Electrochemistry startups that use water, electricity, and CO₂ can make industrial chemicals and fuels like ethylene and ethanol that would typically come through refining and fermentation processes, respectively, and are working to scale beyond the pilot phase. Microbial organisms that thrive on flue gas have been genetically engineered to make valuable industrial chemicals at the scale of 500,000L fermentation tanks.

These technologies can compete where the value of the product exceeds the cost of the energy required to produce it — which is not a given yet in all markets and a significant limitation for the production of chemicals like carbon monoxide (for use in syngas to make jet fuel, as an example) or methane, which are to date much cheaper via conventional means.

Perspectives on the 45Q Carbon Tax Credit

In May 2020, the U.S. Internal Revenue Service released proposed regulations for the long-awaited 45Q carbon tax credit. Though not yet finalized, the regulation in broad strokes is this: companies can claim tax credits for tons of carbon dioxide (or any other "carbon oxide," which presumably refers to carbon monoxide) that are captured and

securely stored underground. If the carbon dioxide is used for enhanced oil recovery (EOR), the credit is worth \$35/ton; if it's otherwise stored, the credit is \$50/ton.

Importantly, the credits are transferable, which enables companies to monetize them: a credit producer can sell an equity stake and, accordingly, transfer credits to another party. That party

is potentially able to both deduct the equity investment and claim the credits. This is an important step toward a market price on carbon dioxide, but key limitations remain: the credits only last for 12 years; only facilities emitting more than 500,000 tons/year are eligible; the credits are pro-rated until 2026; and the credits will have to be returned for any

carbon dioxide that escapes storage within five years of claiming the credit.

All of these factors suggest a regulation that favors existing oil and gas players already engaged in EOR, and that leaves little room for new entrants or expansion into direct air capture. The commenting period ended in August, and we await the finalized rules.

Direct Use

This approach takes purified carbon dioxide gas as an input for greenhouses, the bottling industry, and enhanced oil recovery in aging fossil carbon fields, with an existing demand of ~100 million tons per year.

Examples

- + InfiniTree (direct air capture → greenhouses)
- + ExxonMobil, Chevron, Sunco, Royal Dutch Shell, Equinor, Husky Energy, Occidental Petroleum... (EOR)
- + Beverage industry doesn't have much in the use of captured CO₂, but it's a large sector as-is (AirGas, NuCO₂)

Biological Upconversion

This process uses carbon dioxide as a feedstock to produce value-added chemicals (e.g., ethanol, syngas) or combustible biomass using natural and genetically engineered microorganisms that can partially shortcut energy demands.

Examples

- + LanzaTech
- + LanzaJet
- + Newlight Technologies
- + NovoNutrients

Chemical Upconversion

These approaches use carbon dioxide to create derivative carbon molecules that can be used in building materials (e.g., cement), commodity chemicals (e.g., detergents, plastics), and fuels (e.g., ethanol and jet fuel).

Examples

- + Opus 12
- + Avantium
- + CERT
- + CO₂Exide
- + Dioxide Materials
- + Renew CO₂
- + CarbonCure
- + SkyNano
- + National Carbon Technologies

Geologic Storage

This approach keeps captured gas in subterranean reservoirs, either as part of an enhanced oil recovery effort or in geologic features such as deep saline reservoirs, unmineable coal seams, depleted oil and gas reservoirs, and basalt formations.

Examples

- + Equinor
- + NRG Energy
- + ExxonMobil
- + Shell

[This is basically the same as the list of companies doing point-source capture, as they're funneling it into either EOR or another form of subterranean storage accessed via their wells.]

Investment Notes

Potential U.S. investment in CCUS between 2020 and 2030: **\$41B**

<https://www.bcg.com/publications/2019/business-case-carbon-capture>

Timeline

Technology Development

- 1972** | Pennzoil began operating the world's first large-scale carbon injection project; CO₂ was injected into the Sharon Ridge oilfield for enhanced oil recovery
- 1982** | Yoshiro Hori demonstrated that a metal catalyst could be used to reduce CO₂ into useful products
- 1990** | Walter Seifritz first proposed storing CO₂ via reaction with common silicate rocks and minerals
- 1996** | StatOil began operating the world's first offshore CCS plant; 1M metric tons of CO₂ are captured annually from the Sleipner natural gas field and injected into an underground aquifer
- 2010** | Novacem developed the first green concrete by replacing portland cement with a magnesium oxide material that captures CO₂ when mixed with water
- 2013** | Newlight Technologies developed a process to convert methane and air into high-performance thermoplastics; they supply to Dell, IKEA, Sprint, etc.
- 2016** | Opus12 prototyped a reactor that uses catalytic nanoparticles to reduce CO₂ into sixteen compounds, including ethanol and methane
- 2019** | Indigo launched the Terraton Initiative, aiming to sequester 1T metric tons of CO₂ by tripling the carbon content of agricultural soil
- 2019** | Carbo Culture developed a process to oxidize carbon such that 1 ton of biochar can store 3.12T of CO₂ for over 1,000 years

Public Policy and Awareness

- 1997** | The DOE launched the Office of Fossil Energy's Carbon Storage program
- 2005** | Title XVII of the Energy Policy Act of 2005 allocated \$6 billion of federal loan guarantees to coal-based power generation and industrial gasification facilities that incorporate CCS or other beneficial uses of carbon
- 2008** | The federal government passed the Emergency Economic Stabilization Act, creating a tax credit for CO₂ sequestration
- 2010** | The EPA finalized requirements for geologic sequestration under the authority of the Safe Drinking Water Act's Underground Injection Control (UIC) Program
- 2010** | The NRDC recommend \$100-150 million in federal funding for biochar development
- 2015** | XPRIZE began running a multi-year competition to develop technologies that convert CO₂ into usable products
- 2016** | The DOE and National Energy Technology Laboratory launched the CarbonSAFE Initiative to "address the R&D knowledge gaps and develop the technologies needed to nationally deploy commercial-scale (50+ million metric tons) CO₂ storage"; as of 2019, the initiative had funded 19 projects
- 2018** | The Bipartisan Budget Act of 2018 increased tax credits through 2026: credit for EOR and EGR utilization increased from \$10 per mt to \$35 per mt; credit for geological sequestration increased from \$20 per mt to \$50 per mt

Alternative Proteins

Humans want meat, but its production is quickly becoming a global issue. A single cow can consume up to 30 gallons of water per day. In total, livestock contribute 7.1 gigatons of CO₂-equivalent per year, representing 14% of all anthropogenic greenhouse gas emissions — that is, emissions resulting from human activity. Cattle raised for beef and milk are the animal species responsible for the most emissions, representing 65% of the livestock sector. “It is the biggest environmental threat that humans have ever faced,” says Patrick O. Brown, CEO and founder of Impossible Foods, which specializes in plant-based meats.

New companies are grinding away on two eco-conscious and potentially healthier ways to deliver meat: cellular and plant-based meat.

Plant-based has the higher-profile of the two methods, and it's poised to be a \$7.5 billion global market by 2025. One of the most popular producers is Impossible Foods, founded by Brown, a former Stanford University biochemist. Impossible claims to use 87% less water, emit 89% fewer emissions, and impact 96% less land than beef made from cows.

Cell-based meat — also known as clean or cell-cultured meat — is a more nascent field and one that might appeal to a broader carnivorous population.

Here, agricultural products are produced from cell cultures. Proponents say that this process will require less land and water than conventional meat, will cause exponentially less climate change, and eliminates the environmental repercussions of animal waste and contamination via runoff. It also requires no antibiotics, produces no bacterial

contamination, and won't harm animals.

In 2018, the Association sent a petition to the USDA to impose strict labeling requirements on beef, that is, the tissue or flesh of cattle born, raised, and harvested in a traditional manner rather than coming from alternative sources, such as a synthetic product from plants, insects, or non-animal components or grown from animal cells.

Cell-based agriculture is a pre-revenue industry — it might be years before you bite into a cell-based burger — yet, regulatory adjustments are already afoot. In early 2019, the USDA and FDA announced a formal agreement to regulate cell-cultured food products from cell lines of livestock and poultry. The agencies will collaborate to regulate the development and entry of cellular food into commerce, ensuring that they're produced and labeled properly.

*Adapted from “Where’s the Beef?” by Kara Baskin
For further reading, download Tough Tech N.3, The Food & Ag Issue @ www.engine.xyz*

Cell-based Meat

These technologies attempt to replicate meat, including fish, without the animal. They use devices such as bioreactors to grow muscle cells for hamburgers, meatballs, sausage, etc. Some companies have applied similar approaches to manufacturing seafood products.

Examples

- + Aleph Farms
- + BlueNalu
- + Finless Foods
- + Memphis Meats
- + Mosa Meat
- + New Age Meats
- + SuperMeat

Alternative Proteins

Companies within this sector tend to use plant-based products in some combination with lab-created acellular proteins. Acellular products are created by using types of yeast or bacteria to create a starter culture that then produces proteins traditionally sourced from animals.

Examples

- + Beyond Meat
- + Clara Foods
- + Impossible Foods
- + Kite Hill
- + Motif Ingredients
- + Nature's Fynd
- + Nuggs
- + Perfect Day
- + The Better Meat Co

Investment Notes

The total invested in alternative protein companies in 2019:
\$824M

The total invested in alternative protein companies in Q1 2020:
\$930M

<https://www.gfi.org/record-investment-in-alternative-protein-in-2019-and-q1-2020-media-release>

Timeline

Technology Development

1998 | Jon F. Vein filed a patent (US 6,835,390 B1) in the U.S. for the production of tissue-engineered meat for human consumption

2000 | The NSR/Touro Applied BioScience Research Consortium produced the first edible in-vitro muscle protein; it was created from a goldfish

2002 | A NASA-funded team at Touro College managed to grow cellular chicken for two months before it died

2013 | Beyond Meat began selling Beyond Chicken, made from soy and pea proteins, in Whole Foods Market stores; a Beyond Burger uses 99% less land and 93% less water than a traditional burger

2016 | Impossible Foods introduced a beef substitute, which it claimed offered meat-like appearance, taste, and cooking properties

2019 | Aleph Farms, Finless Foods, and 3D Bioprinting Solutions produced cell-based meat aboard the International Space Station

Public Policy and Awareness

1999 | The FDA approved a bacteria that had been genetically engineered to produce rennet, making it the first genetically engineered product for food

2009 | Sergey Brin anonymously backed research into cultured meat; his name was revealed in 2013 when the first lab-grown burger was presented

2018 | The National Cattlemen's Beef Association pushed back on alternative meat using the label "meat"

2019 | The USDA and the FDA created a framework for regulating cell-based meat and poultry

2020 | Grocery store customers increased their purchases of plant-based meat alternatives during COVID more than meat (264% vs. 45%)

Plant Genetics

As a species, we are nearly completely dependent on plants for our survival, which are, in turn, at the mercy of their environment — too much rain, too little sun, too many insects, or the arrival of a new virus can wipe out an entire harvest.

While plants have evolved strategies to cope with those threats, humanity, for millennia, has also been coaxing them to develop traits that are more appealing to its needs. Selectively breeding plants with desirable qualities together gave us the calorie-rich staple crops we eat today. The field of genetics has allowed scientists to transfer genes from one organism into another, leading to the creation of the first genetically modified organisms (GMOs) in the 1980s.

Today, the next generation of plant scientists is using new gene-editing technologies like CRISPR to modify the genes of food crops directly, allowing them to enhance plants' innate abilities with even greater precision.

The vast majority of the seeds planted on commercial farms today are GMOs. More than 90% of the corn, soybeans, cotton, sugar beets, and canola grown in the U.S. has been genetically modified in some way, and the worldwide market for GMOs is estimated to surpass \$36 billion by 2022. Even if you don't eat corn or beets regularly, it's likely that nearly everything you've consumed today was produced, in some form, from GMOs.

GMO crops have effectively become the industry standard because it takes only about ten years to develop a new GMO plant — compare that to the thousands of years of trial-and-error our ancestors needed to convert an ancient tall grass with small, hard, black seeds into the sweet, starchy, kernel-packed plant we know today as corn.

Different countries have different levels of stringency for GMOs. India has only approved GMO cotton, while Australia permits GMO cotton, canola, and safflower to be grown, but no food crops. The EU has had a de facto ban on the sale of foods produced from GMOs since 2001 but has left it up to its member states to decide whether to plant GMOs on their land (though the EU imports millions of tons of GMO crops every year for livestock feed and other uses). Even in the U.S., which has one of the most lenient GMO policies, the process to develop a new GMO can take up to twelve years and cost upwards of \$130 million. That expense means that only a few companies — namely, Bayer,

Corteva Agriscience, and Syngenta (owned by ChemChina) — have the means to create new GMOs on a global scale.

CRISPR offers another significant advantage over existing GMOs — the USDA announced in early 2018 that it would not regulate plants modified with gene editing technologies as GMOs because the genetic changes produced by those methods could conceivably have arisen through traditional breeding or random mutation.

Just as there is growing acceptance that the “microbiomes” that inhabit our guts have significant effects on our health, there is increasing interest in studying and understanding the communities of microbes that live within plants. Geoff von Maltzahn of Indigo Ag notes, “We thought that the internal plant microbiome could be a home for solutions to every challenge that farmers face in agriculture.”

Indigo Ag analyzes the microbes naturally found inside healthy plants, identifies those that confer certain advantages, and sells seeds pre-coated with microbes to farmers. As the seeds germinate, the microbes incorporate into the seedlings' tissues and provide support throughout the plants' lifetimes.

*Adapted from “The Uncertain Future of Food” by Lindsay Brownell
For further reading, download Tough Tech N.3, The Food & Ag
Issue @ www.engine.xyz*

GMO

These companies employ technologies to manipulate the characteristics of plants at the genetic level by transferring genetic information from one organism to another.

Examples

- + Bayer Crop Science
- + Corteva Agriscience
- + Syngenta
- + ZeaKal*

* The exact technology behind the company's core product remains a trade secret, but GMOs are highlighted in a 2016 Wall Street Journal article.

CRISPR

Unlike GMOs, CRISPR-based technologies alter the genomes of plants by directly "editing" their DNA. Importantly, the USDA does not regulate any plants modified with gene editing technologies as GMOs because the genetic changes produced by these methods could conceivably have arisen through traditional breeding or random mutation.

Examples

- + Benson Hill Biosystems
- + Inari Agriculture
- + Pairwise
- + Plantedit
- + Tropic Bioscience
- + Yield10 Biosciences
- + Corteva Agriscience
- + Syngenta

Microbes

These companies harness "plant-associated" microbiomes to create more resilient crops without altering the genetics of the plant itself.

Examples

- + AgBiome
- + Agrinos
- + BioConsortia
- + Indigo Agriculture

Investment Notes

Valuation of Indigo Agriculture, the highest-valued agtech startup in the world, as of August 2020: **\$3.5B**

<https://www.builtinboston.com/2020/08/03/indigo-ag-raises-360m-hiring>

Value of agriculture VC investment in the U.S. in Q2 2020: **\$502M**

<https://www.statista.com/statistics/277506/venture-capital-investment-in-the-united-states-by-sector/>

Timeline

Technology Development

1973 | Biochemists Herbert Boyer and Stanley Cohen developed genetic engineering by inserting DNA from one bacteria into another

1994 | GMO tomatoes, the first GMO produce created through genetic engineering, became available for sale after studies proved them to be as safe as traditionally-bred tomatoes

2014 | USAID partnered with farmers in Bangladesh to develop a GMO eggplant; this version of the staple crop reduces pesticide use by over 60%; farmers planting this crop increased from 20 in 2014 to 34,000 in 2018

2016 | Indigo started selling microbe-enhanced seeds; these seeds are better able to uptake nutrients and therefore need less synthetic fertilizer; resulting cotton yields increased by 14%

Public Policy and Awareness

1986 | The federal government established the Coordinated Framework for the Regulation of Biotechnology to determine how the FDA, USDA, and EPA work together to regulate the safety of GMOs

2003 | The WHO and the UN's Food and Agriculture Organization developed international guidelines and standards to determine the safety of GMO foods

2015 | The FDA approved an application for the first genetic modification in an animal for use as food, a genetically engineered salmon; approved for sale as of 2019

2018 | In this year, GMO soybeans made up 94% of all soybeans planted, GMO cotton made up 94% of all cotton planted, and 92% of corn planted was GMO corn

Waste Reduction

It's estimated that over 30% of the food in the U.S. never makes it from the field to our stomachs — that's 63 million tons annually, or more than a pound of food per person each day. It rots in the fields, spoils in trucks, wilts on supermarket shelves, or gets scraped from our plates into the trash. As much as all that decay is a tragedy, it is also an opportunity, says Chris Cochran. Cochran is the director of ReFED, a nonprofit dedicated to reducing food waste. "I come at it from the angle of 'How do we feed 10 billion people by 2050 when we don't have the land or additional natural resources to put to food production?'" he says. "One of the most natural places to start is to look at waste in the food system."

Cutting down waste could have a dramatic environmental impact, as well. The majority of natural resources in the U.S. are used for agriculture and food production, Cochran continues, and waste alone accounts for some 20% of water usage and 8% of global greenhouse gas emissions. In fact, tackling food waste is one of those rare enterprises that is a true win-win-win, increasing the supply of food, improving the environment, and potentially saving companies money by increasing efficiency in the system.

Shipping giant Maersk transports 30% of all refrigerated food containers in the world. It recently launched Maersk Growth, a venture arm that has so far invested in five companies tackling the problem of food waste. Of the multitude of methods to reduce food waste, the technologies that delay spoilage and grow food closer to the consumer are of particular interest.

Companies like Mori and Apeel employ coatings that can be sprayed onto fresh produce to extend their shelf-life and cut down on the need for refrigeration. Mori employs a silk-based technology, applying it not only to fruits and vegetables but also to meat, fish, and poultry.

Hazel Technologies used a technology developed at Northwestern to create small satchels that emit a chemical, 1-Methylcyclopropene, that slows ripening and maintains

freshness when packaged with fruit. San Francisco-based Purfresh uses ozone technology to replace the atmosphere in shipping containers to delay the ripening of produce and reduce spoilage from harmful bacteria.

Robotics startup Iron Ox grows produce indoors using 90% less water than traditional farming while growing 30x the amount of crops per acre of land. Other companies, such as AeroFarms, Freight Farms, Plenty, and Bowery Farming, are pioneering indoor farming solutions that significantly reduce the overall carbon footprint required to grow and move popular varieties of fruits and vegetables.

Adapted from "Waste Not" by Michael Blanding

For further reading, download Tough Tech N.3, The Food & Ag Issue @ www.engine.xyz

Spoilage Protection

These approaches use invisible, edible coatings or gases to reduce water loss and oxidation, slowing spoilage.

Examples

- + Apeel
- + Hazel Technologies
- + Mori
- + Purfresh

Alternative Farming

Farming is a deep and diverse sector. These technologies, in particular, employ robotics, vertical farming, and other Tough Tech innovations to grow produce more efficiently and closer to the consumer.

Examples

- + AeroFarms
- + Bowery Farming
- + Freight Farms
- + Gotham Greens
- + Infarm
- + Iron Ox
- + Local Roots
- + Plenty

Investment Notes

Projected vertical farming market worldwide in 2025
\$15.7B

<https://www.marketstudyreport.com/reports/global-vertical-farming-market-2020-by-manufacturers-regions-type-and-application-forecast-to-2025>

Projected value of the North American aquaponic and hydroponic systems market in 2021
\$719M

<https://www.wallstreet-online.de/nachricht/10514340-global-aquaponics-and-hydroponics-systems-and-equipment-market-anticipated-to-reach-1-98-billion-by-2022-reports-research>

Timeline

Technology Development

1977 | Mitsubishi developed the world's first free-oxygen absorbing agent (consisting of reduced iron salts); these sachets were significantly more effective at absorbing oxygen and extending the shelf life of processed foods than previous oxygen scavengers

1997 | AgriHouse and NASA designed a soilless plant-growth experiment to be performed in microgravity aboard the Mir space station; this evolved into aeroponics

2007 | Purdue developed triple-layered, hermetically sealed storage bags that rural farmers use to store cereals and legumes without pesticides for months; five million farmers had used these bags by 2018

2012 | Indoor farming company Mirai developed an LED that allows plants to grow twice as fast with 40% less power, 80% less food waste, and 98% less water than outdoor fields

2016 | U.S. grocery stores began selling produce with Apeel Sciences' postharvest coating; it extends avocado shelf life by a week and reduces GHG emissions by 27% per avocado; grocery chain Edeka reported a 50% reduction in food waste in 2020

2018 | Dutch startup Upprint began upcycling food waste (rejected due to cosmetic or ripeness issues) as 3D printing material; they are currently working with high-end restaurants

Public Policy and Awareness

1975 | The 7th session of the United Nations General Assembly set the goal of a 50% reduction of postharvest losses by 1985

2009 | The African Postharvest Losses Information System was established to collect, analyze, and disseminate data on postharvest losses of cereal grains in sub-Saharan Africa; Ethiopia's postharvest losses of maize were estimated to be worth USD\$500 million in 2018

2015 | The USDA and EPA set a goal to reduce food-waste by 50% by 2030, aligned with the SDG 12

2018 | Congress passed the Farm Bill, with provisions for aquaponics and hydroponics research

2019 | Kroger sold avocados with Apeel coatings in over 1,000 locations in the U.S.

2020 | The NYC 2021 budget eliminated funding for curbside organics waste collection (aka "composting") in order to reduce the budget deficit from coronavirus; food and yard waste accounts for one third of the city's residential waste stream

Electric Vehicles

Transitioning from liquid-fuel-powered vehicles to electric vehicles (EVs) promises to reduce over 15 gigatons (15 billion metric tons!) of CO₂ over a 30-year period, according to Project Drawdown, a leading resource for climate solutions. However, the vehicles themselves are only part of the story. For EVs to truly reach their emissions-free potential, the sources from which they draw power must be renewable, and the raw materials at the heart of their batteries, most notably lithium and cobalt, must be mined with minimal impact.

Electric vehicles are not new. Some of the first passenger vehicles of any type were powered by electric motors. Until recently, however, battery technology was neither durable, efficient, nor powerful enough to compete with incumbent internal combustion alternatives. With the advent of lithium-ion battery technology and ensuing innovations to reduce the cost and extend the operating range of such batteries, the consumer vehicle market finally has EVs that can rival internal combustion vehicles in terms of price, range, and key performance metrics.

Perhaps the most opaque challenge facing the widespread adoption of passenger EVs is consumer sentiment. Tesla has proven that passenger EVs, with compelling design, marketing, and performance, can win over legions of customers, but that is not the case with every EV, even those with similar on-paper specifications. Take the Chevrolet Bolt, for example. The car is the second most popular EV in the U.S. when compared to the Tesla Model 3, but it saw a decrease in sales of nearly 30% between 2017 and 2019, according to electrek, an industry publication. The fact that even a major automaker like Chevrolet cannot create a passenger EV with positive year-over-year sales is concerning and demands further analysis.

While heavy duty trucks comprise just 4% of vehicles in the U.S., they consume more than 25% of fuel. And world-

wide, road freight is responsible for about 6% of all emissions. These statistics, courtesy of Project Drawdown, illustrate the oversized impact of these vehicles — and the potential impact of an electrified trucking industry. EV trucks, while a sector of intense investment, remain under development.

Electrifying the aviation industry carries with it more risks and uncertainty than ground transportation. While emissions from traditional airplanes are immense, so too are the challenges of using batteries as a fuel source. It is likely that we will see more efficient aircraft design coupled with sustainable liquid fuels before a commercially viable electric airplane.

And then there is the key ingredient of the batteries that power nearly every EV: lithium. The demand for the element is expected to quadruple over the next ten years. However, extracting the metal is inefficient and environmentally unsound — requiring vast amounts of fresh water in surface evaporation ponds. New lithium extraction methods, such as those offered by The Engine portfolio company Lilac Solutions, present novel solutions to problems that will only become more significant as demand increases. Lilac can extract 2x the lithium at half the production cost, with a 1,000x smaller footprint and a 5,000x faster processing speed than conventional evaporation-pond extraction methods.

Passenger EVs

Passenger EVs have garnered the most significant investment of any EV category, and for good reason. When price and performance parity is reached for both passenger cars and trucks, well-positioned EV companies will take a significant share of a half-a-trillion-dollar industry in the U.S. alone.

Examples

- + Arrival*
- + Bollinger Motors
- + Canoo
- + Lordstown Motors
- + Lucid Motors
- + Nikola†
- + Nio**
- + Proterra*
- + Rivian
- + Tesla

* specializes in battery-powered buses and vans

** based in Shanghai, China

EV Aviation

There has been interest in electric aviation for decades. Ultralight aircraft have been successfully flown incredible distances using solar power alone. There have also been prototype flights for small battery-powered propeller-driven aircraft. However, planes of commercial size and power remain in the planning stages.

Examples

- + Ampaire
- + Bye Aerospace
- + Eviation
- + H55
- + Joby Aviation
- + Magnix
- + Sion Power
- + Wright Electric

Investment Notes

Projected U.S. EV market share in 2026*:

7.6%

<https://www.bloomberg.com/news/articles/2020-01-13/cheaper-batteries-more-chargers-for-electric-car-buyers-in-2020>

Global market for lithium-ion batteries by 2025:

\$71B

<https://ihsmarkit.com/research-analysis/ihsmarkit-forecasts-ev-sales-us.html>

Global market for lithium-ion battery recycling by 2030:

\$18B

EV Trucks

Long-distance trucking, with its emphasis on efficiency and maximum load size, will be more difficult to transition to pure EV based on the weight, cost, and power of today's lithium-ion battery technology. Last-mile trucking and delivery vehicles are already in the market.

Examples

- + Nikola†
- + Orange EV
- + Rivian
- + Tesla
- + Workhorse

†As of September 2020, Nikola is facing serious allegations of potential fraud and other misleading business practices. We have decided to include the company on this survey because it is, for better or worse, an example of the intense interest and significant investment dollars flowing into the EV sector.

Battery Technologies

With the global market for lithium-ion batteries expected to reach nearly \$100B by 2027, there is no shortage of innovation in the industry. The highlighted organizations featured here are those with potential EV applications and include major battery recycling efforts.

Examples

- + Battery Resourcers
- + Farasis Energy
- + Li-Cycle
- + Lilac Solutions
- + QuantumScape
- + NextOre
- + Northvolt
- + Redwood Materials
- + Renewance
- + South8

Timeline

Technology Development

- 1971** | NASA used an electric Lunar rover on the moon
- 1973** | Howard Johnson filed a patent on a permanent magnet motor
- 1979** | Ned Godshall demonstrated a rechargeable cell with a positive electrode made from LiCoO₂, enabling commercialization of lithium batteries
- 1989** | The first nickel-metal hydride battery (NiMH) became commercially available; this was the most common battery for early hybrid vehicles
- 1991** | Sony and Asahi Kasei released the first commercial lithium-ion battery
- 1996** | GM produced the first EV1; the first 660 had lead-acid batteries
- 2000** | Toyota started selling the Prius in the U.S.
- 2008** | The Tesla Roadster was the first highway legal serial production all-electric car to use lithium-ion battery cells
- 2011** | BASF manufactured the first lithium nickel manganese cobalt oxide (NMC) cathodes
- 2014** | Airbus set the world record for continuous flight with its Zephyr 7 prototype using Sion Power lithium-sulfur battery cells; the flight lasted over 11 days
- 2020** | Tesla Model S achieved an EPA-rated range of 402 miles

Public Policy and Awareness

- 1976** | Congress passed the Electric and Hybrid Vehicle Research, Development, and Demonstration Act
- 1990** | The California Air Resources Board adopted the ZEV initiative, which requires major carmakers to make 2% of their California fleet emission-free by 1998, 5% by 2001, and 10% by 2023
- 1997** | GM's EV1 became a cult classic; discontinued in 2002
- 2005** | *Who Killed the Electric Car* was released in theaters
- 2009** | The DOE awarded \$8 billion in fuel-efficient vehicle loans to Ford, Tesla Motors, and Nissan under the Energy Independence and Security Act of 2007
- 2010** | The federal government implemented a program that offers up to \$7,500 in tax credits to purchasers of new electric vehicles
- 2012** | President Obama issued the EV Everywhere Grand Challenge and announced \$50 million in funding
- 2019** | There were 29 electric vehicle models with over 1,000 U.S. sales, up from 27 in 2018
- 2020** | California Governor Newsom signed an executive order that bans the sale of new combustion-engine vehicles in the state starting in 2035

Autonomous Vehicles

The field of autonomous vehicles (AVs) is worthy of a publication in itself. The race to Level 4 and Level 5 autonomy (highly autonomous and fully autonomous, respectively) has seen billions of dollars of investment and resulted in significant innovation in both the AI systems that control an AV and the sensors that help the vehicle observe its world. It is likely that we will see the adoption of heavy-duty vehicles, like specialized “yard trucks” and similar vehicles that operate within the confines of private properties, prior to the widespread adoption of open-road vehicles. The question of how greatly AVs could reduce CO2 emissions is debated, especially when most are still powered by internal combustion engines.

The University of Michigan Center for Sustainable Systems projects that greenhouse gas emissions from personal transportation could be reduced by 9% due to “eco-driving, platooning, intersection connectivity and faster highway speeds,” which are all “considered as direct effects of connected and automated vehicles.” There have also been studies on existing technologies, such as adaptive cruise control, which have been shown to reduce fuel consumption by 5-7%.

The promise of emissions reduction is highly dependent on how or what AV companies prioritize. Is the objective ultimate vehicle efficiency? Or will an AV take a longer route to reduce time and traffic congestion but, ultimately, consume more fuel? Similar decisions related to acceleration, platooning, and vehicle right-sizing will need to be made during each AV trip in which the vehicle will have to balance passenger satisfaction with the least-polluting driving techniques.

According to a new study from the Insurance Institute for Highway Safety, a third of accidents were due to sensing/perceiving factors. AV sensors alone would eliminate the majority of these crashes. Fewer accidents should translate into longer vehicle life cycles. As *The Guardian* points out, “If you make a car last to 200,000 miles rather than 100,000, then the emissions for each mile the car does in its lifetime may drop by as much as 50%, as a result of getting more distance out of the initial manufacturing emissions.” More accidents can be prevented with AI systems.

The method by which an AV makes these decisions is not consistent across platforms. Some companies are

training AVs on millions of miles of real-world traffic, creating a system that uses billions of learned data points to make decisions. Others, like The Engine portfolio company ISEE, are training autonomous driving brains to not only to anticipate the behavior of other drivers but also to understand the inherent causes. ISEE is using deep learning to teach its AVs “common sense” to help them better understand their environment, and anticipate changing circumstances on the road. Such training is theoretically faster, requiring less time on the road “training.” It is also better at adapting to the innumerable unpredictable scenarios at the end of the long tail distribution that is real-world driving.

Autonomous trucking also holds great potential to reduce greenhouse gas emissions. A truck has many more predefined variables than a passenger car, making it easier to predict routes and speed. Yet many current AV trucking companies are simply retrofitting sensors and computers to existing internal combustion-powered vehicles, which are inescapable emissions producers. Still, trucking has an outsized impact on emissions — trucks represent four percent of vehicles in the U.S., but consume 25 percent of the fuel — so every increase in efficiency, no matter how subtle, can lead to a decrease in fuel consumption.

While there is no doubt AVs will play a significant role in the future of transportation, there is still speculation about the exact role they will play in reducing greenhouse gas emissions, especially when the internal combustion engine remains the propulsion technology of choice.

Autonomous Travel (passengers)

Autonomous passenger vehicles are poised to fundamentally reshape our relationship with how we get around. Their evolution is bolstered by a massive projected market size, and rapidly advancing hardware and software technologies within the vehicles themselves.

Examples

- | | |
|--------------------|-----------|
| + Argo AI | + Pony.ai |
| + AutoX | + Uber |
| + Cruise | + Waymo |
| + Local Motors | + WeRide |
| + Optimus Ride | + Zoox* |
| + Navya Technology | |

*Acquired by Amazon

Autonomous Delivery

In much the same way as autonomous trucks and autonomous passenger vehicles can help reduce emissions, so too can autonomous delivery vehicles — trucks, vans, aerial drones, robots, and others — especially for last-mile deliveries for which battery powered vehicles can be quickly adopted.

Examples

- | | |
|--------------------|-------------|
| + Agility Robotics | + Flirtey* |
| + Amazon** | + Starship* |
| + boxbot | + Uber* |
| + Flytrex* | + Volansi* |
| + Neolix | + Zipline* |
| + Nuro | |

*Aerial drones

**Both aerial drones and sidewalk robots

Autonomous Logistics

Trucking consumes more than 50 billions gallons of diesel per year in the U.S. alone. Making those trucks more efficient can contribute to significant fuel savings and, in turn, emissions reductions. Autonomous trucks can not only be built to navigate their routes more efficiently, but their design is also unconstrained by the typical cab, opening up new aerodynamic possibilities.

Examples

- | | |
|-----------------------|-------------------|
| + Embark Trucks | + Kodiak Robotics |
| + Inceptio Technology | + Plus.ai |
| + ISEE | + TuSimple |

Investment Notes

The projected global autonomous vehicle market size by 2026:
\$556B

<https://www.alliedmarketresearch.com/autonomous-vehicle-market>

The projected global autonomous last mile delivery market by 2030:

\$91.5B

<https://www.statista.com/statistics/1103574/autonomous-last-mile-delivery-market-size-worldwide/>

The size of the U.S. Department of Transportation's 2019 "safe integration of automated driving systems" grant program

\$60M

<https://www.transportation.gov/briefing-room/us-secretary-transportation-announces-automated-driving-system-demonstration-grant>

Timeline

Technology Development

1977 | Tsukuba Mechanical Engineering Lab developed the first vehicle with machine vision

1986 | Ernst Dickmanns retrofitted a Mercedes-Benz S-Class with cameras, sensors, and microprocessing modules; it was capable of detecting objects in the road and filtering out the noise

1989 | Carnegie Mellon developed ALVINN, an artificial neural network designed to control NAVLAB, its famous autonomous navigation test vehicle; the onboard equipment was so heavy that the vehicle was limited to 3.5 mph

1997 | Toyota was the first to commercialize adaptive cruise control

2005 | Stanford was the first team to win the DARPA Grand Challenge

2015 | Google enabled Steven Mahan, who is legally blind, to take the world's first fully self-driving ride on public roads

2020 | Airbus achieved the first fully automatic vision-based taxi and landing

Public Policy and Awareness

1991 | Congress passed the ISTEA Transportation Authorization bill, which allocated \$660 million of federal funding over six years for Intelligent Vehicle-Highway Systems

1997 | The National Automated Highway System Consortium organized a public demonstration with over 20 automated vehicles driving in carpool lanes on I-15 in San Diego

2004 | DARPA's inaugural Grand Challenge; no one finished the 150-mile race to claim the \$1 million prize

2011 | Nevada became the first state to pass an autonomous vehicle law allowing autonomous vehicles to be tested

2016 | The Obama administration unveiled a plan in January 2016 that allotted nearly \$4 billion over 10 years to accelerate the deployment of self-driving cars

2018 | A self-driving car operated by Uber hit and killed a pedestrian in Tempe, Arizona; it is the first known pedestrian death associated with self-driving

2020 | Nuro was the first company to win an exemption from federal safety requirements; they received approval to build up to 5,000 vehicles without side-view mirrors or windshields

Alternative Fuels

There are modes of transportation, namely, heavy-duty marine applications, commercial air travel, and heavy-duty industrial vehicles, that because of their capital cost and established infrastructure will be especially slow to transition to electric propulsion platforms. Alternative liquid fuels and hydrogen can provide emissions-free options that are significantly easier to integrate into existing frameworks.

The alternative fuel sector is still recovering from a disappointing investments in biofuels nearly 15 years ago. Industry observers are quick to point out that the algae biofuel “boom” of 2005–2010 failed to meet the promise of a sustainable, price-competitive liquid fuel. Prior to algae-based fuels, those with sugar and corn feedstocks met a similar fate. Creating a substitute for energy-dense petroleum-based liquid fuels, and doing it sustainably and cheaply, has proven vexing. While ethanol-based fuels are currently in market (E85, for example), there is debate as to the ultimate impact on emissions, as there is significant carbon expenditure in the growing, harvesting, and production of the fuel itself.

Synthetic Genomics continues to pursue algae biofuel and has a development partnership with ExxonMobile. The company is working to optimize the algae production process to minimize the overall energy required for the entire production process and bring the biofuel to price parity with petroleum-based options.

LanzaTech, a unique carbon recycling company, uses CO₂ as a feedstock to produce fuels and chemicals. According to the company, “By recycling carbon from industrial off-gases; syngas generated from any biomass resource; and reformed biogas, LanzaTech can reduce emissions and make new products for a circular carbon economy.” The company launched LanzaJet in June 2020 to accelerate the commercialization of its sustainable jet fuel and diesel.

In June 2020, the U.S. Department of Energy (DOE) announced that it would commit up to \$100M over five years to advance hydrogen and fuel cell technology

R&D. This initiative is emblematic of a larger interest in hydrogen as a clean power source for vehicles and overall grid resiliency. The DOE notes that research will be split between investigating new methods of achieving “large-scale, affordable electrolyzers” and accelerating the “development of fuel cells for heavy-duty vehicle applications, including long-haul trucks.”

Ballard Power Systems, based in British Columbia, has multiple hydrogen fuel cell products in market, including a 200kW marine module that is designed to power heavy-duty marine vessels like ferries and barges. The module, released in September 2020, is the first commercial zero-emission hydrogen fuel cell specifically designed to power ships.

The most significant current market for vehicular hydrogen fuel cells is industrial forklifts. There are tens of thousands of hydrogen-powered forklifts in operation in warehouses around the U.S. Plug Power, the leader in the hydrogen fuel cell sector, expects to be selling 25,000 units a year for various industrial applications by 2024.

Aviation, trucking, ocean transportation, and other modes of heavy-duty transportation produce an outsized amount of CO₂ for the number of vehicles in operation. Take the global aviation industry as an example: according to statistics gathered by Project Drawdown, the industry alone accounts for a minimum of 2.5% of annual global emissions. By implementing efficient flight practices, retrofitting existing aircraft, and transitioning to sustainable jet fuels, the nonprofit also notes that the aviation industry could see a \$2.5 to \$3.65 trillion lifetime net operational savings while reducing CO₂-equivalent emissions by 6.27–9.18 gigatons.

Alternative Liquid Fuels

There's something beautifully simple about liquid fuel: it provides immediate access to power, for whatever duration you need, limited only by the size of your fuel tank. These alternatives are being engineered to capture the best attributes of petroleum-based fuels, while remaining carbon-neutral.

Examples

- + Bradam Energies
- + Fulcrum BioEnergy
- + Green Biofuels Ireland
- + LanzaTech
- + Manta Biofuel
- + Synthetic Genomics

Hydrogen Power for Transportation

There is immense interest in the potential of hydrogen as a reliable, zero-emissions fuel. Hydrogen-powered forklifts are an increasingly common sight in warehouses across the country. But there are still significant costs, both environmental and economic, to produce the element.

Examples

- + Ballard Power Systems
- + Hydrogenics ‡
- + ITM Power‡
- + Plug Power
- + Proton Motor
- + Sunfire
- + Syzygy Plasmonics

‡The core business is industrial hydrogen equipment, but these companies also manufacture and sell equipment for refuelling fuel cell vehicles.

Investment Notes

The investment needed by 2030 for hydrogen to reach price parity with other low-carbon alternatives, according to The Hydrogen Council: **\$70B**

<https://www.ft.com/content/ccbdd868-5499-11ea-90ad-25e377c0ee1f>

Projected global biofuels market in 2024: **\$154B**

<https://www.bccresearch.com/market-research/energy-and-resources/liquid-biofuels-outside-north-america-report.html>

Projected U.S. Hydrogen feedstock (for use in industrial processes like ammonia, fertilizer, and methanol production) in 2023: **17M Metric Tons**

The growing demand for hydrogen as a feedstock will have an impact on the production of the element in general, spurring innovation and driving down cost. <https://www.bccresearch.com/market-research/chemicals/hydrogen-as-a-chemical-constituent-and-as-an-energy-source.html>

Timeline

Technology Development

1978 | Fiat released the first production car to run entirely on ethanol (Fiat 147)

2007 | Sony presented the sugar battery, a biofuel cell using glucose as its fuel with enzymes for catalysts

2012 | LanzaTech developed a microbe that converts industrial off-gas to ethanol that can be made into jet fuel

2015 | Researchers at the Energy Biosciences Institute developed recyclable catalysts that can convert sugarcane biomass into aviation fuel and lubricants that could achieve net life-cycle GHG reductions of up to 80%

2017 | Synthetic Genomics genetically engineered a microalgae strain, *Nannochloropsis gaditana*, that has double the lipid content (20% to 40%), a major increase in the energy yield of the biofuel feedstock

2018 | LanzaTech jet fuel was used on a commercial flight for the first time

2019 | Vertimass developed consolidated alcohol dehydration and oligomerization (CADO), a one-step process to convert ethanol into hydrocarbon fuel that lowers the cost and improves the quality; ANL's GREET simulation suggests that hydrocarbon blends made with CADO will emit 46% fewer GHGs

Public Policy and Awareness

1978 | Congress passed the 1978 Energy Tax Act, which included the nation's first tax credit for fuels comprised of ethanol

1980 | President Carter enacted the Energy and Security Act, providing incentives for ethanol producers in the form of insured loans, price guarantees, and purchase agreements

2005 | The Energy Policy Act of 2005 created the Renewable Fuel Standard, which incentivized corn ethanol and "advanced biofuels" production by granting the EPA authority to set annual quotas for biofuel blends

2009 | President Obama announced that \$786.5 million from the American Recovery and Reinvestment Act would go to accelerate advanced biofuels R&D and expand commercialization

2011 | Airlines gained approval to use derivatives of up to 50% biofuels for commercial flights

2016 | The FAA approved ATJ-SPK, another alternative jet fuel; the FAA speculated that operation with ATJ-SPK could reduce greenhouse gas emissions on a life-cycle basis by up to 85%

2018 | EU RED defined sustainable aviation fuel (SAF) by its GHG emissions compared to the status quo: SAF produced before 2021 must emit 50% fewer GHGs; fuel produced after 2021 must emit 65% fewer GHGs

Materials

Modern life is possible thanks, in large part, to three massive industries — steel, cement, and chemicals. Unfortunately, the production of these materials is a top contributor to GHG emissions. The steel industry alone ranks third in CO2 emissions, only outranked by China and the U.S. Like steel, the cement industry is a country-size emitter of CO2, accounting for roughly 8% of the global total. The chemical industry is responsible for another 7% of CO2 emissions. Introducing efficiencies to industries of this scale can help prevent gigatons of greenhouse gas from entering the atmosphere.

There's no escaping the heat needed to produce steel. Raw iron ore must be melted before it is refined. Conventional technologies use coal to form the reaction that frees iron from the ore — emitting CO2. Further heating in a series of furnaces is also required. Boston Metal sidesteps the need for coal by using a process called molten oxide electrolysis. By using electricity to convert raw ore to liquid metal, and generating that electricity with renewable energy, the company's process eliminates greenhouse gas emissions.

Other metals companies, such as Modumetal, are pioneering processes to create better versions of steel that last longer. Modumetal's nanolaminated alloys, produced by modulating electrical current, can be engineered to have a variety of properties, including better strength and resistance to corrosion.

The chemical sector is the largest industrial consumer of oil and gas. Its emissions need to peak in the next few years to stay on track with the UN's Sustainable Development Scenario. Outside of process optimization and the creation of a dependable worldwide renewable energy grid, reducing emissions of the chemical industry will require significant investment in low-energy technologies like innovative filtration, photocatalysis, and bioengineering.

Via Separations creates specialized membranes with nanometer-scale pores to eliminate 90% of the energy used in thermal separation, a process that currently consumes 12% of all energy in the U.S. Such technology can be applied to liquid-liquid chemical production and more.

Syzygy Plasmonics aims to dramatically reduce the CO2 emissions from chemical plants with a completely new type

of reactor powered by light rather than the heat that comes from burning fossil fuels. Solugen is creating products like hydrogen peroxide by using specialty enzymes to convert plant sugars into the final chemical, thereby creating a carbon-negative chemical.

Both Syzygy and Solugen offer modular solutions — meaning chemical production can be decentralized, placing the source closer to the destination, which reduces the emissions produced during transportation.

Solidia Technologies, Carbicrete, and Carbon Upcycling Technologies are prime examples of the latest in cement and concrete innovation. Solidia aims to lower concrete's carbon footprint by 70% by altering the ratio of limestone to sand and using recycled CO2, instead of water, to cure the material. The company's cement can be made at significantly lower temperatures with fewer raw materials, and it cures in less than 24 hours (as opposed to the 28 days required for traditional concrete). Like Solidia, Carbicrete uses CO2 to cure its concrete. It is commercializing a technology called *carbonation activation*, which eliminates the need for cement by replacing it with ground steel slag, a by-product of steelmaking. And Carbon Upcycling Technologies combines carbon dioxide with cheaply available feedstocks to create a portfolio of nanoparticle additives that can make a variety of products stronger or more efficient — including concrete.

*Adapted from "Cleaning up Steel" by Elizabeth Thomson
For further reading, download Tough Tech N.4, The Industry
Issue @ www.engine.xyz*

Metals

The world of metals production is filled with large incumbents implementing gradual process improvements to technologies that have, essentially, remained unchanged for decades. The companies highlighted here are pioneering solutions that promise step changes in energy efficiency.

Examples

- + Boston Metal
- + KoBold Metals
- + Lilac Solutions
- + Modumetal

Chemicals

As diverse as the worldwide chemical industry is, it is united in its demand for energy. How that energy is produced will play a major role in the overall reduction of its CO₂ emissions. The companies highlighted below are focused on developing innovative technologies to reduce CO₂ during the chemical production process.

Examples

- + Lygos
- + Syzygy Plasmonics
- + Solugen
- + Via Separations

Timeline

Technology Development

1976 | Nippon Steel introduced coke dry quenching, a heat recovery system that quenches hot iron before transportation and uses the resultant heat for steam production

1985 | Lone Star Industries patented the first geopolymers cement; this was a slag-based variety

1994 | Arvedi patented endless strip production (ESP), which uses 40-60% less energy than conventional steel casting and rolling processes

2007 | Nature Works developed a low-cost process for the production of polylactic acid (PLA), a bio-based polymer commonly used in food packaging and medical tools

2010 | Scientists at the Argonne National Lab identified a new class of silver-based catalysts for the production of propylene oxide, which is used in the creation of plastics and propylene glycols

2014 | Joule printing leveraged resistive heating to rapidly and efficiently melt low-cost metal wire into high-quality near-net-shape parts

2015 | Researchers at the Swiss Federal Institute of Technology Lausanne developed a microfluidic membrane-less electrolyzer that is used in chlor-alkali reactors

2018 | Tata Steel commercialized HIsarna, a smelt reduction technology that reduces energy consumption by 20-50%

2019 | Kalion commercialized the first fermentation process that transforms glucose into high-purity glucaric acid; at scale, it is expected to be cost competitive with polyethylene terephthalate (PET)

Cement

Creating environmentally-friendly cement and concrete is still a relatively small-scale endeavor compared to worldwide production numbers. Yet, many of the core technologies, if successfully scaled, promise to have an outsize impact on the industry's emissions, without greatly disrupting established production methods.

Examples

- + CarbonCure
- + Carbicrete
- + Carbon Upcycling Technologies
- + CO₂Concrete
- + Solidia Technologies

Investment Notes

The projected value of the global green cement market by 2026:

\$43.6B

<https://www.aggregateresearch.com/news/green-cement-market-tipped-to-be-worth-us43-59bn-by-2026/>

The projected growth of global green chemicals market 2019-2023:

\$50.4B

<https://www.businesswire.com/news/home/20200319005600/en/Green-Chemicals-Market-Demand-Emerging-Economies-Boost>

Public Policy and Awareness

1976 | Congress passed the Resources Conservation and Recovery Act (RCRA), which established a regulatory framework for solid waste and directed the EPA to study the sources and composition of "special wastes," such as cement kiln dust waste

1995 | The EPA launched the Voluntary Aluminum Industry Partnership (VAIP) to reduce perfluorocarbon (PFC) emissions in the aluminum industry by 40% by 2000 relative to 1990; by 1998, aluminum producers had reduced PFC emissions by 48%

1996 | The EPA created the Green Chemistry Challenge Awards to promote the development of novel green chemistry; the resulting technologies collectively prevented 7.8 billion pounds of CO₂ emissions in 2019

2003 | The DOE launched the Climate VISION program, a private-public partnership that coordinated trade associations representing 12 major industrial sectors committed to reducing GHG intensity in the next decade; industry targets ranged from 3% to 12%

2007 | The DOE and China's National Development Reform Committee (NDRC) signed a Memorandum of Understanding to increase cooperation and energy efficiency in China's industrial sector, which accounts for 70% of energy demand

2010 | The EPA enacted the Mandatory Reporting of Greenhouse Gases Rule, which requires large sources and suppliers in the U.S. to report GHG emissions annually; 25 source categories, including chemical suppliers and cement producers, are affected

2020 | Rocky Mountain Institute and university partners launched the Coalition on Materials Emissions Transparency (COMET) to create a universal standard GHG calculation framework for the mineral and industrial supply chains

Buildings

Project Drawdown, a nonprofit resource for climate solutions, notes that the world has “more than 230 billion square meters of building space. Another 65 billion square meters could be added this decade.” And unlike many physical goods we produce, buildings last for decades — or even centuries. Optimizing the way we build, as well as the systems inside those buildings (most notably, heating and cooling), can reduce CO2 emissions by the gigaton.

Buildings are uniquely intimate things. They are where humanity spends most of its time — they are where life plays out. Any innovation in the built environment must consider the human as well as the climate at large.

WoHo, an early-stage company that specializes in efficient and scalable building systems, is committed to doing both. It is developing an automated manufacturing process that, like the iPhone, can be located anywhere. By creating sections of a building in factories close to construction hubs, then assembling these sections into custom-designed structures on-site, WoHo builds more efficiently and reduces the transportation of raw materials. The company expects to reduce the ecological footprint of its buildings by 70% over similar structures.

There is also significant interest in 3D printing buildings. Companies like ICON, Apis-cor, and CyBe use specially formulated concrete/mortar mixes that are extruded through nozzles, similarly to desktop-sized 3D printers, but at a home-sized scale. These techniques, especially when coupled with low-carbon materials, can drastically reduce the overall emissions generated by traditional construction methods.

As the world is becoming simultaneously warmer and

more wealthy, the demand for air-conditioning continues to rise. The refrigerants in the heart of many air-conditioning units are fluorinated gases — potent greenhouse gases.

The Kigali Amendment to the Montreal Protocol, in effect since 2019, outlines an international agreement to reduce hydrofluorocarbons like those in air-conditioning systems. This amendment has spurred innovation in companies around the world. Large chemical and HVAC companies — Honeywell, DuPont, and Arkema, in particular — have created new alternative refrigerants that are less harmful.

Other companies seek to redefine the hardware and software behind most HVAC systems. Durham-based Phononic, for example, has created a modular solid-state semiconductor that uses up to 30% less power than traditional heat pumps while having no moving parts and the associated maintenance requirements.

By retrofitting older buildings with more efficient HVAC systems and constructing new buildings with advanced manufacturing and materials, we can not only live more comfortably but also rest easy knowing that the structures in which we spend the majority of our time are not contributing to the degradation of the climate that surrounds them.

Efficient Structures

More efficient building practices and technologies have significant crossover with materials innovation in general. Greener concrete means a greener building. Cleaner steel means a building with a smaller ecological footprint. The companies listed here are explicitly focused on the structure itself.

Examples

- + Apis-cor
- + Blokable
- + COBOD International
- + Connect Homes
- + CyBe Construction
- + Factory OS
- + ICON
- + Intelligent City
- + Mighty Buildings
- + WoHo
- + XtreeE

Heating & Cooling

The degree of climate control that is required to produce a safe, comfortable space in which to live and work is highly dependent on the building type and climate. These technologies are broadly applicable to most environments.

Examples

- + 75f
- + Core Energy Recovery Solutions
- + Ecobee
- + enVerid
- + Nest Labs
- + Phononic
- + SkyCool Systems

Investment Notes

The projected value of the refrigerant market by 2025:
\$30.4B

<https://www.grandviewresearch.com/press-release/global-refrigerant-market>

3D printing's share of construction technologies used by U.S. single-family builders in 2019:

2%

https://www.nahbclassic.org/fileUpload_details.aspx?contentTypeID=3&contentID=271134&subContentID=736503

Timeline

Technology Development

1974 | Frank Rowland and Mario Molina published a paper linking CFCs to ozone depletion; they were awarded the 1995 Nobel Prize in Chemistry

1979 | The first buildings started using spray foam for insulation (40 years after its invention); buildings treated with spray foam insulate up to 50% better than those with traditional insulation products (e.g., fiberglass)

1981 | DOE-funded research cultivated in the nation's first low-emissivity coating for windows; NREL estimated that the films could reduce building energy use by as much as 33%

1988 | The University of Sydney developed the first cost-effective vacuum insulating glass, which was commercialized by Nippon Sheet Glass in 1994

2008 | ecobee created the world's first smart thermostat; a 2012 study in Massachusetts found that ecobee users reduced gas usage by 8% per thermostat compared to non-smart systems

2010 | DuPont and Honeywell developed a new refrigerant, R-1234yf (GWP less <1), which is a drop-in replacement for the industry standard R-134a (GWP of 1,430)

2018 | University of Delaware professors created smart glass that is 90% less expensive

Public Policy and Awareness

1987 | The Montreal Protocol, designed to close the hole in the ozone layer by banning CFCs and HCFCs, was agreed upon; since then, 196 states and the EU have ratified it

1996 | The EPA approved ammonia as an alternative refrigerant (for only some use cases due to high toxicity)

2007 | The EPA created the GreenChill program to reduce the refrigerant emissions of food retailers; GreenChill partners have refrigerant emissions rates nearly 50% lower than the EPA-estimated industry average

2013 | The U.S. increased energy and water conservation standards for consumer products manufactured after 2022; this applies to air-conditioning units, heat pumps, etc.

2016 | 170 countries agreed to the (legally binding) Kigali Amendment to the Montreal Protocol, an international agreement to gradually reduce the consumption and production of HFCs; this single reduction has the potential to avoid 0.4C of global warming by 2100

2019 | The DOE passed new residential air-conditioning and heat pump standards; beginning in 2023, only cooling units with a seasonal energy efficiency ratio (SEER) above 14-15 (depending on the region) and heat pumps with a heating seasonal performance factor (HSPF) above 8.8 can be sold

AI's Climate Change Paradox

According to a recent University of Massachusetts Amherst study, the amount of CO2 emitted from energy generation plants to power the computation involved in creating a new state-of-the-art AI model is the equivalent of five automobile lifetimes' worth of CO2 emissions.¹

Recommended reading

BloombergNEF 2020 Sustainable Energy in America Factbook

[https://data.bloomberglp.com/professional/sites/24/BNEF-BCSE-2020-Sustainable-Energy-in-America-Factbook_FINAL.pdf]

Carbon Plan

[<https://carbonplan.org/>]

EIA Potential Energy Impacts of Automated Vehicles

[https://www.eia.gov/analysis/studies/transportation/automated/pdf/automated_vehicles.pdf]

EPA Greenhouse Emissions Data

[<https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data>]

IEA Clean Energy Innovation Flagship Report

[<https://www.iea.org/reports/clean-energy-innovation>]

IEA ETP Clean Energy Technology Guide

[<https://www.iea.org/articles/etp-clean-energy-technology-guide>]

As Professor Scott Stern, Professor of Management of Technology at the MIT Sloan School of Management, noted in our previous publication dedicated to artificial intelligence, AI can be thought of as both a “general purpose technology” that can be used to enable other technologies, and as a “method of invention” that allows for the creation of fundamentally new products separate from the AI itself.

Stern goes on to compare the technology to lenses that were used to make eyeglasses in the 1400s. “People got good at grinding lenses so that people could see,” he says. “But Galileo took those lenses and built the first telescope and was immediately able to resolve the existence of moons around planets. It allowed us to literally resolve phenomena we couldn’t even imagine, and ask new types of questions.”

Such is the potential for AI in discovering new approaches to combating climate change.

But creating AI powerful enough to do such discovery poses a paradoxical challenge. The mechanics of the technology — its hardware and software — demand an ever increasing amount of energy and produce an ever increasing amount of CO2 as a result, thus contributing to the problem they are trying to solve.

Rick Calle, the AI business development lead for M12 (Microsoft’s venture fund), puts this energy demand into perspective: “According to a recent University of Massachusetts Amherst study, the amount of CO2

emitted from energy generation plants to power the computation involved in creating a new state-of-the-art AI model is the equivalent of five automobile lifetimes’ worth of CO2 emissions. If that’s what it takes to train only one new AI model, you can see that it is just not compatible with a prioritization of sustainability.”

He and his colleagues propose a joint optimization framework of three things: energy-efficient AI hardware, co-designed efficient AI algorithms, and AI-aware computer networks. The details of this framework are featured in his interview in Tough Tech N.5, our AI issue.

Others, like The Engine portfolio company Inorganic Intelligence (II), are pioneering joint hardware and software solutions to AI’s energy problem. II is integrating the efficiency and performance of photonics (light-powered computational chips) with electronic AI systems. Its AI hardware and software platform, when commercialized, will provide a superior combination of total operations per second (TOPS), per watt, per dollar compared to today’s traditional AI chips.

/1/ Energy and Policy Considerations for Deep Learning in NLP, <https://arxiv.org/abs/1906.02243>

For further reading, download Tough Tech N.5, The AI Issue @ www.engine.xyz

IPCC Special Report on Climate Change and Land
[<https://www.ipcc.ch/srccl/>]

IPCC Chapter Climate Change 2014 Synthesis Report
[https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf]

Project Drawdown
[<https://drawdown.org/>]



Get the Sources

Scan the QR Code or visit www.engine.xyz/climate_sources to access the sources behind the technology survey timelines.

The Portfolio Companies

The Engine invests in founders solving the world's biggest problems through the convergence of breakthrough science, engineering, and leadership.

We've seen our investments coalesce into three areas of impact: those companies whose core technology will help solve climate change; those that will create new human health solutions; and those that will usher in a new era of advanced systems.

Climate Change

[Boston Metal](#)

[Commonwealth Fusion Systems](#)

[Form Energy](#)

[Lilac Solutions](#)

[Quaise](#)

[Syzygy Plasmonics](#)

[Via Separations](#)

Human Health

[Biobot Analytics](#)

[Cellino](#)

[E25Bio](#)

[Kytopen](#)

[Lucy Therapeutics](#)

[Mori](#)

[Seaspire Skincare](#)

[Suono Bio](#)

[Vaxess Technologies](#)

Advanced Systems

[Analytical Space](#)

[C2Sense](#)

[Cambridge Electronics](#)

[HyperLight](#)

[Inorganic Intelligence](#)

[ISEE](#)

[Radix Labs](#)

[RISE Robotics](#)

[Sync Computing](#)

[WoHo](#)

[Zapata Computing](#)

WoHo

Founders	[1] Antón García-Abril [2] Débora Mesa [3] Israel Ruiz
Background	MIT, Ensemble Studio
Industry	Advanced Materials, Advanced Manufacturing

Why is construction, a process both ubiquitous and ancient, still so fragmented and inefficient? Why is there such a gulf between innovation in building materials and the process by which these materials are assembled into functional structures? Why is it that most buildings must start from a blank slate, with each step making the final product more expensive and less impactful? Questions like these drive [WoHo](#), a company founded by Antón García-Abril, Débora Mesa, and Israel Ruiz, to change the way we build, design, and develop. The company expects to lower the costs of construction by more than 20%, shrink project delivery time by 50%, and reduce the ecological footprint of buildings by 70%, all while improving project predictability and construction quality.

The seeds of what would become [WoHo](#) were planted in 2012, when Mesa and García-Abril founded the Prototypes of Prefabrication Laboratory (POPlab) at MIT. The pair had experimented with offsite construction and prefabricated parts as early as 2007, when they built the Hemeroscopium House in Madrid from precast concrete. But it was at POPlab that they turned their focus to lightweight materials while continuing research on prefabricated systems. The pair are also the founders of Ensemble Studio, an award-winning global architectural firm based in Madrid and Boston, where they work as both hands-on builders and architects on projects around the world.

Ruiz, [WoHo's](#) CEO and an engineer, met Mesa and García-Abril at MIT, where he served as the Executive Vice President and Treasurer. While at MIT, Ruiz oversaw the capital renewal and construction program of over one thousand residential units and over two million square feet of labs and offices. Ruiz was also instrumental to the real estate development of Kendall Square.

The three united over a shared philosophy — that the complexities of modern development

are, in many ways, a relic of a process that has remained unchanged for decades and that reimagining the way buildings are designed and made can actually increase the quality of the finished product, creating welcoming and resilient places to live and work.

Ruiz, García-Abril, and Mesa see [WoHo](#) as a new approach to architecture — no longer is the discipline the visionary planning phase of a project, instead it is interwoven through every chapter of a structure's life. The company has developed a system of discrete foundational components that can be scaled and configured to span both residential and commercial buildings such as multifamily housing, hotels, labs, offices, and dormitories. Such an approach gives [WoHo](#) control over the design, material selection, and overall quality of each assembly at a finer level than traditional construction, allowing the team to continuously iterate and improve facets of their assemblies without stalling production.

The company is planning to build lean, modular factories that balance automation and handwork close to construction hubs, simplifying the logistics, lowering the costs, and reducing the environmental footprint of its buildings. It is also building an ecosystem of partners and preferred suppliers. The team likens its [WoHo](#) Production System (WPS) to the automotive industry, with its network of value-add suppliers and assembly lines, with their optimized interplay between human and machine.

“Despite the impact of the COVID-19 pandemic, the fundamental needs of physical structures, whatever we call our Home, remain. We are undergoing a paradigm shift for architectural design and construction,” Ruiz notes. He continues, “[WoHo](#) is building the new generation of intelligent, safe, and sustainable spaces. We are raising the standards and expectations for how buildings are created. [WoHo](#) is changing how we design and construct our world — so that everyone wins.” +



Creating beautiful, intelligent,
and scalable building systems
that raise the standards of
low-to-high rise construction.



[1]

[2]

[3]

Quaise

Founders	1 Henry Phan 2 Paul Woskov 3 Carlos Araque 4 Matthew Houde 5 Franck Monmont
Background	MIT
Industry	Energy, Advanced Materials, Advanced Engineering

Our generation lives at a crossroads. Take one path and, within 15 years, we exhaust the planet's carbon budget for a 1.5C global temperature increase, exacerbating with terrible certainty the effects of climate change we see today. Take the other path, unbridling the power of inexhaustible emissions-free energy, and we keep the worst at bay. But that latter path, the one in which we do away with fossil fuels, will require solutions with far more power density than the current renewable energy sources such as wind and solar will be able to provide without widespread baseload energy storage.

Enter geothermal energy. If we dig deep enough, we can harness this thermal energy with power densities consistent with fossil fuels. These conditions exist everywhere on the planet at depths of 10 - 20 kilometers. Quaise, a startup born from research at the MIT Plasma Science and Fusion Center, is pioneering a new type of energy drilling system to reach the depths necessary to exploit the largest source of power-dense clean energy on Earth.

There are few experimental sites on the planet, such as Russia's Kola Superdeep Borehole, that have drilled over 10 kilometers deep using conventional methods. Quaise hopes to dig even deeper in just 100 days, orders of magnitude faster than such experiments. To do it, they will need much more than a tough drill bit.

Carlos Araque, co-founder and CEO, was introduced to the experimental work of Paul Woskov (a scientific co-founder) in 2017. Woskov, working at

the MIT Plasma Science and Fusion Center, pioneered a technique of using electromagnetic waves to blast through rock. The waves are generated by a gyrotron — a large machine that is frequently used in industrial settings for heating and curing processes, as well as in nuclear fusion experiments, and for defense purposes.

Araque, who holds an engineering degree from MIT, spent nearly 15 years working for Schlumberger, one of the world's foremost providers of drilling services to the oil and gas industry. It was his time in the traditional energy industry — seeing its consequences from the inside — that drove him to lead a clean energy company. And his technical expertise helped him recognize the potential of Woskov's innovations and the possibilities of a hybrid boring platform.

"We're not replacing what currently exists, instead we are using it to our advantage to give us a 100-year head start," Araque notes. "We're also building a global team, leveraging the best drilling, plasma physics, and gyrotron experts in the world — with members and partners in Boston, Houston, U.S. National Labs, and Cambridge, UK."

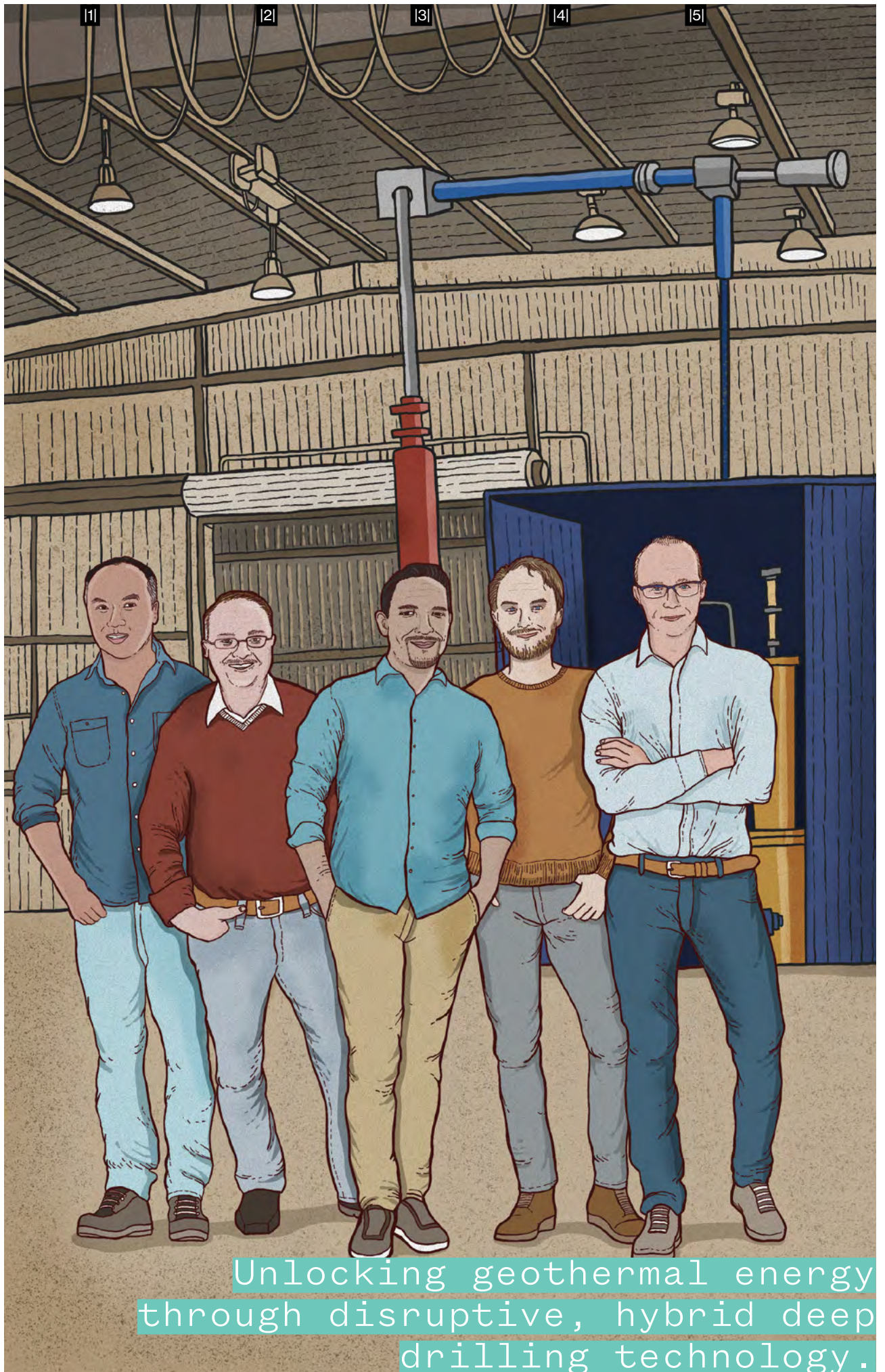
Although Quaise's core innovation is its gyrotron-powered millimeter-wave energy drilling system, it plans to harness the established infrastructure, supply chain, and expertise of the oil and gas industry. The traditional energy industry has been drilling holes up to five kilometers deep for decades. Their tools and techniques are refined and already deployed at scale.

Using conventional technology, Quaise plans to drill up to five kilometers. Once there, it will deploy its energy drilling system to reach depths of 10 - 20 kilometers. It is a straightforward plan but one that requires leaps in technical innovation and excellent engineering and operational execution.

As an early-stage Tough Tech startup, Quaise must complete many of its scaling experiments in the lab before it tests its technology on site. It hopes to have its gyrotron-powered drilling platform sufficiently refined by 2023 to drill through more than a meter of rock. From there, it is a matter of scaling in size and power.

Matthew Houde, a co-founder and geologist, remains undaunted. He notes that for millennia the Earth has shown us that stable holes of incredible depth are possible. Volcanoes draw their power from far deeper.

The transition from fossils fuels to emissions-free energy represents an existential challenge — one that must be solved if future generations are to inhabit a flourishing planet. Although renewable energy sources such as wind and solar provide potential alternatives to fossil fuels, there is simply not enough landmass for them to be deployed at the scale necessary to supplant the current dominant energy sources. Supercritical geothermal energy, with its small land footprint and ability to harness over 100 years of fossil fuel drilling, surveying, and transmission infrastructure, represents a potential power source too compelling to ignore. +



Unlocking geothermal energy
through disruptive, hybrid deep
drilling technology.

Inorganic Intelligence

Founders	[1] Preet Virk [2] David Lazovsky [3] Michelle Tomasko
Background	Intermolecular, POET Technologies, NVIDIA, Google, Groq, Macom, Transmeta, Applied Materials
Industry	Semiconductors, Artificial Intelligence, Machine Learning

AI has a problem. It is becoming too powerful for its own good — literally. Today’s AI and machine learning algorithms require massive amounts of raw computational power that, in turn, requires loads of energy. Organizations and devices that rely on AI can choose to consume more power (resulting in significant operating costs, decreased battery life, or both), or they can sacrifice performance for more efficient hardware. They must compromise.

Photonic chips, which use light to perform the calculations at the heart of AI processes, have incredible efficiency and performance but pose novel design, integration, and manufacturing challenges and have yet to be commercialized. Enter [Inorganic Intelligence \(II\)](#). The startup is integrating the efficiency and performance of photonics with proven electronic AI systems to provide a uniquely superior combination of total operations per second (TOPS), per watt, per dollar compared to today’s traditional AI chips.

Unlike many other forays into photonic AI chips that are usually born straight from academia, [II](#) was created from the top down by a team of semiconductor, manufacturing, and AI software experts who built their careers at corporations such as NVIDIA, Google, Applied Materials, and MACOM.

David Lazovsky, the company’s CEO, approached the initial idea for [II](#) from an intellectually agnostic point of view. He saw the inefficiencies in the status quo, recognized the potential

for improvement, and, during his time as a venture partner at Khosla Ventures, conducted an extensive review of advances in the fields of photonics and semiconductors with the goal of developing an architecture that would address key integration and manufacturing challenges, while also providing ease of adoption to future customers.

This style of research and leadership was honed at Applied Materials, where he managed over \$1B in semiconductor manufacturing equipment business before founding his first startup, Intermolecular, and leading it through its IPO.

It was during his time at Khosla that Lazovsky met Professor Nikos Pleros, the innovator of the company’s core photonic technology and an expert in neuromorphic computing. By drawing on Lazovsky’s deep industrial experience and breakthroughs in optical computing architectures from Professor Pleros’ lab, the pair began to design [II](#)’s proprietary optical neural network (ONN) technology that combines silicon photonics with a control ASIC in a system-in-package (SiP).

Lazovsky wasted no time in recruiting the two other members of the founding team: Preet Virk and Michelle Tomasko. Virk is an expert at managing engineering teams in the semiconductor and data communications sectors, having previously served as an SVP at MACOM and Mindspeed Technologies, two noted designers and manufacturers of semiconductors.

Tomasko brings significant software experience to [II](#), observing

that “every good chip company has twice the number of software engineers than hardware engineers — software cannot be overlooked when bringing semiconductors to market.” At NVIDIA, she served as a director of software, driving all aspects of software development for some of its leading GPU architectures and its first consumer android device. She then managed Google’s first ML/image processing accelerator system-on-a-chip for the Pixel 2 phone. Prior to [II](#), she was the VP of Engineering at Groq, a developer of AI ASIC platforms.

With their emphasis on system-level design, manufacturability, and ease of adoption, the [II](#) team hopes to be the first to truly unlock the potential of optical computing. The company envisions its platform liberating the potential of AI at the “edge” (processing AI algorithms within devices such as vehicles, consumer electronics, and the built environment) as well as drastically reducing the costs associated with large-scale data-center-based computing.

The future is, undoubtedly, algorithmic. Our lives are becoming increasingly intertwined with AI. From the digital lives we build, to the streets we drive on, to the medical care we receive — AI is both intensely individual and intensely communal. We may not know where it will take us next, but we can be confident companies like [II](#) will be behind the scenes, providing the platform developers need to create massively capable and efficient AI solutions — everywhere. +

|1|

|2|

|3|



Building an AI hardware
and software platform that
integrates photonics and
digital chips into AI systems.

Climate Change

Boston Metal

Founders & Leadership

Tadeu Carneiro, Rich Bradshaw, Adam Rauwerdink, Donald Sadoway, Antoine Allanore, Jim Yurko, Bob Hyers

Background

MIT Department of Materials Science and Engineering

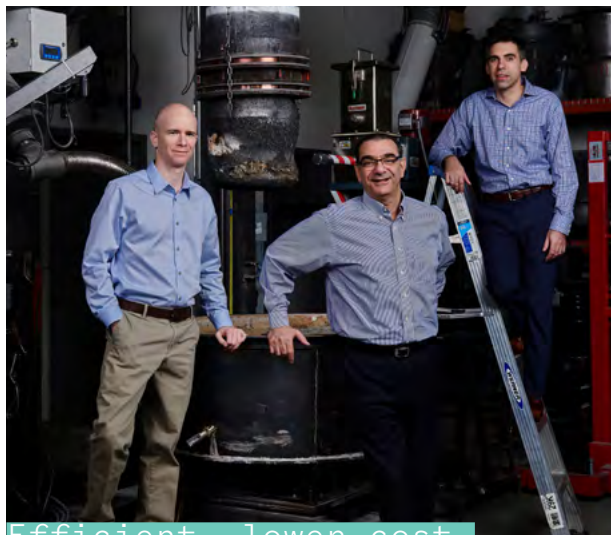
Industry

Advanced Manufacturing, Energy

Boston Metal has invented a coal-free, emissions-free, modular method of industrial steel and ferroalloy production using electricity. It is called molten oxide electrolysis (MOE) and combines transformative materials engineering and novel systems engineering with elements from industrial aluminum production, traditional blast furnaces, and arc furnaces to produce steel and ferroalloys more efficiently, at lower costs than traditional methods, and with zero greenhouse gas (GHG) emissions.

Significance

Today, the steel industry is the largest industrial source of CO₂ emissions because of a reliance on coal. Boston Metal removes coal from the process, driving CO₂ emissions to zero while providing substantial OPEX and CAPEX savings.



Efficient, lower-cost production of steel and alloys with zero emissions.



Creating safe, unlimited, carbon-free fusion power for the grid in 10-15 years.

Commonwealth Fusion Systems

Founders & Leadership

Bob Mumgaard, Brandon Sorbom, Dan Brunner, Dennis Whyte, Martin Greenwald, Zach Hartwig

Background

MIT Plasma Science and Fusion Center

Industry

Energy, Advanced Materials

Commonwealth Fusion Systems (CFS) aims to provide a new path to fusion power by combining proven fusion physics with revolutionary magnet technology to deploy the first working, economic fusion reactors to the world. The team will develop high-field magnets based on a new class of high-temperature superconductor materials that will allow fusion reactors to be 10 times smaller, economically feasible, and operational in the next 10 years.

Significance

Fusion energy is the holy grail of clean energy: limitless, no greenhouse gases, baseload, concentrated, no meltdown, and no proliferation. If successful, the world's energy systems will be transformed.

Form Energy

Founders

Mateo Jaramillo, Ted Wiley, William Woodford, Yet-Ming Chiang, Marco Ferrara

Background

MIT Department of Material Science and Engineering, 24M Technologies, A123, Tesla Energy

Industry

Energy, Advanced Materials

Form Energy will solve large-scale renewable energy's most fundamental limitation — reliability — through energy storage. Rather than thinking of batteries in the traditional sense, simply as storage vessels, Form is designing bidirectional power plants. Built to displace fossil fuel baseload generation plants, Form Energy's core technology will store and supply hundreds of megawatts via the existing energy grid.

Significance

Form Energy will help bring renewables to the masses at an affordable price by storing energy from sources such as wind and solar to power thousands of homes and businesses.



Engineering a bidirectional power plant to make renewable energy available 24/7.



The fastest, most sustainable, and most efficient lithium extraction platform.

Lilac Solutions

Founders

Dave Snydacker, Nick Goldberg, Tom Wilson

Background

Northwestern University

Industry

Advanced Materials

Lilac has developed a patented ion exchange technology that facilitates the production of lithium from abundant brine resources with minimal cost and ultra-low environmental footprint — its platform is significantly faster, cheaper, and more scalable than existing technology. Lilac's mission is to enable the expansion of global lithium resources needed to supply an electrified transportation system.

Significance

Lilac has the potential to be the technology of choice for all new lithium brine projects. The company is harnessing its proven technology to transform the lithium industry to supply the resources necessary to meet the demands of an electrified transportation system.

Climate Change

Syzygy Plasmonics

Founders

Trevor Best, Suman Khatiwada, Naomi Halas, Peter Nordlander

Background

Rice University, Baker Hughes

Industry

Advanced Manufacturing, Energy, Advanced Materials

Syzygy Plasmonics is pioneering a new type of chemical reactor driven by light rather than heat, eliminating the greenhouse gas (GHG) emissions associated with burning fuel to power a reaction. At the heart of the reactor is a novel photocatalyst with 10,000x greater efficiency than competitive examples. The company has focused its first efforts on hydrogen production, but the underlying technology platform can be tailored to produce other chemicals as well.

Significance

Syzygy Plasmonics' technology platform allows for the production of chemicals on site and in a modular, scalable, and cost-effective way, with reduced GHG emissions. This will revolutionize the entire chemical manufacturing industry not in the least because the decentralization can open new markets by avoiding the need to rely on costly or inefficient transportation chains.



Chemical manufacturing driven by light, enabling cheaper, scalable, on site production.



Up to 90% energy savings in separation process in the pulp & paper, chemical, and dairy industries.

Via Separations

Founders

Shreya Dave, Brent Keller, Jeff Grossman

Background

MIT Department of Materials Science and Engineering

Industry

Energy, Advanced Materials, Advanced Manufacturing

Separation processes are the building blocks for materials, chemicals, and consumer goods — they are core to the industrial ecosystem. Currently, most separations are done with thermal processes such as evaporation and distillation, which are very energy intensive. Via Separations is commercializing novel membrane materials and manufacturing processes to replace evaporation and distillation with filtration.

Significance

The company's technology has the potential to replace thermal separation processes, saving the energy equivalent used by the entire gasoline industry every year in the U.S.

Human Health

Biobot Analytics

Founder

Mariana Matus, Newsha Ghaeli

Background

MIT

Industry

Biotech & Life Sciences, AI & ML, Data Science

Biobot Analytics is a wastewater epidemiology company that is transforming wastewater infrastructure into real-time public health observatories. Its wastewater monitoring technology analyzes urine and stool samples to create health information that is independent from hospital reporting systems, free from societal biases affecting who can and cannot seek care, and most importantly, is rapidly adaptable to new and emerging public health threats.

Significance

While Biobot's platform has been widely adopted during the COVID-19 pandemic to help communities across the U.S. gain a clearer understanding of the disease's scope and scale, it can also be applied to a broad range of other public health issues. The company has used the same platform to help identify opioid hotspots, and it can analyze other viruses like influenza as well as types bacteria.



Data analysis that will transform wastewater infrastructure into public health observatories.



A natural coating that reduces food spoilage and packaging waste.

Mori

Founders

Adam Behrens, Sezin Yigit, Benedetto Marelli, Livio Valenti, Fiorenzo Omenetto

Background

MIT Laboratory for Advanced Biopolymers, Tufts University SilkLab

Industry

Food & Agriculture, Advanced Materials

Mori is addressing the problem of food spoilage and waste by pioneering a natural, ultra-thin, water-based coating that preserves the freshness of food longer. It is tasteless and invisible and can be applied to everything from fresh and cut produce to proteins such as meat and fish. The coating dramatically extends shelf life by slowing the exchange of gases that cause decay, making food accessible to more people for longer times. In addition, the coating has the potential to support enhanced nutrients for food and also help reduce packaging.

Significance

One-third of the food produced in the world is wasted. Mori's technology helps to reduce food spoilage across the supply chain, decreases logistics costs, and makes healthy food more accessible.

Human Health



A tissue foundry for regenerative medicine.

Cellino

Founders

Nabiha Saklayen, Matthias Wagner, Marinna Madrid

Background

Harvard Physics Department, Harvard School of Engineering and Applied Sciences (SEAS), Harvard Medical School

Industry

Biotech & Life Sciences, Advanced Manufacturing, AI & ML

Cellino is building a platform that enables the precise creation of cell and tissue therapies. Inspired by the scale and precision of semiconductor manufacturing, the Cellino Tissue Engineering Platform manufactures high-quality, impurity-free tissues for new regenerative medicines. Cellino will use its platform to manufacture tissues at scale, delivering the highest quality human tissues made to date. Such tissues are poised to offer transformative benefits to patients and address significant unmet needs.

Significance

Cellino's approach for high-throughput, computer-guided engineering of human stem cells will create new tissues as regenerative medicines for patients.

E25Bio

Founders

Irene Bosch, Bobby Brooke Herrera, Lee Gehrke

Background

MIT Institute for Medical Engineering & Science, MIT Tata Center

Industry

Biotech & Life Sciences

E25Bio is pioneering an at-home rapid fever panel for mosquito-borne diseases. With its first-in-class antibodies identified with a novel screening method, E25Bio's diagnostic test is the first of its kind to distinguish between dengue (as well as all four subtypes of the disease), chikungunya, and Zika. In addition, E25 is rapidly advancing a COVID-19 antigen test through clinical studies for FDA approval.

Significance

E25Bio is putting a specialized central medical testing facility within a single over-the-counter test. The company's rapid fever panel will empower patients, healthcare workers, and public health officials in Latin America, and the COVID-19 test will empower the U.S. and potentially other countries. The company's ability to quickly produce effective antibody pairs means that it has the potential to help patients across the globe.



Rapid, accurate diagnosis of infectious diseases at the point of care.



Cellular engineering at unparalleled speeds, from discovery to the clinic.

Kytopen

Founders

Paulo Garcia, Cullen Buie

Background

MIT Department of Mechanical Engineering

Industry

Biotech & Life Sciences, Advanced Manufacturing

Kytopen aims to transform the cell and gene therapy industry with its microfluidics and electric-field-based platform that can automate and manufacture the genetic engineering of cells 10,000x times faster than current methods. With continuous flow of cells during genetic manipulation, the products in development address both small and large sample volumes and enable both drug discovery and manufacturing at scale.

Significance

Cell and gene therapies currently suffer from major challenges in efficiency, reproducibility, and cost. Kytopen's solution can solve a huge bottleneck in the development and manufacturing process, reducing costs and accelerating time to market for these therapies.

Lucy Therapeutics

Founder

Amy Ripka

Background

University of Wisconsin-Madison, The Scripps Research Institute

Industry

Biotech & Life Sciences

Lucy Therapeutics is pursuing more effective clinical results in neurological diseases such as Rett Syndrome, Parkinson's, and Alzheimer's by targeting dysfunctional mitochondria in neurons. The insights that underpin Lucy Therapeutics' drug discovery platform may also lead to a biomarker that would enable early, presymptomatic diagnosis of these diseases.

Significance

Imagine a world in which doctors can diagnose and treat patients before the tremors, the dementia, or the seizures from neurological diseases such as Rett Syndrome, Alzheimer's, and Parkinson's take control. This is a world that Lucy Therapeutics is working to realize.



Breakthrough mitochondrial-based therapies for neurological diseases.

Human Health



The future of sustainable skincare.

Seaspire Skincare

Founders

Camille Martin, Leila Deravi

Background

Northeastern University

Industry

Advanced Materials, Biotech & Life Sciences

Seaspire is pioneering a new category of multifunctional materials with extensive implications for human health and environmental safety. The team can recreate and package the chemical machinery of the chromatophore, a pigment-containing organ found in the skin of cephalopods. Seaspire will use this class of pigments to enable multifunctional performance colorants and active ingredients in a broad range of consumer and industrial goods.

Significance

Research indicates a link between UV chemical filters and the health of marine ecosystems such as coral reefs. There are also worldwide efforts to re-evaluate the safety of some ingredients within sunscreens for human use. As components of sunscreens and cosmetics, Seaspire's unique pigments could transform these industries as sustainable, high-performance, and nontoxic alternatives to the status quo.

Suono Bio

Founders & Leadership

Carl Schoellhammer, Robert Langer, Gio Traverso

Background

MIT Department of Chemical Engineering

Industry

Biotech & Life Sciences

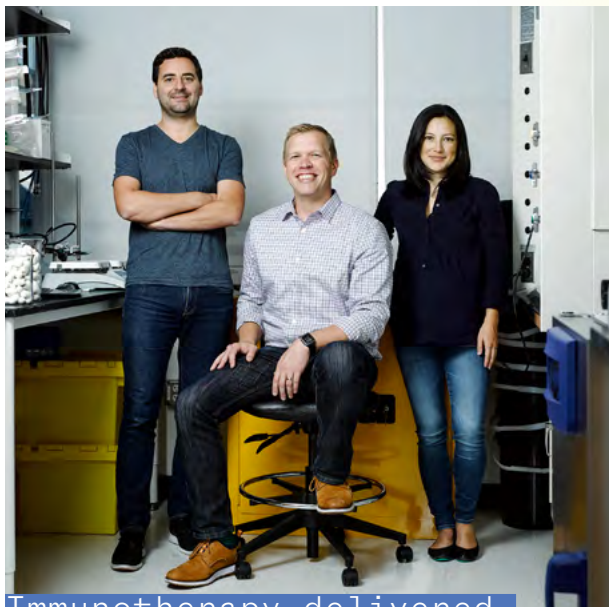
Suono Bio has reimagined ultrasound as an effective and elegant delivery mechanism for the most delicate therapeutics. Its technology can push molecules such as DNA, RNA, and proteins directly into cells without disrupting the surrounding tissue or harming the molecule itself. The flexibility and efficacy of the Suono Bio therapeutic platform brings with it the potential to treat and cure diseases with targets once deemed undruggable.

Significance

Suono Bio will more effectively treat challenging chronic gastrointestinal diseases and enable new therapies for other pressing health challenges such as diabetes, cancer, and viral infections.



Ultrasound drug delivery for difficult-to-treat diseases.



Immunotherapy delivered in a patch, mimicking natural challenges to the immune system.

Vaxess Technologies

Founders

Michael Schrader, Kathryn Kosuda, Livio Valenti, David Kaplan, Fiorenzo Omenetto

Background

Harvard Business School, Tufts University SilkLab

Industry

Biotech & Life Sciences, Advanced Materials, Advanced Manufacturing

Vaxess Technologies is pioneering a technique it calls Infection Mimicry to help increase the effectiveness of immunotherapies for infectious diseases (e.g., flu and COVID-19) and cancer. The company's first product, named MIMIX, is inspired by the body's natural immune response to infection. MIMIX is a smart-release therapeutic patch that, after only minutes of wear-time, can release treatments into the skin for up to months after the initial application.

Significance

The same biology that allows MIMIX to activate the immune system against infectious diseases such as influenza may also be used to activate the immune system against cancer cells. When a MIMIX patch loaded with a chemo agent is applied to certain tumors, for example, it can initiate a natural immune response, potentially eliminating metastases throughout the body. Furthermore, MIMIX is applicable to many COVID-19 vaccine approaches, promising a more effective product that can be shipped directly to the home.

Advanced Systems

Analytical Space

Founder

Dan Nevius

Background

NASA, Planetary Resources, White House, HBS

Industry

Space, Internet of Things

Analytical Space (ASI) is building a network of in-orbit communication relay satellites that offers expanded connectivity for data transfer, without any change to existing hardware. This results in faster data downloading, more access to download windows, lower latency, and improved cost structures, while being compatible with heritage satellites and new satellites alike.

Significance

ASI will liberate and deliver terabytes of untapped data gathered by hundreds of satellites, helping industries from agriculture to defense to operate with greater precision, efficiency, and insight.



Real-time satellite network connecting space to Earth 24/7.

Advanced Systems

Cambridge Electronics

Founders

Bin Lu, Tomás Palacios

Background

MIT Microsystems Technology Laboratories, MIT Department of Electrical Engineering and Computer Science

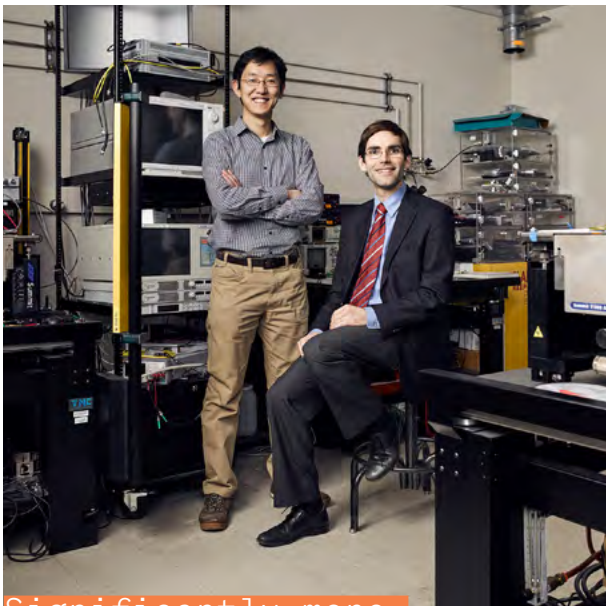
Industry

Semiconductors, Advanced Materials

Today's electronics rely on silicon processing. From data centers, to electric vehicles, to consumer electronics, the ubiquitous material is used to control and convert power. As these technologies advance, industries are challenged to build increasingly efficient (and increasingly compact) power electronics. In many cases, we have reached the limits of silicon. Cambridge Electronics has invented a proprietary gallium nitride (GaN) technology that is less expensive and exponentially more efficient than silicon, while also having a smaller footprint.

Significance

Cambridge Electronics' technology will bring significant energy savings to diverse and power-reliant industries such as data centers, renewable energy, manufacturing, automotive, and consumer electronics.



Significantly more efficient electronics — from data centers to electric vehicles.



Gas sensing technologies to track and quantify the invisible.

C2Sense

Founders & Leadership:

George Linscott, Tim Swager, Eric Keller, JT Mann

Background

MIT Department of Chemistry

Industry

Advanced Materials, Internet of Things

A digital olfactory sensor platform for industry, C2Sense's technology transforms smell into real-time data that can be accessed remotely. With high-fidelity electrochemical sensors at a low price point, C2Sense will empower a broad array of industries, including those involved in food supply, product authentication, and chemical production, to take control of their environments. The team is currently investigating the use of its Halo technology to rapidly read COVID-19 tests.

Significance:

Tiny, inexpensive, efficient, and highly selective, C2Sense's sensors will enable a future of ubiquitous mobile gas sensing — a future in which experts in medicine, agriculture, and security will be empowered to make the world a healthier and safer place.

HyperLight

Founders

Mian Zhang, Marko Loncar, Cheng Wang

Background

Laboratory for Nanoscale Optics at Harvard University

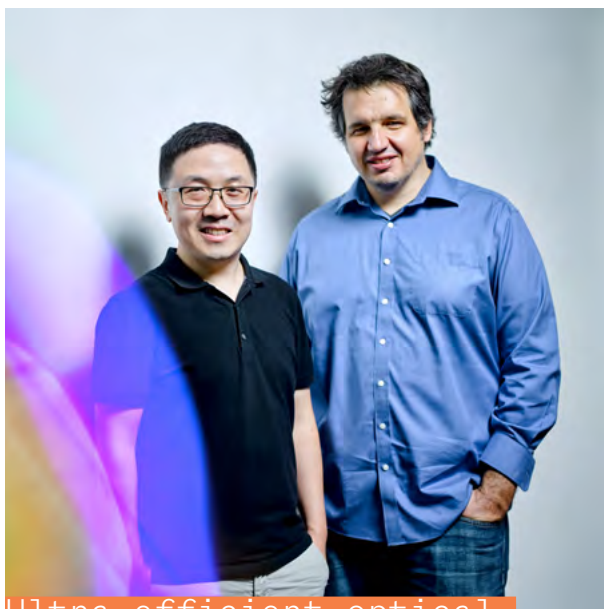
Industry

Semiconductors, Advanced Materials, Advanced Manufacturing

HyperLight has invented unique processes and designs for fabricating integrated, chip-scale lithium niobate (LN) modulators with extremely low signal loss. These integrated optical circuits hold the potential to reshape the world's relationship with optical data and enable novel functionalities from communication to spectroscopy. The startup's technology was developed at Harvard University and is featured in multiple publications in the journal, "Nature."

Significance

HyperLight's integrated optical circuits have the potential to reshape the world's relationship with optical data. Its devices set new benchmarks for performance, including extraordinary speed and efficiency, that will force industries such as telecom and data centers to rethink and reimagine their current standards.



Ultra-efficient optical circuits to de-bottleneck data centers and telecom networks.



Automating the logistics industry with a humanistic AI-powered autonomous driving system.

ISEE

Founders:

Yibiao Zhao, Debbie Yu, Chris Baker

Background

MIT Computational & Cognitive Science Group

Industry

Deep Software, AI & ML

ISEE is engineering next-generation, humanistic AI to automate the logistics industry from dock to door. Their technology is built for complex environments with high uncertainty (shipping yards and congested highways) and can integrate into an existing logistics workflow without infrastructure change. ISEE was the first to achieve exit-to-exit autonomous highway driving, the first to merge onto a highway in heavy snow, and the first to handle congested traffic better than a leading autonomous driving startup.

Significance:

ISEE plans to first automate the shipping yard, reducing yard costs by 50% and increasing yard throughput by 30%. The same AI that will power yard trucks can be used to transport freight across our highways; it will add value and increase safety throughout the logistics supply chain.

Advanced Systems

Radix Labs

Founder

Dhasharath Shrivathsa

Background

Olin College, MIT Media Lab

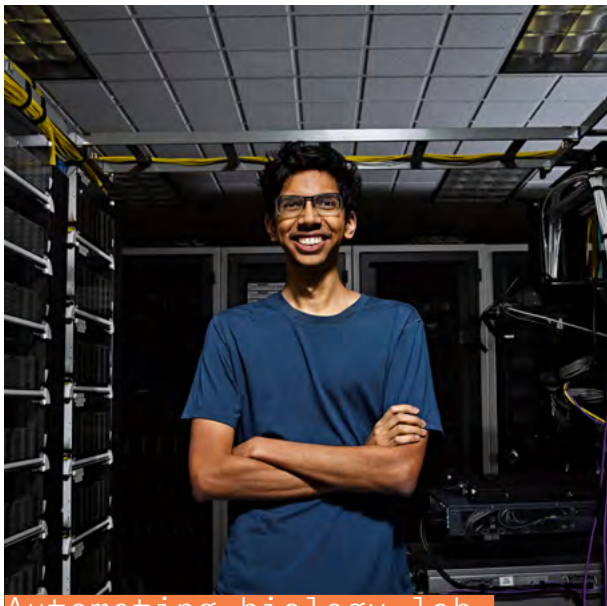
Industry

Robotics, AI & ML, Internet of Things, Biotech & Life Sciences

Radix Labs has built a programming language that unites biologists and their lab machinery in one automated unit. This programming language is the heart of software that manages both human and machine tasks. For the first time, disparate lab machinery can communicate with one another under the control of one centralized platform — it is, for all intents and purposes, an operating system for biology labs.

Significance

With Radix, biologists will spend less time in the lab and more time focusing on experimental design and analysis, thanks to its platform's approachable user interface and robust backend integration.



Automating biology lab processes from experiments to mass production.



Enabling the next era of fully electrified heavy machinery.

RISE Robotics

Founders

Arron Acosta, Blake Sessions, Toomas Sepp, Kyle Dell'Aquila

Background

MIT

Industry

Robotics

RISE Robotics has invented a replacement for hydraulic systems that will enable the next era of fully electrified heavy machinery — one that is at once sustainable, robust, and precise. The startup's core technology is an electrically powered mechanical linear actuator with all the abilities of a hydraulic cylinder but with vastly improved efficiency and control. RISE also supplies electrification systems through partnerships with heavy machinery OEMs, helping maximize the impact of its hardware.

Significance

RISE will lead the next revolution of heavy machinery. Its electrically powered platform will help us transition from diesel and hydraulics to fleets of fully electric, sustainable, and precise equipment used to build our world.

Sync Computing

Founder

Jeff Chou, Suraj Bramhavar

Background

MIT Lincoln Lab

Industry

Advanced Computing

Sync Computing is developing a novel approach to high-performance computing. The company has created a novel computing technology coined “Optimization Processing Unit” (OPU) that harnesses natural (or analog) processes. This OPU can be used to find solutions to important combinatorial optimization problems that traditional digital computers cannot efficiently tackle. Solving this class of problems will deeply impact drug discovery, financial modeling, route optimization (logistics), telecom frequency optimization, and more.

Significance

Sync’s platform is an elegant and accessible alternative to complex and temperamental options such as quantum computing. Their computing chips will democratize the power of high-performance computing, efficiently solving combinatorial optimization problems once thought intractable.



Building the world’s first optimization processing unit to help unlock solutions from computing to networking.



Quantum software and algorithms to solve industry’s hardest problems.

Zapata Computing

Founders

Christopher Savoie, Alán Aspuru-Guzik, Jonathan Olson, Peter Johnson, Yudong Cao, Jhonathan Romero Fontalvo

Background

Harvard Department of Chemistry, University of Toronto
Department of Chemistry

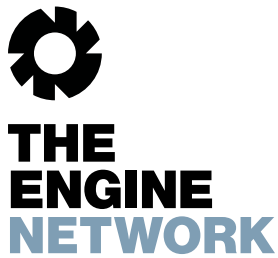
Industry

Advanced Computing

The team at Zapata Computing writes algorithms that harness the power of quantum computing to help predict and simulate some of the universe’s most complex interactions, such as the behavior of molecules at an atomic level. When used in tandem with quantum hardware, these algorithms have practical industrial applications, such as the optimization of supply chains and travel routes or the prediction of drug efficacy before compounds are synthesized in the lab.

Significance

By creating algorithms that bridge advances in quantum computing hardware and commercial applications, Zapata has the potential to discover new life-saving molecules, energy-efficient materials, and much more.



The Engine Network facilitates the creation of long-term, mutually beneficial relationships between founders, startups, strategic corporates, policy makers, and investors across the capital stack — in short, all the stakeholders necessary to build successful Tough Tech companies.

The Engine Network convenes to build relationships between early-stage ventures and our corporate and government partners. The Tough Tech Summit, held every October, brings together 500 individuals to focus on building and investing in Tough Tech companies. The Tough Tech Business Development Day enables highly curated one-

on-one meetings between startups and corporate partners. Quarterly technology landscape briefings provide insight into exciting emerging fields. Network partners also participate in The Engine's efforts to nurture future founders coming out of prestigious academic labs through The Engine Blueprint Program.

Strategic Members

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Breakthrough
Energy VENTURES

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Gold Members



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for more information



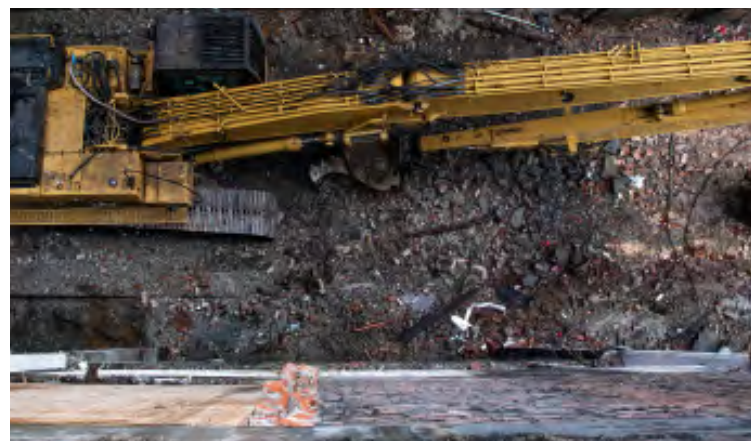
The Engine's new home.

Under construction.

Our 200,000 sq/ft expansion project at 750 Main Street in Cambridge, is well underway. When open, the building will provide 100 companies and 1,000 people access to fabrication space, chemistry and biology labs, office space, and more.

"We have the chance to forge a foundational infrastructure that can potentially change the geography of innovation. A thriving hub can propel the Boston region into the future as a magnet for world-changing Tough Tech companies."

Katie Rae
CEO & Managing Partner
The Engine







All Summer in a Day

It was as if, in the midst of a film concerning an avalanche, a tornado, a hurricane, a volcanic eruption, something had, first, gone wrong with the sound apparatus, thus muffling and finally cutting off all noise, all of the blasts and repercussions and thunders, and then, second, ripped the film from the projector and inserted in its place a beautiful tropical slide which did not move or tremor. The world ground to a standstill. The silence was so immense and unbelievable that you felt your ears had been stuffed or you had lost your hearing altogether. The children put their hands to their ears. They stood apart. The door slid back and the smell of the silent, waiting world came in to them.

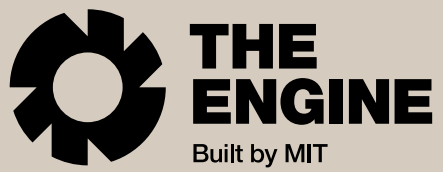
The sun came out.

RAY BRADBURY

1954

Image: Vasjen Katro





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