Deep Tech: The Great Wave of Innovation

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Only four years after BCG and Hello Tomorrow's initial 2017 report, deep tech has evolved into a distinct approach to innovation, with very specific characteristics, driving the next great wave of innovation.

This paper is the first of a series of reports on this topic, whose goal is to provide an overarching reference framework for deep tech. We will explain what it is, how it works, how different stakeholders can contribute to it, and how it can be harnessed for competitive advantage.

In this first report, we will outline the deep tech approach: the "why now" question; and the characteristics that participants must understand in order to partake and thrive in the deep tech ecosystem.

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Executive Summary

Deep tech is being heralded as the 4^{th} wave of innovation. The 1^{st} wave consisted of the first and second industrial revolutions. The 2^{nd} wave was driven mainly by corporate labs like IBM, Xerox Parc, with high-caliber multi-disciplinary teams strongly involved in the scientific community, doing basic research. The 3^{rd} wave saw the decline of corporate research and the emergence of small disruptive firms, backed by venture capital, which later defined a “Silicon Valley” model that focused on IT/digital and biotechnology. Just as each wave grew from the last, the 4^{th} is now gathering momentum. Picture the early 90s, when the Internet was starting to get traction. That’s how we need to think of this 4^{th} wave.

Deep tech ventures are characterized by four main attributes. They are problem-oriented, not technology-driven. They situate themselves, instead, at the convergence of technologies (96% of deep tech ventures use at least two technologies, and 66% use more than one advanced technology). Building on the advancements stemming from the digital revolution, deep tech has shifted innovation away from the digital world ("bits") towards the physical one ("bits and atoms"), developing mainly physical products, rather than software (83% of deep tech ventures are currently building a product with a hardware component). Lastly, deep tech ventures rely on a deeply interconnected ecosystem of actors, without which it cannot thrive.

Deep tech can transform the world as the Internet did. The potential is huge. We need only to look at Tesla and SpaceX to see how start-ups can completely turn industries upside down to grasp deep tech's potential. It can drive fundamental innovation and address crucial issues in an economically sustainable way while unlocking growth.

Fusion, the first supersonic plane after the Tupolev, the synthetic biology revolution, flying taxis, a vaccine for COVID developed in nine months with a novel mRNA approach... What do these innovations all have in common? They are all driven by deep tech ventures, and they're only a small fraction of what start-ups and scale-ups can achieve today.

Investors have begun to recognize this potential. technology risks (which are considered risks of failure), according to our preliminary estimates, we have seen a massive deep tech funding increase during those same years from 2016 to 2020 from $15B to more than $60B. When focusing on start-ups, the latest Hello Tomorrow survey confirmed an increase in amounts per investment event from $360K to $2M between 2016 and 2019. Our preliminary estimates indicate that the disclosed private investments in deep tech by "Smart Investors" increased from $0.9B to $5.2B between 2016 and 2020, growing from 20 to 44 deals. It's now time for business leaders to recognize the opportunity and to understand the rules of the deep tech game.

The deep tech approach is characterized by 3 core elements. First, **problem orientation** is the compass guiding the venture throughout its lifetime. Second, the driving forces of the deep tech are **the convergence of approaches** (science, engineering, and design) and **the convergence of technologies around three different clusters** (Matter & Energy, Computing & Cognition, and Sensing & Motion). Finally, the **Design-Build-Test-Learn (DBTL) cycle** is the engine. It leverages the convergences and lies at the core of the deep tech approach.

Weakened obstacles to innovation are key to the growth of deep tech. These include: the dropping price of equipment; availability of info & data; increasing availability of capital; and thanks to advancements in science, the emergence of platform technologies. Because of the underlying exponentials, the iterative nature of the DBTL cycle, and the convergence of the technologies, the deep tech wave is upon us, driving innovation much faster than people expected, and making the impossible possible.

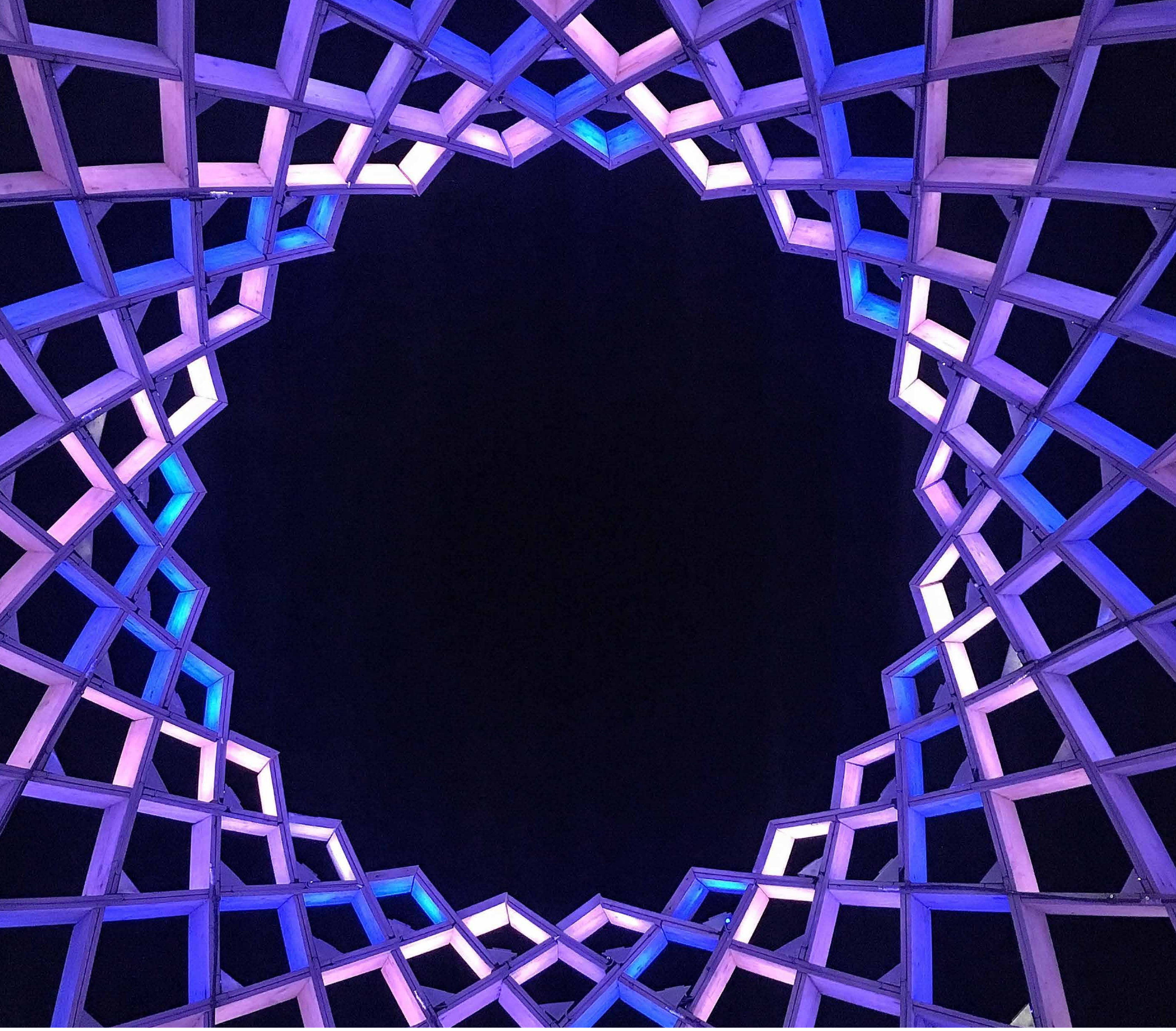
Despite all its potential, there are still multiple challenges to the growth of deep tech. Four challenges stand out, impacting all stakeholders:

- the need for reimagination
- the need for continuing to push science boundaries
- the difficulties in scaling up
- the difficulties in accessing funding.

To be successful, deep tech ventures must embrace the fundamental principles behind the approach: being problem (and not solution) oriented; hypothesis-driven; cross-disciplinary; anticipating frictions throughout and front-loading risk; shortening the engineering cycle; always keeping economics in mind; designing to cost and leveraging the ecosystem. These principles are reflected in 4 moments of truth:

- **The Copernicus Moment** on how to frame the paradigm, i.e., what is the problem, and could reality be different?
- **The Newton Moment** on forging the theory, i.e., how can we make this possible?
- **The Armstrong Moment** on taking the first step, i.e., can we build it today?
- **The Asimov Moment** on shifting reality, i.e., what does it take to become the new normal?

The power of the 4th wave lies in its ability to massively broaden the option space at unprecedented speed and solve fundamental problems. Of all the innovation waves, it promises to be the most transformational. The greatest our world has ever seen. The great wave.



Making the Impossible Possible, Fast

"We wanted flying cars and we got 140 characters"

That is how, in 2011, the iconoclastic investor Peter Thiel provocatively summarized his dissatisfaction with the status of innovation. Fast forward to 2020, and we now have multiple companies, mainly start-ups, working on flying cars. Take Lilium, for instance: a German start-up whose aim is to "make urban air mobility a reality" through fast, affordable, environmentally-friendly, and available on-demand flying taxis. Given their many technological challenges - like batteries, propulsion, and aerodynamics - flying electric air taxis are a far cry from the 140 characters Peter Thiel was referring to.

Flying cars are only one example of the kind of fundamental innovation that start-ups can produce today. Ever since the invention of the tokamak by Andrei Sakharov in 1958, fusion has been told to be 10 years away. Given that this timeline has not changed, people are skeptical about whether fusion will actually happen.

Fusion is already possible today, but it requires more energy than it produces. Reaching an energy net gain through fusion would mean providing the world with a clean and unlimited source of energy. It's no wonder, then, that a consortium of 35 countries came together in 2006, with more than US$ 20B in funding to build the biggest tokamak fusion reactor, called ITER, in France, with the goal of achieving a first positive result by 2035.

There is no better example to demonstrate the innovative power of start-ups than the comparison between ITER and Commonwealth Fusion Systems (CFS), a Boston startup. In fact, CFS, which was founded in 2018 and has raised US$ 215M so far, plans to build the first net-gain fusion reactor by 2025.

It is a striking picture. On the one hand, we have a consortium of 35 countries, with a budget of US$ 20B and a 30-year timeframe to build a gigantic tokamak. On the other hand, we have a startup, with US$ 215M and a 7-year timeframe in which to build a compact tokamak. How is this monumental difference possible?

While ITER is laudable and valuable in more ways than one, it is the result of a more traditional approach to innovation. It focuses on a specific technological challenge whose size and scale require a major effort, with the appropriate resource allocation. This is what the state-of-the-art thinking was in the early 2000s and this is an approach to which many corporations can relate.

But there is another way to approach this kind of fundamental innovation. Instead of starting with the technology, it starts with a problem that needs a solution. It then rallies the best possible technologies and iterates until the right solution is found. This is precisely the approach that CFS embraced.

Instead of focusing on the plasma physics of fusion, CFS focused from the onset on building a net energy gain, compact, high-magnetic field tokamak fusion system as a new source of clean energy; one capable of providing the grid with electricity by confining fusion-grade plasma with strong magnetic fields. In other words, CFS focused on a product (an electricity-producing tokamak fusion system) instead of a technology (fusion). They did so not by investing in the core technology (the plasma dynamics of "fused" hydrogen), but by investing in technologies (high-temperature superconducting magnets) that were crucial to achieving their goal: a net-energy-gain system.

This distinction is crucial, because it allowed CFS to iterate on the magnets using the Design-Build-Test-Learn (DBTL) cycle, which, with each iteration, takes them one step closer to the final goal. Such progress is not possible by focusing on plasma, since it requires much longer testing cycles and is intrinsically more complex to understand and learn from.

If this sounds like the lean start-up approach of Build-Measure-Learn, it is because it was directly inspired by it. From the very beginning, the CFS team built its master plan following the lean start-up approach, which is clearly reflected in their approach to building a fusion plant. They started by getting the plasma physics basics done and are now working on the enabling technology (the magnets). Starting in 2021, they will be working on the "MVP" (Minimum Viable Product in the lean start-up parlance), in this case a compact tokamak, which proves that net gain fusion is possible. The last step, after it proves net gain in 2025, will be to finally begin building the world's first fusion power plant.

CFS is not the only start-up working on making fusion happen. There are many others, including TAE Technologies, General Fusion, and Tokamak Energy. What is striking is that what used to be an area of competition among states (not even corporates), is now a competition among start-ups.

As we will see, problem orientation and the use of the DBTL cycle are crucial to start-ups achieving a different level of impact. But that's not the whole story. This level of potential startup-driven impact is not limited to fusion. Who has the biggest constellation of satellites in orbit? A start-up (Planet Labs). One, called Boom Supersonic, is working on building a supersonic airplane, while others are leading the synthetic biology revolution (e.g. Ginkgo Bioworks and Zymergen), revolutionizing food by developing cultivated meat and plant-based meat and dairy (e.g. Memphis Meat, Impossible Food, PerfectDay), and making steel using electricity (Boston Metal).

A clear message is emerging from today's innovation landscape. Business leaders must start engaging with deep tech and all the fundamental disruption it will bring: a new approach to innovation, built upon the digital revolution, enabled by emerging technologies and driven by start-ups.

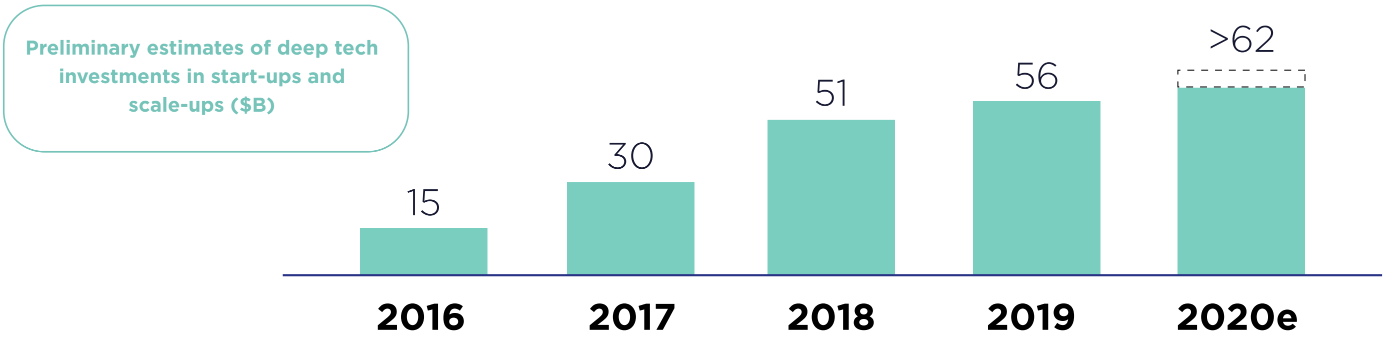
We don't yet know whether, and how, any of the aforementioned start-ups will be successful. But there is no need to look at the future to understand their disruptive potential. One only needs to look at how SpaceX and Tesla, originally two start-ups, have already fundamentally disrupted existing industries, which were previously dominated by incumbents, to realize that the paragraph above is not hyperbole. It's real.

Additional proof of the potential impact of deep tech is represented by the successful COVID vaccine development by Moderna and BioNTech, two biotech scale-ups, that applied the deep tech approach in developing the mRNA technology, which for years had been regarded as simply impossible.

And the growing trust from investors in deep tech confirms that potential. According to our preliminary estimates, investment in deep tech start-ups and scale-ups more than quadrupled from $15B in 2016 to more than $60B in 2020. Similarly, the disclosed private investments in deep tech start-ups and scale-ups involving corporates among investors rose from $5B in 2016 to $18B in 2020 (Exhibit 3), the average amount per private investment event rose from $13M in 2016 to $44M in 2020 (Exhibit 4) and the number of merge and acquisitions of deep tech ventures peaked at 89 transactions in 2019 (Exhibit 6). The amount invested by "Smart Investors" (mutual funds with a proven track record) in deep tech increased from $0.9B in 2016 to $5.2B in 2020 (Exhibit 7). When focusing on start-ups, the latest Hello Tomorrow survey confirmed an increase in amounts per investment event from $360K to $2M between 2016 and 2019 (Exhibit 2).

And funding sources are expanding. While ICT and biopharma companies continue investing substantially in deep tech, more traditional, large enterprises are also increasingly active. Sumitomo Chemical has signed a multi-year partnership with Zymergen to bring new specialty materials to the electronics products market, Bayer has created Bayer Leaps (their corporate VC) to address 10 fundamental challenges, in true deep tech fashion, and invest in companies addressing them. ENI has invested $50M in Commonwealth Fusion Systems and joined its board of directors. Sovereign Wealth Funds entered the movement as well, like Singaporean Temasek Holdings which invested in JUST (plant-based egg), Commonwealth Fusion Systems (fusion) and Memphis Meats (cell-based meat).

Exhibit 1: Deep tech investments grew from $15B in 2016 to more than $60B in 2020

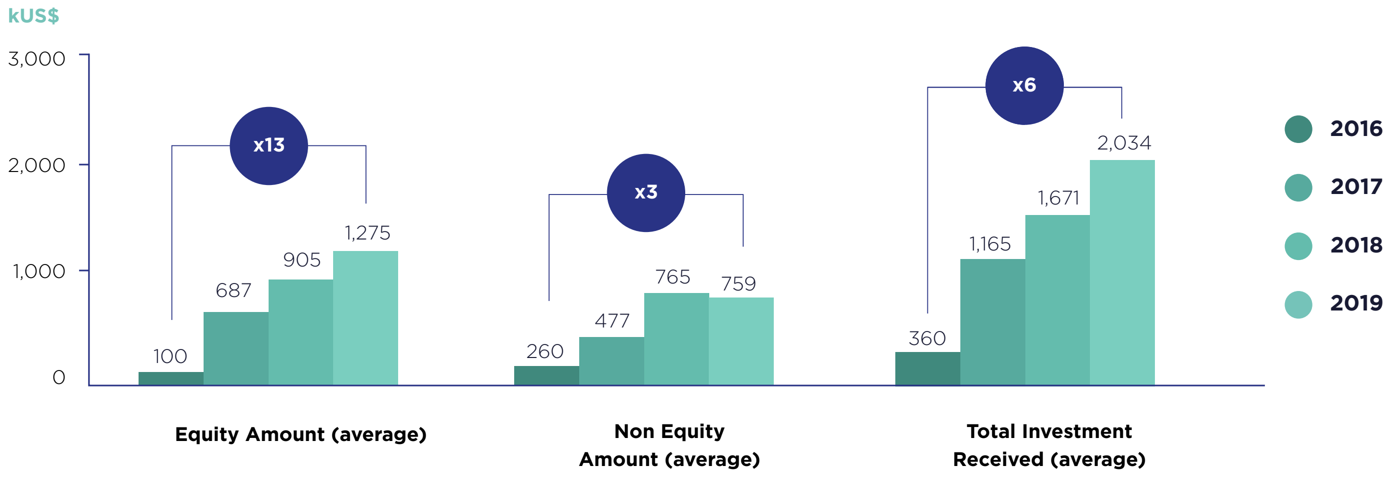


Note: investments include private investments, minority stakes, initial public offerings and M&A; ~25-30% of undisclosed transactions; 2020 figures assumed to be incomplete
Source: Capital IQ; Crunchbase; Quid; BCG Center for Growth and Innovation Analytics; BCG and Hello Tomorrow analysis

Elements of methodology for deep tech investment estimates
'Deep tech' is not yet a standard criteria in transaction data providers. The investment estimates of this report are based on a pre-selection of ventures founded after 2005 and who own patents in specific technology fields (including Artificial Intelligence, Synthetic Biology, Advanced Materials, Photonics and Electronics, Drones and Robotics, Quantum Computing...) or whose key team members (e.g. founders, CEO, CTO, VP of Research...) are patent inventors in these specific technology fields. This pre-selection is manually curated and enriched by BCG and Hello Tomorrow market research and analysis..

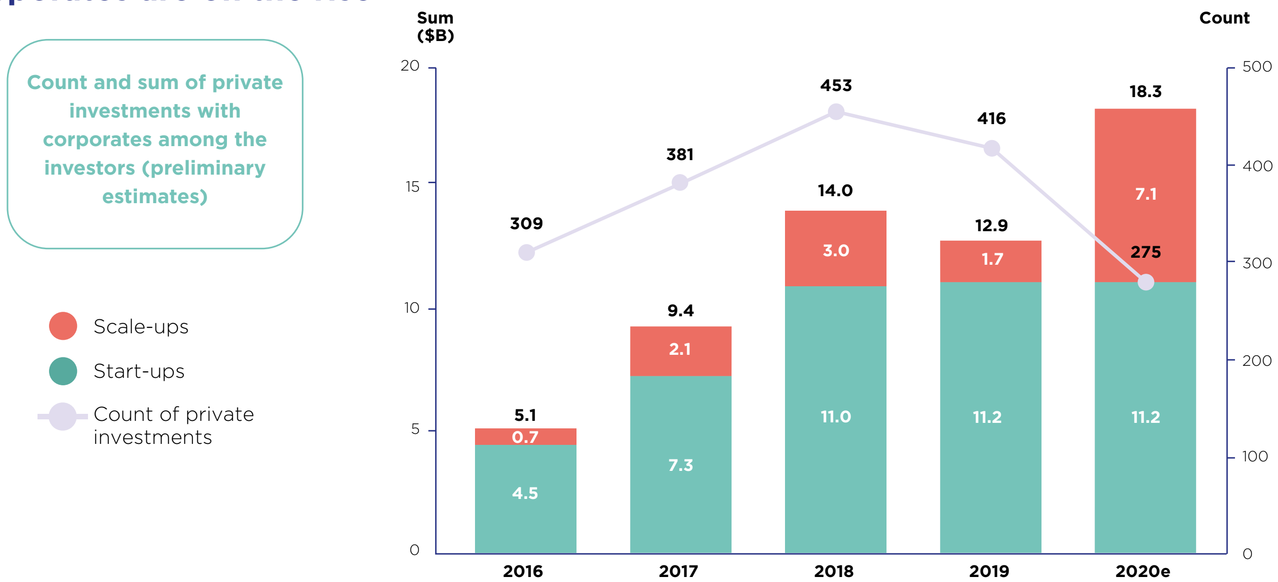
Capital IQ and Crunchbase are the data sources of investment events; their analysis is performed in Quid. The investment events are equity-based: private investments, minority stakes, public offerings and mergers & acquisitions. These events represent the investment period of a venture until it goes public (including Initial Public Offerings and transactions with Specialty Purpose Acquisition Companies). Grants are excluded from the estimates to avoid inconsistencies across data sources. In addition, ~25-30% of private investments amounts remain undisclosed across 2016-2020, and due to the publishing date of the report (January 2021), we assume that not all 2020 transactions have been reported yet in transaction data providers.

Exhibit 2: Average funding in deep tech start-ups is increasing with years



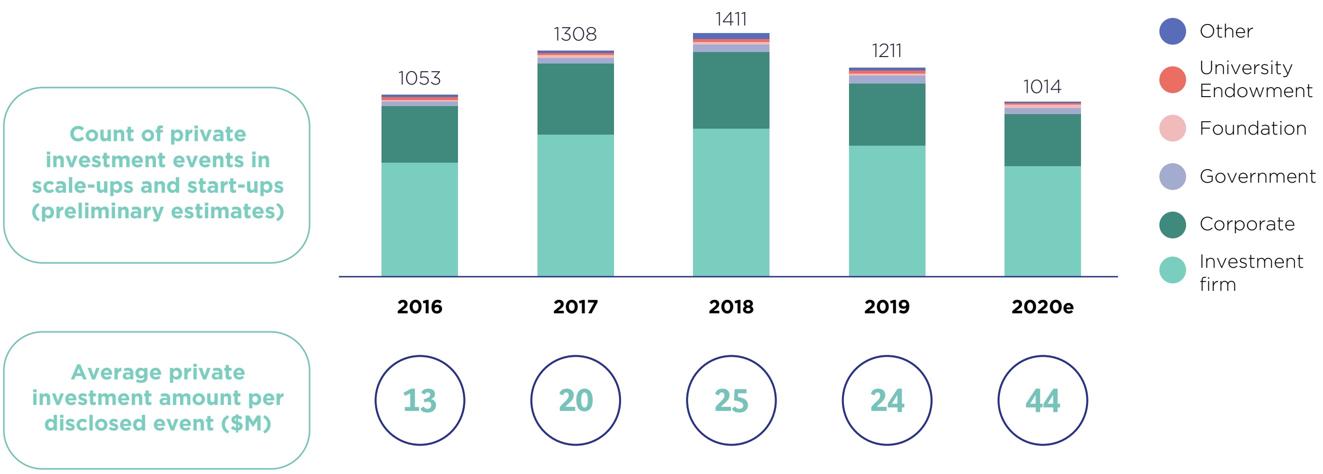
Source: Hello Tomorrow Challenge survey 2016-2019 (total of 2219 respondents)

Exhibit 3: Private investments in deep tech start-ups and scale-ups involving corporates are on the rise



Note: ~25% of private investment amounts in deep tech start-ups and scale-ups remain undisclosed; 2020 figures assumed to be incomplete
Sources: Capital IQ; Crunchbase; Quid; BCG Center for Growth & Innovation Analytics; BCG and Hello Tomorrow Analysis

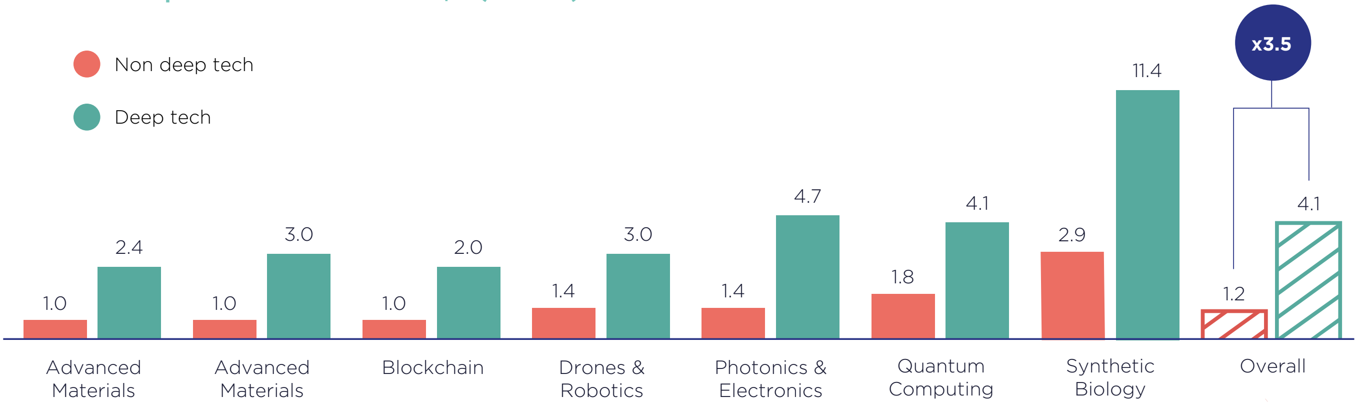
Exhibit 4: Private investments in deep tech start-ups and scale-ups are mostly led by investment firms and corporates, with increasing amounts per event



Note: 25-30% of private investments amounts remain undisclosed; 2020 figures are assumed to be incomplete
Sources: Capital IQ; Crunchbase; Quid; BCG Center for Growth & Innovation Analytics; BCG and Hello Tomorrow analysis.

Exhibit 5: Deep tech start-ups and scale-ups attract more funding per private investment event than others

Median size of private investment event $M (2016-19)

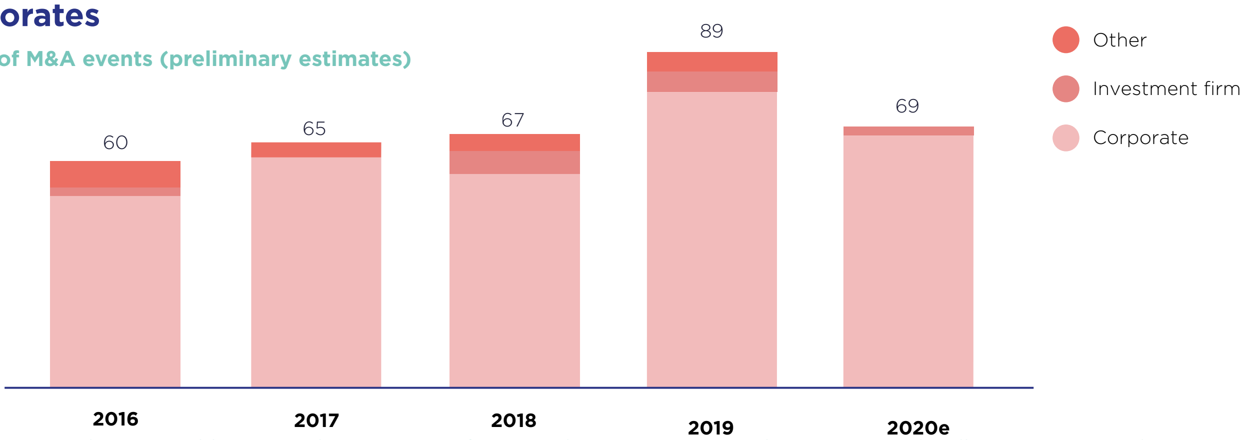


Note : Deep tech companies are here differentiated from non deep tech companies as they have done or are doing the basic/applied research in the relevant field to develop the technology for broader use. For example, companies that are doing research on the underlying Blockchain technology are deep tech versus companies that are simply developing commercial/enterprise solutions based on existing Blockchain protocols/services.

Sources: Capital IQ; Crunchbase; Quid; BCG Center for Growth & Innovation Analytics, BCG and Hello Tomorrow analysis.

Exhibit 6: Increasing acquisitions of deep tech start-ups and scale-ups, mainly by corporates

Count of M&A events (preliminary estimates)

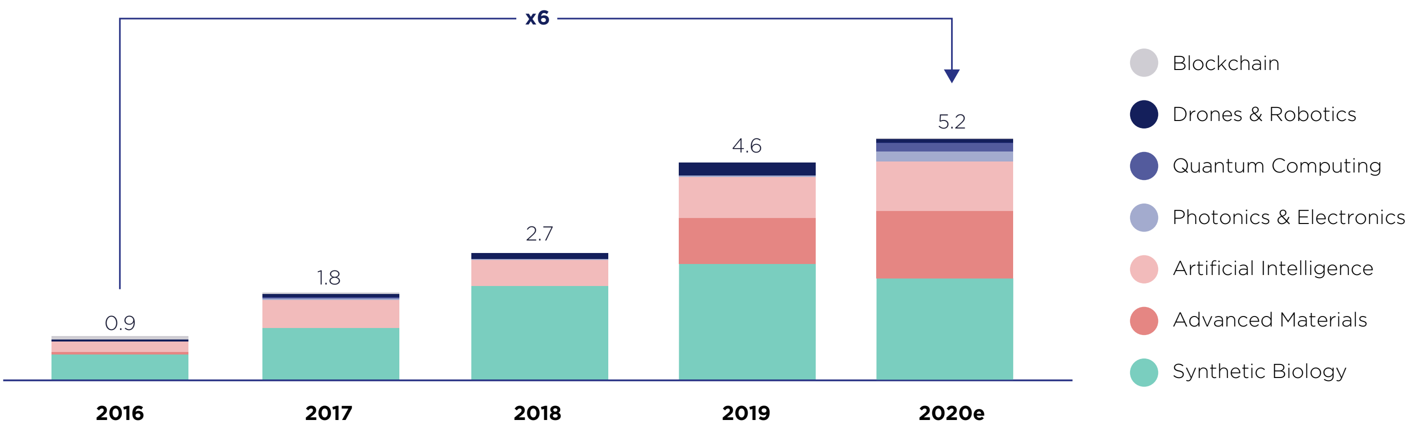


Sources: Capital IQ; Crunchbase; Quid; BCG Center for Growth & Innovation Analytics. BCG and Hello Tomorrow analysis

Exhibit 7: Deep tech investments involving smart investors have almost been multiplied by 6 since 2016

Smart investors are mutual fund companies with a proven performance record

Private investments involving "smart investors" among the investors (preliminary estimates $B)



Note: ~10% of private investment amounts involving "smart investors" in deep tech start-ups and scale-ups remain undisclosed.
Sources: Capital IQ; Crunchbase; Quid; BCG Center for Growth & Innovation Analytics, BCG and Hello Tomorrow analysis

Four dimensions define successful deep tech ventures:

- They are **problem-oriented in the very first place, and not technology-driven**. Very often they work on solving large and fundamental issues: 97% of deep tech ventures contribute to at least one of the UN's sustainable development goals. (Exhibit 8)

- They search **the best existing or emerging technologies while rooting themselves in science and advanced engineering to solve the problem and thus often generating defensible IP** (Exhibit 9). They are not about finding the best use case for their technology. Rather, their technologies have to be the best solution among all possible solutions for the problem they are trying to solve. Therefore, they operate at the convergence of technologies: 96% of deep tech ventures use at least two technologies, and 66% use more than one advanced technology.

- They are shifting the innovation equation **from bits only (digital) to "bits & atoms" (physical)**. They build on the ongoing digital transformation and the power of data and computation to mostly develop mainly physical products, rather than software. 83% of deep tech ventures build a product with a hardware component.

- They are at the center of a deeply interconnected ecosystem[1]**.** It's impossible for two people in a garage to come up with meaningful innovation. Some 1,500 universities and research labs are involved in deep tech, and deep tech ventures received some 1,500 grants from governments in 2018 alone.

Technology itself is not the defining dimension of a deep tech venture. More central is the nature of deep tech as an approach. This means that the technologies used are simply the best solutions to the problem at hand.

Exhibit 8: Deep tech ventures innovation addresses big problems

1. 1277 companies surveyed (in 2018/2019), many start-ups address more than one UN Sustainability Development Goal
Sources: Hello Tomorrow Challenge, BCG & Hello Tomorrow analysis

1. https://www.bcg.com/publications/2019/dawn-deep-tech-ecosystem

There Is No Such Thing as a "Deep Technology"

One question often asked, when talking about deep tech is: which technologies are considered "deep technologies"? For the very same reason that Clayton Christensen moved from "disruptive technology" to "disruptive innovation", the answer is that there is no such thing as a "deep technology"; only a deep tech approach. According to Christensen, few technologies are intrinsically disruptive or sustaining in and of themselves. It's actually the application and the resulting business model that are disruptive. The same applies to deep tech.

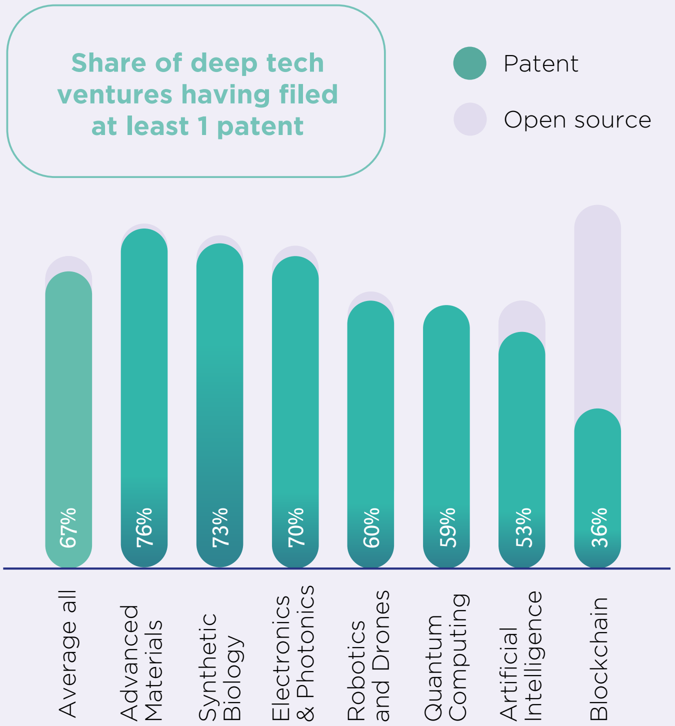
While there is no such thing as a deep technology, deep tech, at its core, relies on recombining existing technologies or on leveraging emerging technologies rooted in science and advanced engineering that offer significant advances over those currently in use. In fact, 70% of deep tech ventures own patents on the technology they use (Exhibit 9). They also usually require significant R&D and engineering to develop practical business or consumer applications while bringing the technologies from the lab to the market and using them as the starting point for deep tech ventures to address fundamental problems.

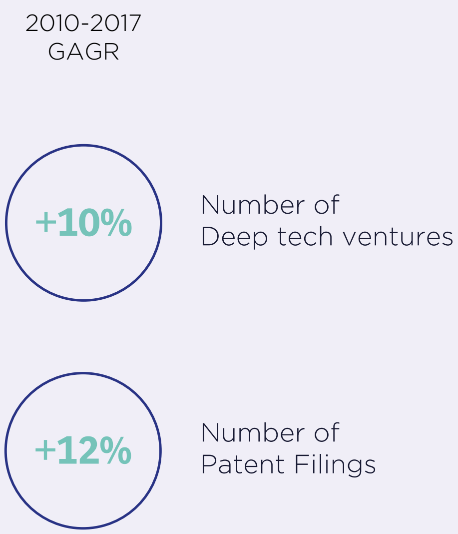
The novelty of the technologies, and the ways in which they are used, are the factors that make the deep tech approach possible. They provide the power to create new markets or disrupt existing industries. The reliance on emerging technologies defines two additional characteristics of the deep tech approach:

- It takes time to transition from basic science to real-life application. The amount of time varies substantially according to each case, but it is almost always longer than an innovation based on available technologies and existing engineering approaches. That said, because of the convergence of technologies progressing exponentially and the lowering of barriers to innovation, as we will see, the amount of time needed is being significantly reduced.

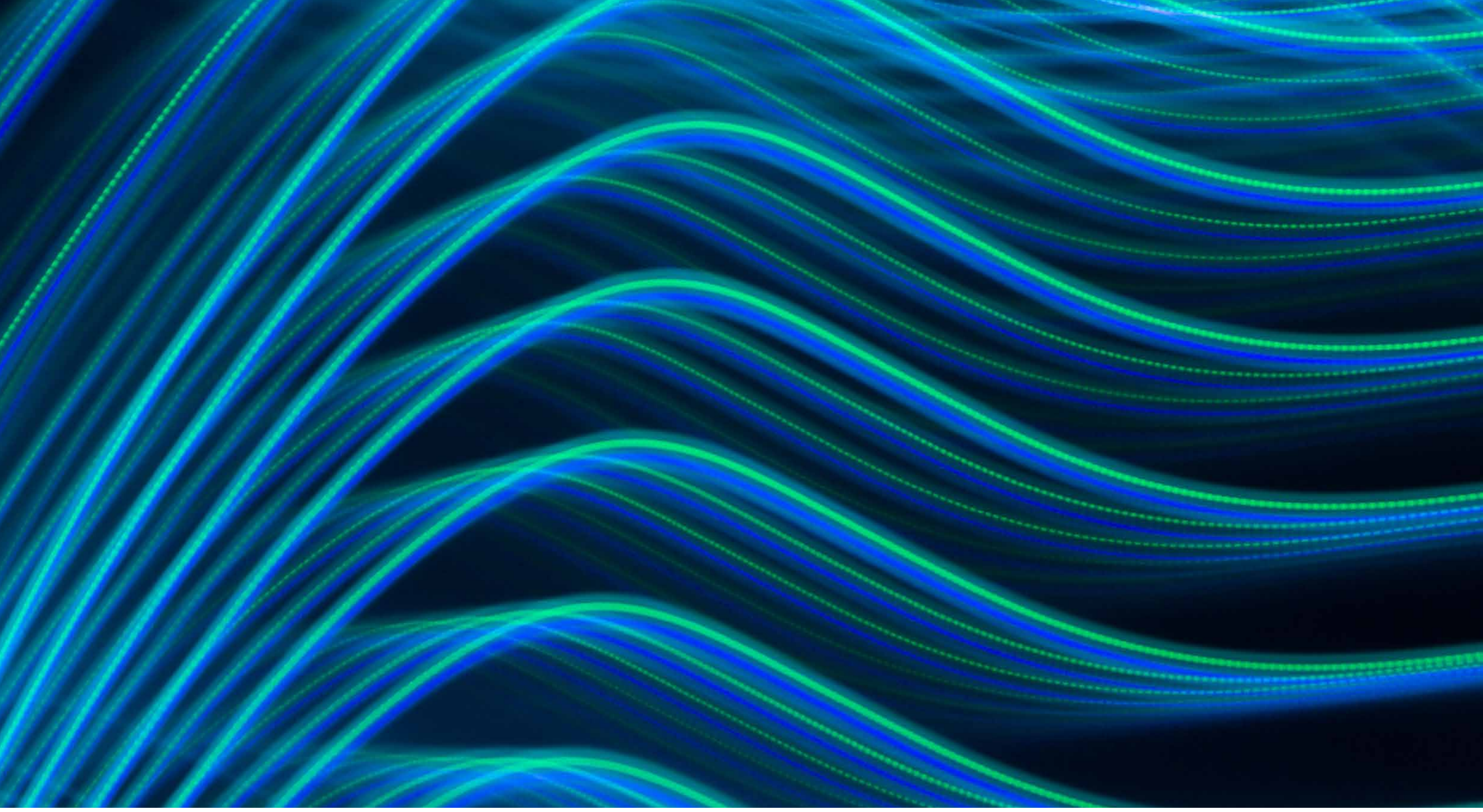
- It requires continuous investment at all stages of development, from ideation to commercialization. There are often intensive capital requirements, complicated by both technology and market risks. These can be de-risked through the DBTL cycle and by remaining problem focused. Both public and private funds & resources are often needed for full development, particularly in the beginning. But similarly to time, also here the convergence of technologies progressing exponentially and the lowering of barriers to innovation are making the deep tech approach more and more accessible investment-wise.

Exhibit 9: Deep tech ventures rely on defensible IP -70% of the start-ups own a patent and they grow at the same pace as patent filings





Source: Capital IQ; Crunchbase; Quid; BCG Center for Growth & Innovation Analytics; Derwent Innovation; LexisNexis PatentSight; BCG and Hello Tomorrow analysis



Deep Tech and the Fourth Wave of Innovation

One could argue that, over the last several decades, start-ups have been a core source of innovation and disruption. So, what is different now with deep tech? Why should business leaders care? And why are investors betting on it? At first glance, there doesn't seem to be anything new about start-ups driving innovation...

To fully understand the potential of deep tech and how it is different from the status quo, one must first examine the evolution of corporate and business innovation. Without any aspiration of a comprehensive academic examination (and with a focus on the US), one can identify three main waves of innovation, each building on the previous one[1].

The first wave of innovation started with the first industrial revolution but really flourished with the second one. This was the wave that laid the foundations of our industrial society, with major advancements in chemistry (e.g. the Haber-Bosch process for Ammonia, the Houdry process for the catalytic cracking of crude oil), in materials (the Bessemer process to produce steel), electricity and communication with phone and radio. This was the time of the great inventors and entrepreneurs that have shaped much of society as we know it, with some of the innovations still used today, like Haber-Bosch and Bessemer.

1. For a more comprehensive analysis see Arora, Ashish and Belenzon, Sharon and Patacconi, Andrea and Suh, Jungkyu, The Changing Structure of American Innovation: Some Cautionary Remarks for Economic Growth (May 2019). NBER Working Paper No. w25893, Available at SSRN: https://ssrn.com/abstract=3398063

Following World War Two, the second wave of modern business innovation gave birth to large company R&D, particularly in the ICT, pharma, and chemical sectors. These corporate labs led to phenomenal achievements:

- The Corporate R&D division of IBM pioneered most of the advances of the mainframe computer era from 1950 to 1980
- Xerox PARC hosted in the 1970s the creation of the first personal computer with a graphical user interface, the laser printer, and Ethernet networking technology
- 14 Bell Labs alumni were awarded the Nobel Prize, 5 were recipients of the Turing Award
- In the 1960s Dupont published more articles in the Journal of the American Chemical Society than MIT & Caltech combined.

While corporate labs were at the center of it, they could leverage an emerging ecosystem, relying on massive federal support for research and universities as partners and source of high caliber scientific personnel. This was the innovation wave that landed us on the moon and gave us the personal computer.

The third wave of innovation, the digital revolution, started in the early 1980s with two guys in a garage (or a Harvard dorm room), paving the way for what became the Silicon Valley, and, later, China's Gold Coast, in the form of massive global centers of computing and communications technology and economic growth. This wave built on the achievements of the second one, but also on the decline of the corporate labs, triggered by the rise of shareholder value, which left little economic room for corporate labs. This was not the only cause. Science had also become less crucial, with innovation coming from new ways of arranging existing technologies rather than inventing new ones, like computing. Most importantly the rise of Venture Capital, fueled by a regulatory change allowing institutional investors to invest in VC funds, and a new tax regime for capital gains, was a fundamental catalyst for the third wave of business innovation.

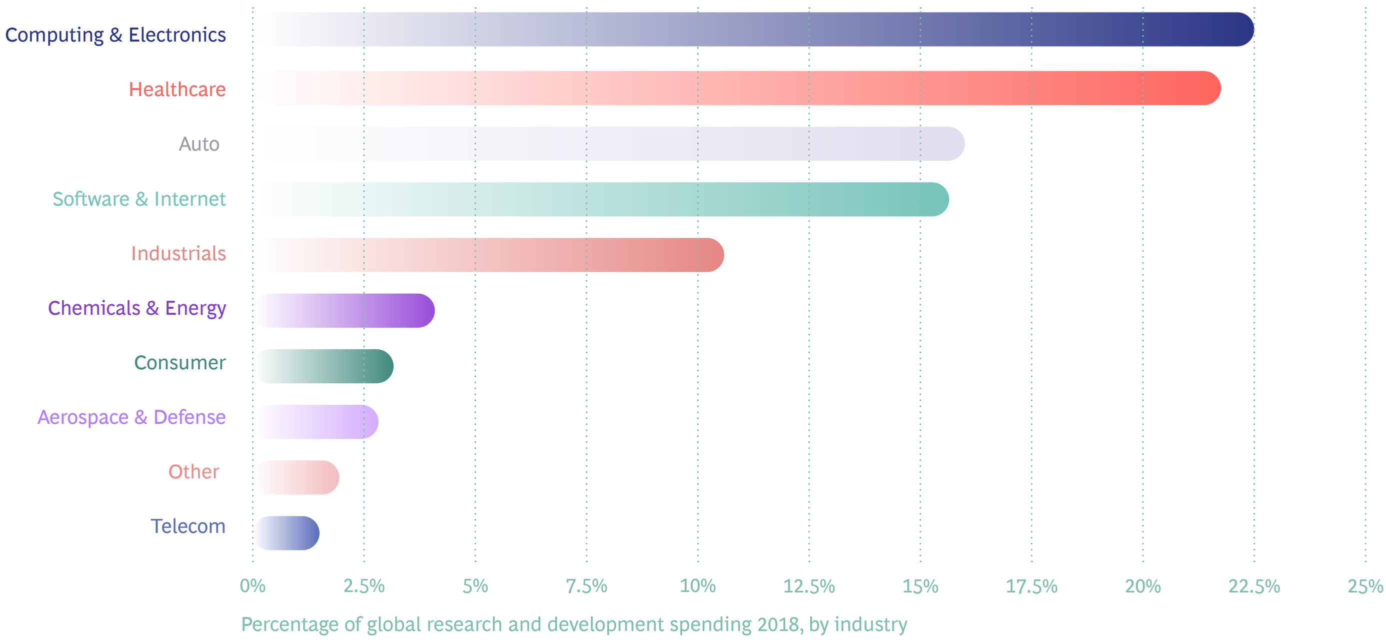
The engine of innovation that used to be the corporate labs had now been replaced by start-ups funded by venture capital. It started with Microsoft, Apple, and Genentech, moved to Amazon, Google, Facebook (but also Alibaba and Tencent), and resulted in today's unicorns. What hadn't changed was that much of the fundamental research that was powering it had been funded by the state, through DARPA for ICT and NIH for biotech. And those two sectors became the main pillars on which the Silicon Valley we know was built, with the ICT and biomedical sectors together consistently accounting for 80 percent of all dollars invested by venture capitalists and providing most of the returns. The third wave has been extremely successful. By the end of 2000, we had a 20% share of venture-backed companies among publicly traded companies and their contribution to the total equity market capitalization equal to one third of it[1].

But some of the limits of it in terms of innovation engine are also starting to surface. Peter Thiel's statement in 2011 about flying cars and 140 characters was an early signal; and now, in 2020, additional signals are surfacing, as testified by articles like "Why venture capital does not build the things we really need...[2]" or "How Venture Capitalists are deforming capitalism[3]" and the study by two Harvard Business School professors titled "Venture Capital's Role in Financing Innovation: What We Know and How Much We Still Need to Learn[4]".

Some of the limits, as is often the case, are also what makes the third wave successful. Over time, the overall ecosystem behind the third wave crystallized around the two industries at the core of it, creating two very standard approaches to ICT and biotech investments, with very well-oiled blueprints to support them. And the two blueprints build on different extremes of risk profiles. On one side, ICT with mostly low technology risk and high market risk (i.e., we can build it, but is there a market for it?), and on the other side, biotech with high technology risk and low market risk i.e., if the drug gets approved, very little market risk is associated with it). Additionally, both industries are the ones with the highest R&D spend (Exhibit 10), making external innovation attractive and a viable option. The problems start when we move outside of these two well-defined blueprints, with frequently-tested mechanisms and approaches as well as established track records. (We'll take a deeper look at the need for a new approach to investing in the forthcoming "The Deep Tech Investing Paradox" report)

1. Paul A. Gompers and Josh Lerner, The Money of Invention: How Venture Capital Creates New Wealth (HBS Press, 2001)
2. https://www.technologyreview.com/2020/06/17/1003318/why-venture-capital-doesnt-build-the-things-we-really-need/
3. https://www.newyorker.com/magazine/2020/11/30/how-venture-capitalists-are-deforming-capitalism
4. https://www.aeaweb.org/articles?id=10.1257/jep.34.3.237

Exhibit 10: Computing & eletronics and Healthcare are the largest industries in terms of R&D spending

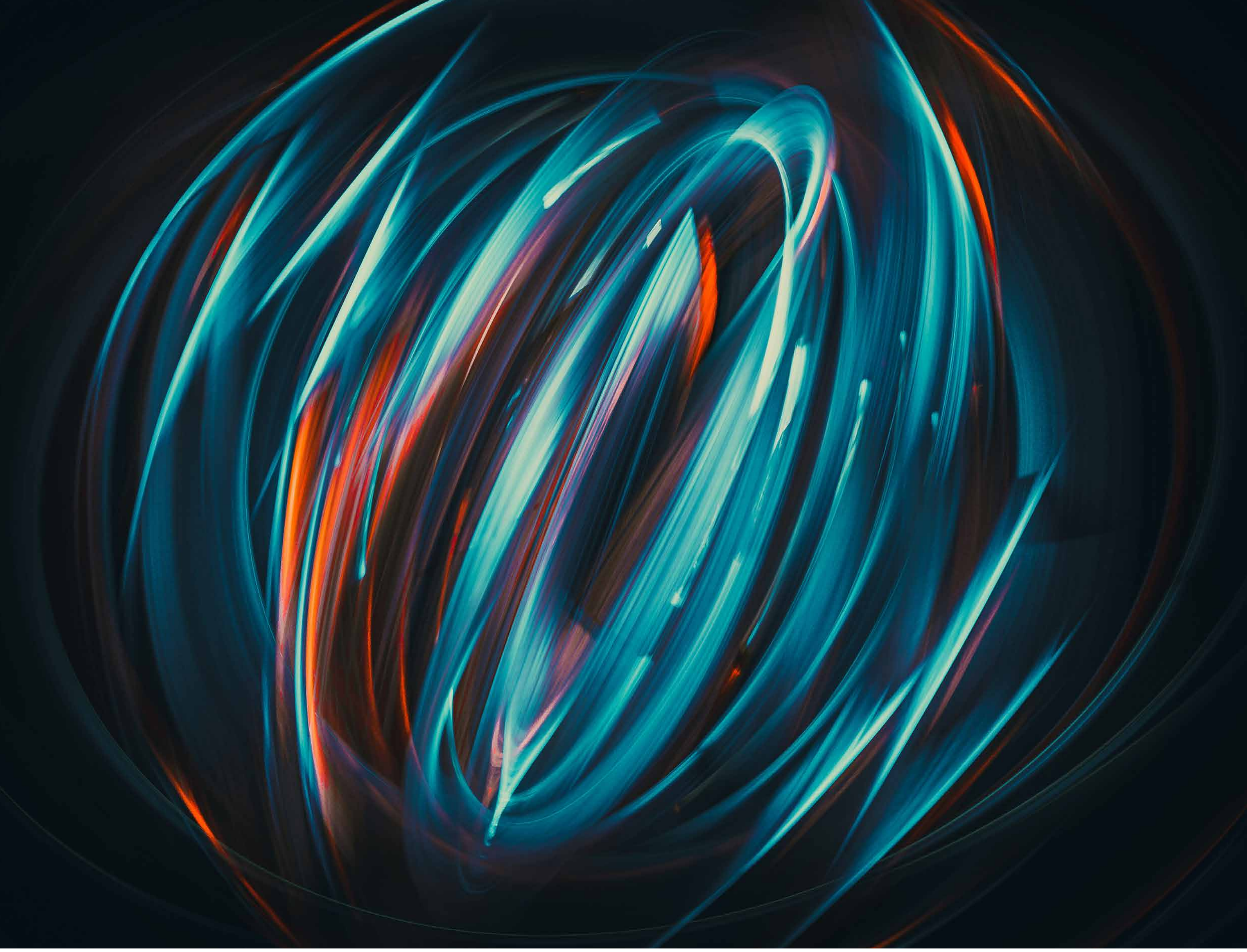


Source: Bloomberg, Capital IQ, Thomson Reuters, Statista

How can this wave deal with risk profiles that are different and/or in between the two extremes? how does it deal with products that are not digital or healthcare related? How does it deal with industries with a very different R&D spend profile? If we look at the climate tech boom and bust around 2010, the answer is: not so well[1].

Similar to what happened with the shift from the second to the third wave of innovation, we now have a new wave that is building on the previous one and is about to fundamentally reshape the approach to innovation. It allows us to deal with risk profiles that are different from the two extremes of ICT and healthcare, enables us to deal with all kinds of products, and can be applied to all industries, regardless of their R&D profile. This is the next great wave of innovation: the deep tech approach.

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



Powering the Wave: The Deep Tech Approach

The deep tech approach allows to address and solve some of the problems that were remaining unsolved or partially solved in the previous waves.

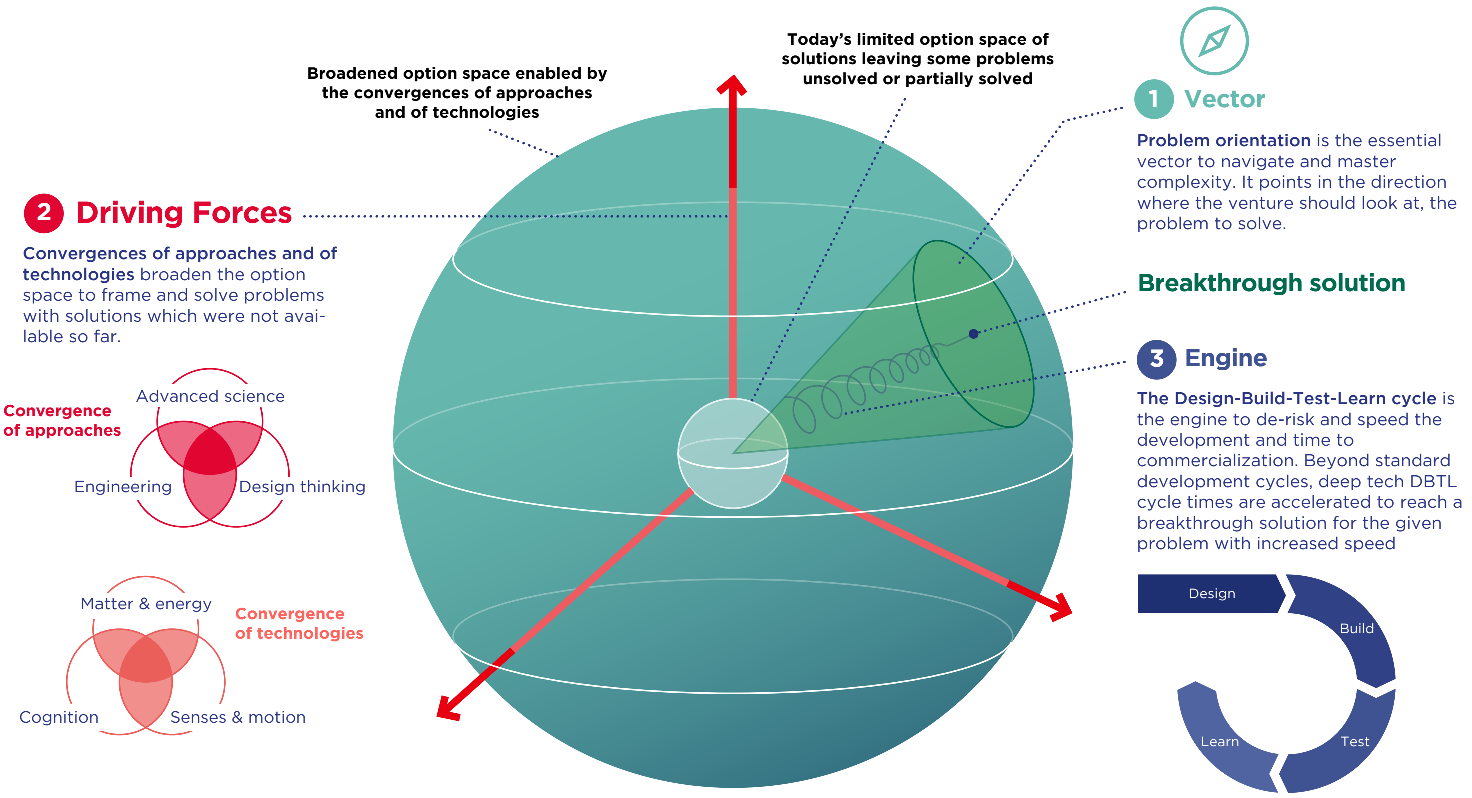
To do so, successful deep tech ventures rely on a three-fold approach (Exhibit 11)

1. **Problem orientation** is the essential **vector** to navigate and master complexity. It points in the direction where the venture should look at, the problem to solve

2. **Convergences of approaches and technologies** are the **driving forces** to power innovation. They broaden the option space to frame and solve problems with solutions which were not available so far

3. The **Design-Build-Test-Learn** cycle is the **engine** to de-risk and speed the development and time to commercialization. Beyond standard development cycles, deep tech DBTL cycle times are accelerated to reach a breakthrough solution for the given problem with increased speed

Exhibit 11: The Deep Tech Approach



Source: BCG and Hello Tomorrow analysis.

Thanks to the two parallel convergences (combined with falling barriers to innovation and multidisciplinary teams), today's ventures can achieve things with the deep tech approach that were considered impossible or limited to the realm of corporates or even states (e.g. CFS).

The first convergence is the one of science, engineering, and design which enables use-inspired, basic research, in small and agile teams. These are often start-up environments, rather than big corporate labs. This convergence also generalizes the DBTL cycle as a core way of driving innovation. This amplifies the innovation potential of the corporate labs we saw in the second wave, combined with the Schumpeterian forces of the third one, and projects it into the 21st century.

The second convergence is that of cognition and computing (e.g. neuro/behavioral science, AI and ML), sensing and motion (e.g. robotics and internet of things) with matter and energy (e.g. synthetic biology and nanotechnology) which brings together bits and atoms. This convergence opens up the option space by including matter and energy in the innovation equation, with computing and robotics, in turn, accelerating the DBTL cycle and making it more powerful.

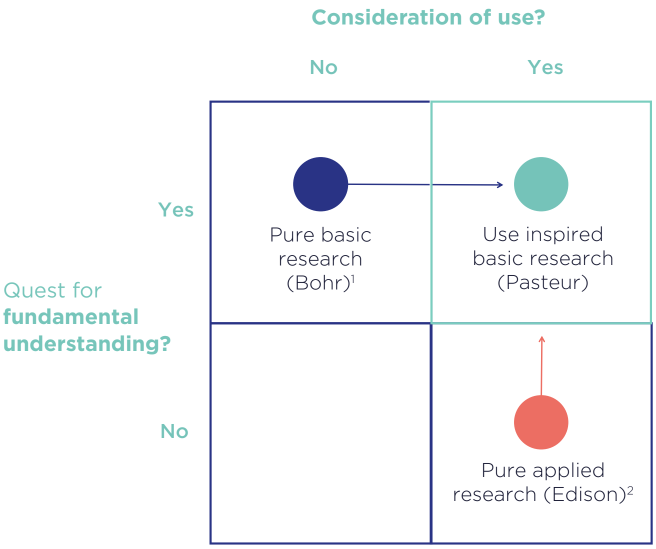
The two convergences bring a whole new dimension to the digital revolution, linking it directly to the first wave (the two first industrial revolutions), now enhanced by the combined power of the second and third waves and massive advancements in science and engineering. As we will see, this results in a fundamentally different approach leading to unprecedented results, like the ones of the ventures mentioned at the beginning of this paper.

Entering the Pasteur's Quadrant

When Donald Stokes introduced the notion of Pasteur's quadrant in 1997[1] (Exhibit 12), he had identified two main dimensions that described different types of basic, applied research:

1. Is the research driven by the quest for fundamental understanding?
2. Is the research driven by the consideration of use?

Exhibit 12: Deep tech ventures enters Pasteur's Quadrant



1. Main motivation is to acquire new knowledge
2. Great interest in utility, much less interest in knowledge for knowlege's sake

Source: Donald E. Strokes in his book, Pasteur's Quadrant.

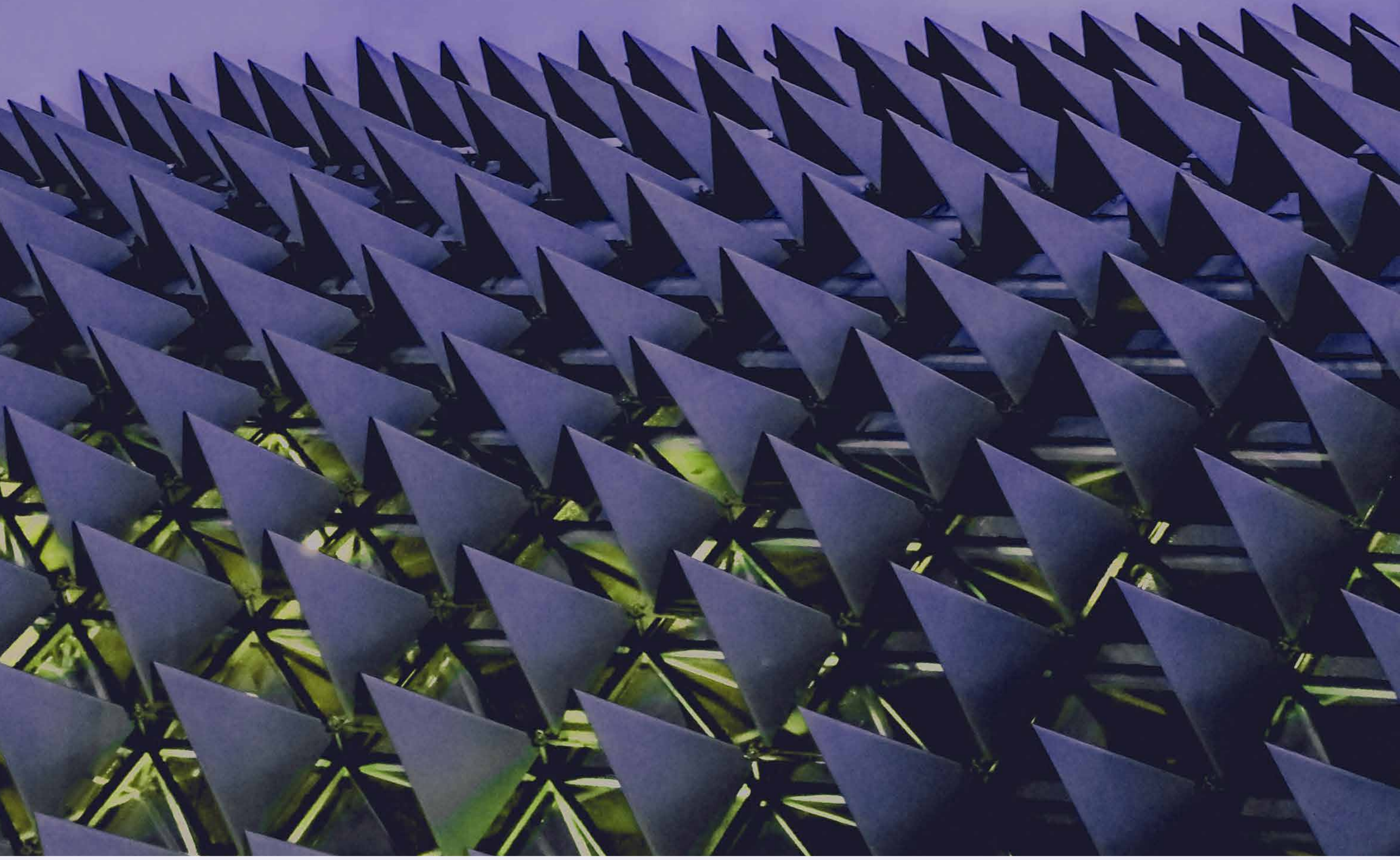
This allowed him to identify three relevant quadrants: the Bohr's, the Edison's, and the Pasteur's quadrants. The Bohr's quadrant is characterized by the quest for fundamental understanding (i.e., the main motivation is to acquire new knowledge, like around quantum mechanics, but does not require applying the knowledge developed). This is the quadrant that, according to Stoke, describes pure basic research.

The Edison's quadrant is characterized, instead, by a great interest in utility, and much less by an interest in knowledge for knowledge's sake. The classical example here is the invention of the light bulb by Edison, with thousands of filaments tested, before identifying the right one. This is the quadrant that describes applied research.

The most interesting quadrant of the three is the Pasteur's quadrant, where the quests for understanding and consideration of use coexist, leading to impactful outcomes. The quadrant is inspired by Louis Pasteur, who managed to advance science (he is considered the father of microbiology) while always having clear consideration of use in mind, as shown with vaccination, microbial fermentation, and pasteurization, all of which were Pasteur's "inventions".

It turns out that Stokes' framework is the right one to also explain the rise of the deep tech approach to innovation. For the first time, in fact, start-ups are now able to move into the Pasteur's quadrant and operate from there. They have a fundamental understanding of the science (e.g. plasma physics, biology) but also the tools to address a very clear use (e.g. electricity-producing plant, replacing animal proteins). It is not about one or the other, it is about both. But there is a very important, third component, which builds a bridge between science (fundamental understanding) and design (clear use). This third component is engineering. The mix of the three capabilities can lead to exceptional results.

1. Stokes, Donald E., *Pasteur's Quadrant – Basic Science and Technological Innovation*, Brookings Institution Press, 1997.

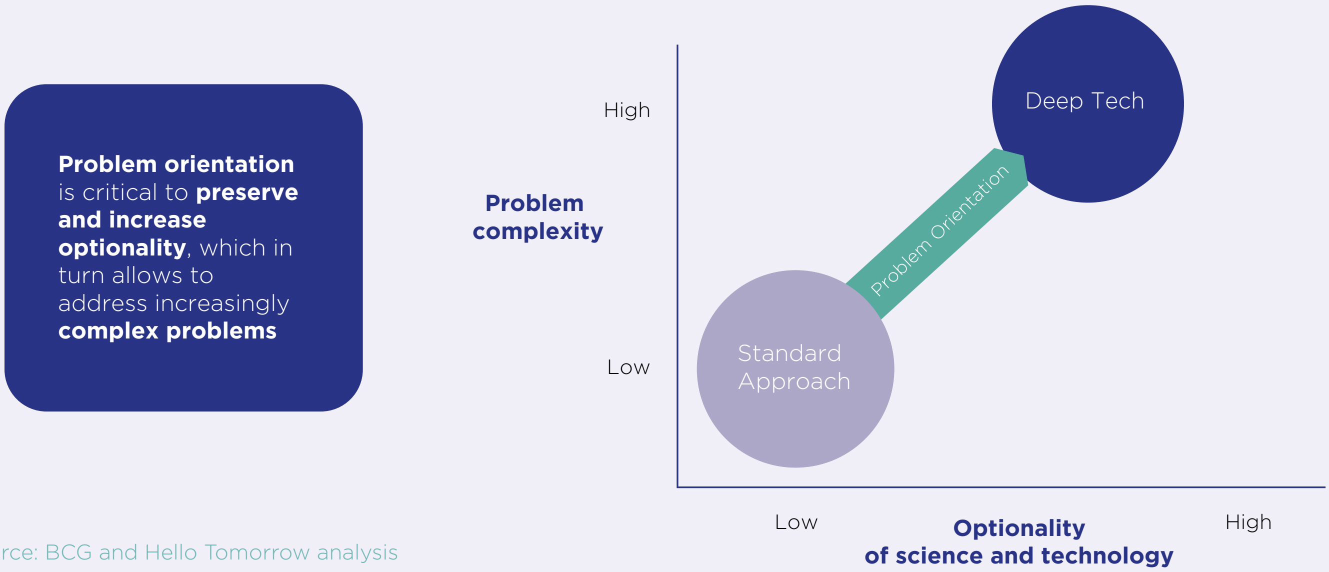


Problem Orientation and The Role of Optionality

As articulated earlier, problem orientation is one of the defining dimensions of deep tech. In the context of Pasteur's quadrant, it becomes clear why it is so important: it generates and preserves optionality, which in turn can lead to the strong impact that characterizes deep tech.

Generating optionality means leveraging the deep understanding of science and technology to address the widest possible set of problems. Preserving optionality, by contrast, means avoiding the restriction of the solution space by focusing, instead, on desired outcomes. The underlying condition for these two elements to thrive is an appropriate problem framing. With this in place, the broad option space it creates will allow for the emergence of solutions to complex problems that would otherwise seem impossible (Exhibit 13).

Exhibit 13: Problem Orientation is a core element of deep tech



Source: BCG and Hello Tomorrow analysis

The ideal definition of the 'deep tech problem' statement is directly inspired by design thinking, more than by a rigorous and detailed scientific problem statement. But it has a specific deep tech twist.

In design thinking, a good problem statement relies on three characteristics: it is human-centered, it is broad enough to allow creative freedom but narrow enough to make that problem manageable.

In the case of deep tech, the last two characteristics are similar. The first, however, the human-centered characteristic, focuses instead on the critical needs and possible impact of meeting them. With deep tech, ventures can go deeper and address problems at a fundamental level. As a result, developing the right problem framing becomes one of the most important steps in a breakthrough solution. For instance, Joyn Bio and Pivot Bio reverted to the original problem of fixing Nitrogen onto plant roots, choosing not to improve the current solution (Haber-Bosch process). Similarly, Moderna and BioNTech focused on a completely different path through mRNA, allowing the body to produce the vaccine itself. By not attempting to make existing vaccines more efficient, they were ultimately much more successful.

The "going deeper" phase, leveraging science and technology to identify possible solutions to critical needs, with the biggest impact, is not only the most important, it's also one of the most difficult. This is true for start-ups, because they are coming at it from the technology angle, from the point of view of the solution, which can make it difficult for them to take a step back and frame the problem correctly. It is also true for corporates, because they very often lose the ability to see the original problem and focus on improving the existing solution.

Going deeper and looking for the highest impact needs to be counterbalanced by the other two characteristics of deep tech problem orientation. On the one hand, going too deep with the science or the technology could limit the option space, which is why it is very important to focus on a problem broad enough to have a real impact. Meanwhile, one must allow new, creative solutions to surface. In order to achieve this balance, it is very important to define the problem in terms of outcomes expected and not in terms of solutions desired.

On the other hand, there is always the risk of a problem being too broad, which can feel daunting for members of the team. For instance, defining the problem that needs to be solved as "Climate Change" is problematic, insofar as it is likely to escape a single person's comprehension and confidence. It is important, therefore, to break the problem down and make it relatable to the venture. The work might ultimately contribute to fighting climate change, but it will need a more specific framing to steer the deep tech venture, like solving the problem of nitrogen fixation while eliminating the greenhouse gas emissions produced through the Haber Bosch process.

By preserving and generating optionality, problem orientation can impact deep tech along three main dimensions:

1. Before looking for a product/market-fit, an important step in the evolution of a startup, deep tech ventures should start by looking for a *problem/*market-fit. This represents a kind of shortcut or a collapsing of the two conventional steps of finding the problem/solution-fit and then the product/market-fit. Instead, deep tech ventures are better advised to start with their problem orientation (including the critical needs) and then measure it against the possible markets. This holds true only under the assumption that because of their deep science and technology understanding they can provide a better solution.
2. Thanks to the optionality and the problem orientation, once they have their problem/market-fit, deep tech ventures can often define their strategy based on value (i.e., go after the most valuable offering so as to generate the highest return, to drive scale or the fastest revenue growth to support the overall venture.)
3. The right problem orientation should also serve as a "technical" purpose for the venture, driving its operations and organization and not just the market strategy. It helps the venture to remain purpose-driven and outcome-oriented, and develop the right operating system – for instance, by leveraging OKRs and providing the north star that is needed for agile and nimble cooperation. This might be redundant in the early days, but it can become crucial when scaling up. Additionally, purpose through problem orientation ensures talent retention, global momentum, and a coherent dialogue between multidisciplinary teams.

Interestingly, for many deep tech ventures, problem orientation is not the starting point, but a necessary mindset in order to succeed. It is very common for deep tech ventures to have a solution-focused starting point, because they often come from universities, where a breakthrough on the technology front is typically one that enables new applications. In this context, these scientists turned entrepreneurs then try to find a problem to solve, to make that application relevant to real life. But to be successful, it is of paramount importance that each venture manages to evolve and shift its focus from a specific technical solution to the underlying problem, and then invest time and energy to define the problem they want to address. This shift is what makes the difference between a successful, and unsuccessful, deep tech venture.

The Convergence of Approaches

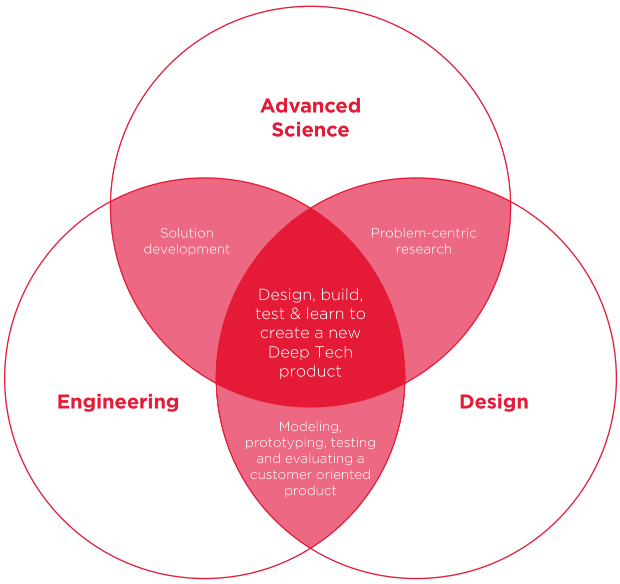
The convergence of approaches is one of the key enablers to moving to Pasteur's quadrant, and a prerequisite to making deep tech happen. Business leaders, along with start-up founders and investors, must realize that only when the three dimensions are simultaneously present and thriving, can true breakthrough success be achieved and scaled: advanced science, engineering and design. Solutions that seemed impossible suddenly become possible.

It all starts with design, or a more prosaic problem orientation, which allows for interdisciplinary co-creation through context analysis, problem finding and framing, and ideation. It progresses into advanced science, which, through a deep understanding of matter and energy, computation and cognition, sensing and motion, provides the theory to come up with the solution. Then, there is the engineering phase, which guarantees technical and economic feasibility. It is important to note that what sounds like a linear process is in reality something that needs to happen in parallel. Therein lies the difficulty of the deep tech approach. You need to have science and engineering on the table from the very beginning, and at a level of depth and competence that can make the solution a reality.

A good example of this convergence of approaches can be found in Cellino Biotech, a start-up that combines a clear problem orientation (making regenerative medicine possible) with science (stem cell science) and engineering (the way to approach the process to turn adult cells into stem cells).

From its very inception, every deep tech venture should ask itself four fundamental questions: What is the friction or problem that we are addressing? How can we use science and technology to solve this problem in a better way that has not been used before? And can we deliver this, outside of a lab? At the right price point? While most deep tech innovators would agree on these points, putting the three approaches in place at the same time, asking the questions from the very beginning, and addressing them in parallel, is much easier said than done, and less common than one might think. (Exhibit 15).

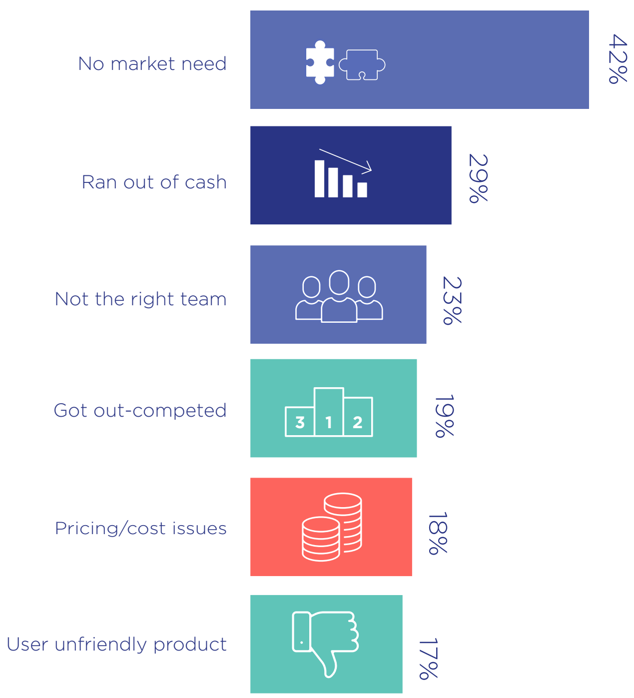
Exhibit 14: Deep tech ventures live at the convergence of three approaches



Source: BCG and Hello Tomorrow analysis

Exhibit 15: Absence in market need is the first reason why start-ups fail

Key reasons why start-ups fail



Source: CB insights, 2019

The answers to these questions and their quality will vary significantly depending on the stakeholders involved. Start-ups will usually be in a very good position to answer the science question (most of them being university spinoffs). Some of them (usually the successful ones) might come to it with a problem orientation, but will often lack the engineering capabilities, which can then be acquired in the market, by hiring executives from established companies. A very common mistake made by start-ups is to start with a technology and then go in search of a solution, instead of starting with the problem. As one deep tech founder put it, "A technology is not a product, a product is a product". Given how difficult it is to have a single person capable of answering all four questions, it is important that founding teams are well assorted from the get-go and well aware of the needs.

Investors will usually engage with these questions from the opposite starting point. They might have a clear problem or friction point that needs to be addressed (usually with a market size attached to it), some understanding of the science or technology, but usually little engineering know-how to evaluate the feasibility. This lack of understanding of the science and engineering aspects is very often one of the biggest reasons why investors are reluctant to invest in deep tech. That said, some very successful VCs like Flagship Pioneering manage to master all three dimensions, adopt a problem angle, have the science and engineering know-how (or the necessary access to it) to come up with the right solutions.

Corporates are in the toughest position of the three stakeholders. They usually have the engineering capabilities needed but are lacking the necessary problem orientation. They tend towards improving existing solutions, often due to incumbent bias, while lacking the science and technology knowledge to be able to operate at the convergence of the three approaches (which is necessary for "10x better" innovation, vs. 10% improvements). Business leaders who want to harness the potential of the deep tech approach should be very clear about the problem or friction point they are trying to solve, ensuring that the right scientific and technological knowledge level is available, while also embedding a process that allows for cross-disciplinary co-creation and ideation. Deep tech is not about bringing in-house the last shiny technology. It is about enabling the convergence of approaches.

An interesting example that brings together the startup, investor and corporate views can be found in Ginkgo Bioworks. They initially engage with deep tech from the science side (organism design), but they identify the problems where they see the biggest potential and then build companies around them, in partnership with other investors or corporate partners, to overcome engineering and operational hurdles. To do so, they utilize an investment fund they have created for this purpose, together with other investors. That way, they signed a joint venture with Bayer for microbial fertilizers (Joyn Bio), created a new company for food ingredients (Motif), and partnered with Battelle and other strategic investors for bioremediation (Allonnia).

The Convergence of Technologies

Beyond the convergence of approaches, the other key enabler of deep tech is the convergence of technologies. Much has already been said about how computation and cognition are shaping, or even "eating"[1] the world, and how in combination with sensing and motion they are leading to great advancements[2], such as self-driving vehicles, internet of things, robotics, and much more. Many start-ups started working on issues enabled by such a convergence during the third wave of innovation, with a lot of emphasis on automation and better sensing.

Now, with the advancements in gene sequencing, editing, and writing as well as on the nanotechnology front, a whole different option space for innovation is emerging. What used to be considered mostly a given or a constant, like living and non-living matter, has become an accessible innovation variable, as we identify the right tools for designing and producing at the nanoscale, leveraging nature (for more on this see the Nature Co-Design report: A Revolution in the Making[3]). This has very deep implications on innovation and profoundly characterizes the deep tech approach and the fourth wave – to the extent that the same actor claiming that software eats the world is now claiming that "Bio eats the world[4]". The impact of adding this dimension is well explained in Exhibit 16.

Before adding matter and energy to the innovation equation, we only had one overlap in the Venn diagram (between "Computation and Cognition" as well as "Sensing and Motion") enabling internet of things (IoT), robotics and self-driving vehicles. This kind of overlap is where massive innovation can happen: by combining technologies, entirely new problem sets become addressable. By adding "Matter and Energy", we now have two additional simple overlaps, spilling into a greater one in which all three dimensions converge, enabling a whole new different approach to innovation: deep tech.

1. https://a16z.com/2011/08/20/why-software-is-eating-the-world/
2. https://www.bcg.com/de-de/publications/2020/value-in-iot-platform-based-business-models
3. https://hello-tomorrow.org/bcg-nature-co-design-a-revolution-in-the-making/
4. https://a16z.com/2019/10/28/biology-eating-world-a16z-manifesto/

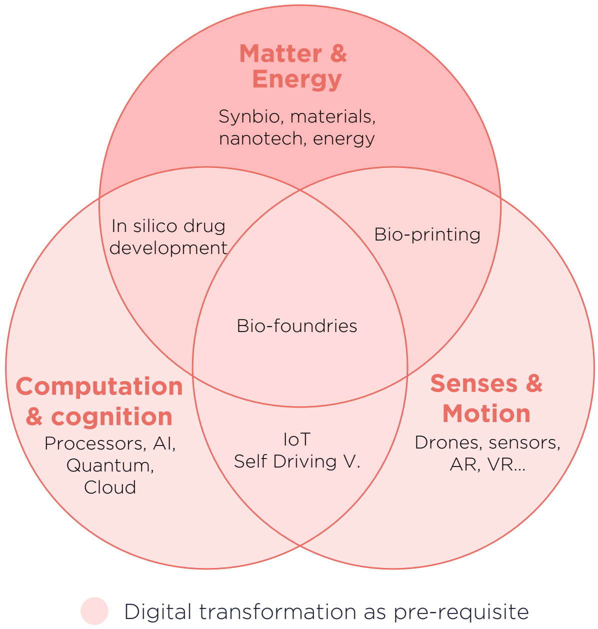
Exhibit 16: Convergence of technologies widens the option space

Powerful technologies are emerging faster...

- Artificial Intelligence
- Quantum computing
- Synthetic biology
- Nanotechnology
- NextGen UX (Augmented/Virtual Reality)
- Blockchain
- Robotics
- Universal Printing

...And they converge to solve biggest business issues

- Process automation for materials
- New chemical development via AI or Quantum Computing
- Neuron-machine interface



Exponentials are brought together

- Data volume
- Moore's law
- DNA sequencing cost (in progress)
- DNA synthesis cost (in progress)
- Quantum (in progress)

Source: BCG and Hello Tomorrow analysis

By looking at biology alone, we can realize the potential of these intersections. In-silico drug development, by predicting the folding of proteins leveraging AI, and bioprinting, are set to revolutionize drug discovery and medicine. Meanwhile, at the intersection of the three dimensions, bio-foundries shows that this is where the most exciting developments are taking place. Bio-foundries are integrated facilities that can design genetic constructs by leveraging AI, building and testing them through robotic process automation, which leads to incredible advancements in the "programming" of organisms, as shown by the success of start-ups like Ginkgo Bioworks. Similarly, Zymergen uses biofabrication techniques that use advanced AI, automation and biological engineering to create novel, never-before-seen materials.

Another stunning example is again Cellino Biotech, which is working on scaling up the transformation of adult cells in stem cells by bringing together stem cell biology, laser physics, and machine learning.

But it is not only about biology. A good example of the power of adding Matter & Energy to the innovation equation can be found in Commonwealth Fusion System. One of the fundamental breakthroughs they achieved was thanks to the discovery of a new material, a high-temperature superconductor, which allows them to build significantly stronger magnets that double the magnetic field, resulting in a smaller net gain fusion device.

The power of converging technologies extends beyond an ability to address previously unsolvable problems. Most of the technologies are powered by underlying exponentials. Their convergence leads to a dramatic acceleration of what can be achieved.

The consequences of such convergence vary, between start-ups and established players. Successful deep tech start-ups use their problem orientation to identify and convene different emerging technologies, at an exponential pace. It is in their DNA and raison d'être to look for the best possible solutions that can harness all available and nascent technologies. While start-ups are born from the convergence of technologies, established players very often miss this important dynamic. One only needs to look at the difficulty these established players faced when they attempted to embrace the digital world - not to mention, later on, the convergence of computing, cognition, sensing and motion - to understand the challenges awaiting them in the additional convergences of matter and energy.

The one area that saves established players is also the glue that binds the convergence of approaches: engineering. Dealing with bits and atoms at the convergence of technologies requires strong engineering capabilities (and a strong infrastructure, too, in many cases). Scaling the solutions also requires engineering, and years of experience. And engineering is probably one of the core assets that corporations dispose of when dealing with deep tech, but they should in fact ensure that they leverage it properly.

T-Shaped and Multidisciplinary: What It Takes to Converge

It is very important, for all actors involved in deep tech, to reflect on the consequences of the aforementioned convergences from a human resources dimension. They must also act upon them if they want to reap the full rewards of the deep tech approach.

Regardless of the role (founder, investor, or corporate leader), all individual participants need to be able, simultaneously, to feel at ease with multiple topics or areas of expertise while fully mastering a specific area. This so-called "t-shape" profile is particularly important for people coming from a strong scientific background, with deep specialization. To be able to come up with real breakthroughs, at the intersection of different technologies and approaches, people need to speak a common language and understand other people's issues and arguments. This is something that only a t-shaped profile can enable.

What is true at the individual level also applies at the team level, where multidisciplinarity is a "must". Having the right mix of people is essential, because it is extremely rare for someone to be able to master all the relevant aspects. While this might tend to happen more naturally for start-ups, it is going to be very important for corporates to ensure that people with different backgrounds engage with the deep tech endeavor at hand; because too narrow a view might preclude access to the power of convergences.

Falling Barriers to Innovation

Whether convergence of technologies or that of approaches, the core enabler is the same: the falling barriers to innovation. The trends outlined in The Dawn of The Deep Tech Ecosystem[5] report hold true and, since the report was published, have been amplified by the underlying exponentials, further and significantly lowering the barriers.

The emergence of computing and technology platforms continue to be the most important contributor to lowering the barriers to innovation. Cloud computing is steadily increasing its performance and spectrum of application, while bio-foundries are in the process of becoming for synthetic biology what cloud computing is for computation. Similar platforms are starting to arise for advanced materials as well (e.g. IBM RoboRNX, Kebotix, VSParticles)

5. https://media-publications.bcg.com/BCG-The-Dawn-of-the-Deep-Tech-Ecosystem-Mar-2019.pdf

The cost of doing business continues to decrease: like the falling price of equipment (e.g. liquid handling in wet labs); the cost of important technologies (e.g. DNA sequencing and synthesis); and access to infrastructure becoming easier and cheaper (e.g. The Engine or LabCentral).

The increased use of standards, toolkits and an open innovation approach, paired with the ever-growing availability of info and data, is also playing an important role in lowering the barriers to innovation.

And while still not being enough to support the full potential of deep tech, the increased availability of capital is also helping to facilitate innovation.

The lowering of barriers to innovation reinforces the importance of problem orientation, since an increased access to innovation must be channeled in the right way, to address the right issues. But lowering the barriers also underscores the importance of defensible IP, through patents – something that should be high on the strategy of deep tech ventures.

The Heart of The Deep Tech's Engine: The Design-Build-Test-Learn Cycle

If the convergences of approaches and of technologies are the driving forces of the deep tech approach, the engineering cycle of design-build-test-learn (DBTL) is its engine and, simultaneously, its catalyst. Both convergences are powered by it. DBTL is the bridge between the problem being addressed, the science, and the technologies being put in place for the convergence of approaches. In fact, one more reason for the importance of problem orientation is that it also represents a fundamental prerequisite for the DBTL to successfully operate. Every iteration in the DBTL is measured in terms of contribution to the problem at hand. Iterating without a problem being solved quickly becomes a futile exercise.

It is with the convergence of technologies, though, that the true power of the DBTL cycle comes to life within the deep tech approach. The impact of different, but converging, technologies doubles within the cycle. The first impact dimension is represented by the best possible technologies, brought together to address the problem at hand. The second, and equally powerful, dimension, is the layering of different technologies along the DBTL cycle itself, with each of the steps relying on different technologies, which in turn reinforce each other at every iteration of the cycle.

Design. In the design stage, which is the core of the innovation process where much of the value is created, faster access to information, alongside cheaper and more powerful computing equipment, accelerates a hypothesis-driven process. A massive increase in the availability of information in the last 10 years, combined with more open-source and faster access, has fostered collaboration. Open innovation reigns in new several new technologies, including synthetic biology, advanced materials and AI.

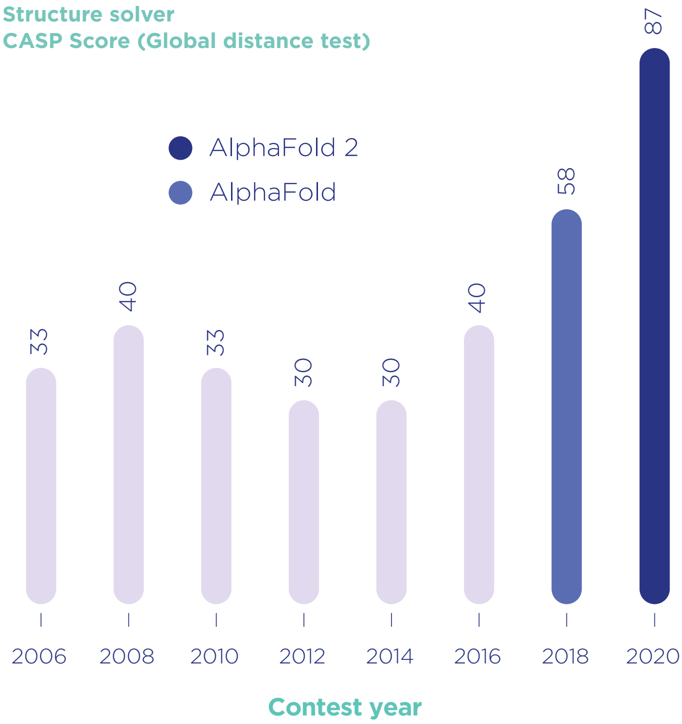
Faster, more affordable, and more specialized computing equipment, both in-house and in the cloud, makes it much easier to design models in such R&D fields as new materials, molecules, images and sounds, and architecture. This has boosted the use of generative computing (including the use of generative adversarial networks), which broadens the design approach beyond simple discovery. Prototypes can be scanned and equipped with sensors that provide real-time performance data, which is looped back into the design process, allowing the object to codesign itself. As these advanced technologies become more accessible, they will allow more non-experts to partake in the design phase, even if they do not have extensive scientific backgrounds. A good example of this is what happened with the design of an airplane partition panel by Airbus. Thanks to generative design techniques, using software from Autodesk, advancement in material science, and 3D printers, Airbus managed to create an airplane partition panel 2x lighter to reduce fuel consumption and generate less CO^2 emissions.
Similarly, augmented and virtual reality tools like Nanome make it possible to design a product virtually, rather than having to physically build it. One benefit of virtual reality is to lower the number of physical prototypes needed and increase the precision of each iteration, simultaneously reducing building costs and improving product design.

In the future, quantum computers are expected to provide massive new calculation capabilities. Quantum machines can process huge amounts of information and execute some algorithms exponentially faster, opening new possibilities for what can be achieved computationally. They are expected to have a major impact in fields like biopharma[6], chemicals, materials design, and fluid dynamics. We don't yet know when quantum computers will be available. It could be within decades, or probably sooner, given the latest developments. Regardless, the power of quantum is already here, in the form of quantum-inspired algorithms. The French start-up Aqemia claims to be able to identify the right binding molecule for drug development 10.000 times faster, using a quantum-inspired algorithm.

Similarly, the London-based start-up Rahko is building a robust quantum chemistry platform that provides best-in-class toolboxes for running quantum and quantum-inspired methods, and therefore faster and more accurately simulate materials for the discovery and development of new molecules at a greatly reduced cost.

While we wait for quantum to reach maturity, one recent example epitomizes the power and the potential of AI in the design phase: the success of AlphaFold 2 by DeepMind at the CASP14 competition. CASP is the biannual Critical Assessment of Protein Structure Prediction competition, aimed at predicting the folding of proteins with the highest possible precision. After years of stagnation in performance, DeepMind was able to more than double the average performance of the prediction since entering the competition in 2018, reaching an astonishing 92.4/100 for average molecules and 87.0/100 for more complex ones ones (Exhibit 17).

Exhibit 17: AlphaFold 2 Shows The Potential Power of Design in the Cycle



A score above 90 is considered roughly equivalent to the experimentally determined structure

Source: Nature, Deepmind

6 https://www.bcg.com/publications/2019/quantum-computing-transform-biopharma-research-development

Without entering into the meaning of such an advancement for drug development and synthetic biology, which is massive, such a powerful and fast development of the design capabilities was impressive in itself and shows what we can expect in terms of design power in the future.

Build and Test. The build and test stage can achieve huge economies of scale, high speed and throughput, and much improved precision, thanks to the rise of platforms and robotic process automation, and falling costs.

Large communities of users harness and contribute to emerging platforms in multiple deep tech fields. This enables even small start-ups to achieve scale and access capabilities that would be too costly, time-consuming, or technologically challenging to develop in-house. Cloud computing platforms, synthetic biology materials platforms, and shared spaces can all be used to build and test designs. Robotic process automation transfers the testing process from human to bots and automates it. Testing runs 24-7, produces fewer errors, and can multitask, allowing for big increases in the number of tests, leading to better-performing solutions, faster.

For instance, enEvolv (acquired by Zymergen in 2020) creates chemicals, enzymes, and small molecules based on an automated process that builds and tests billions of unique designs from many modifications of one DNA molecule.

Learn. AI and other advanced technologies speed up the learning stage. Just as digital platforms and IoT sensors accelerate the rate at which information is generated, gathered, and processed in the build and test stages, huge data volumes can be leveraged to feed machine learning algorithms, which in turn learn from the characteristics of the developed product and the test results. The algorithms can learn which type of product is opportune and which is not, and automatically return the results to the design stage via feedback loops. The rate of learning speeds up exponentially, with time scales dropping from weeks or months to a day or a few minutes. It also becomes one of the most important competitive dimensions as competition evolves into a competition on the rate of learning[1].

The falling price of computing equipment is another powerful lever. It accelerates machine learning speed, improves the scalability of the process, broadens its scope across traditional boundaries, and enhances its ability to learn and adapt on the fly.

1. https://www.bcg.com/publications/2018/competing-rate-learning

The learn phase is ultimately where the "intelligence" of the deep tech approach resides, and with it, its power. In the design phase, enhanced creativity leads to more and better possible solutions. The enhanced building and testing capabilities of the following phases allow for the generation of significantly more data points. These are leveraged in turn in the learn phase, when all data is evaluated using AI and machine learning. This ultimately triggers a new DBTL cycle and the automated feedback loop, to improve the design phase of the new cycle. All of this makes the deep tech DBTL cycle an incredibly virtuous one, leading to massively improved results at every iteration, from one phase to the other, from one cycle to the other.

The power of the cycle becomes clearer and more tangible when looking at ventures that have implemented it successfully and accelerated their innovation cycles. CFS has been using it since its inception. The founding team first worked on Alcator C-Mod, a compact high magnetic field tokamak at MIT's Plasma Science and Fusion Center, and are now using that research as they build HTS Magnets (the enabling technology, i.e., high-temperature superconductor magnets) and design SPARC, the first net energy machine. A similar DBTL approach is being taken by Lilium Aviation, with the construction of a 2-seater technology demonstrator, then a 5-seater technology demonstrator. According to their website, they *"are using data from their flight test campaign to inform the design of the serial aircraft, which is happening simultaneously".*

The DBTL cycle is also at the core of the nascent field of nature co-design (rethinking how to address today's problems by using nature as an engineering and manufacturing platform), which is the subject of a separate article in this series.

Ginkgo Bioworks, one of the unicorns of nature co-design, is using it to design custom organisms for its clients. It draws upon data analytics and robotics to speed up the process of testing and making new organisms for applications as diverse as food, therapeutics, and agriculture. For each data point under study, data analytics and robotics allow Ginkgo to lower the cost of the data point as much as possible and extract value out of it.
Similarly, Zymergen, another nature co-design unicorn, implements DBTL using a technology platform that combines biology, machine learning, and automation as well as one of the largest libraries of proprietary genomic data in the world. This identifies pathways that humans alone simply can't.

For material science, Kebotix, a Boston startup, is a fully autonomous discovery lab, positioned along all the Design-Build-Test-Learn cycle. It combines machine learning algorithms to model molecular structures with an autonomous robotics lab that synthesizes, tests, and feeds back the results to the algorithms. By applying deep learning, the algorithms adapt to the results from the lab, creating a 'closed loop' for fast learning and simulation.

A similar approach is taken by VSPARTICLE (VSP), a company pioneering the work at the nanoscale to achieve required material properties and creating a new DBTL cycle for nanoparticles. VSP has developed a process to remove variability and manual effort from the production of nanoparticles. The incumbent wet chemical synthesis process involves months of lab work to make and analyze a single nanoparticle, which is incompatible with a healthy DBTL cycle and difficult to scale. VSP's technology can produce nanoparticles with the required specifications, without manual work, reducing development time by an order of magnitude from months to days.

Design and Engineering cycles are nothing new per se. Their importance in driving innovation has already been clearly articulated, through for instance the lean start-up approach, with the build-measure-learn loop (or cycle) as one of its core instruments. The benefits of the DBTL cycle are similar to those obtained with the build-measure-learn loop (speed and agility). But there are also some significant differences here that should be understood.

First, the level of impact of the DBTL cycle in deep tech is massive. Most often, this impact manifests itself in the rapid improvement of orders of magnitude, which then often leads to making the impossible possible. Contrary to the build-measure-learn loop, which takes place only in the world of bits (i.e., software), the DBTL cycle happens in the world of bits and atoms. It can include technologies like AI, or even quantum-inspired algorithms (see Aqemia), advanced sensing, robotics, and additive manufacturing. The compounding of all these technologies, their advancements, and their underlying exponentials lead to improvements by several orders of magnitude, and not by mere percentage points. CFS was able to reduce the cycle from one year to one month. In synthetic biology, thanks to AI and (ultra) high-throughput analysis, the increase in speed reaches several orders of magnitude, compared to traditional approaches. In early demonstrations of the tech platform, Kebotix was able to reduce the development time of OLED materials from previously 7 to 1.5 years.

Second, because of its multidimensionality, the design (and not only the execution) of the DBTL cycle itself becomes a source of competitive advantage. Each of the steps of the cycle has its own peculiarities and the technologies supporting it evolve at a very fast pace. Deep tech ventures need to allocate time and resources to ensure, on the one hand, that they design the cycle to extract the maximum value out of it, and on the other hand, that they are able to go through it at the maximum viable speed. For instance, the choice of the right MVP (Minimum Viable Product), a very important step in the lean start-up approach, or even the identification of the right area on which to run the DBTL cycle, becomes extremely critical. Because of the difficulties of scaling up processes in nature co-design, choosing the wrong MVP could be lethal. Very often, processes that work at lab scale do not work at all at scale. Thinking of having an MVP only once things work at lab scale can be very dangerous; because what seems to be a viable solution is not necessarily so (See scaling up in Nature Co-Design: A Revolution in the Making[2]). CFS chose to have the HTS magnets as an MVP, and the item on which to run the DBTL cycle. They chose not to apply this to the plasma physics, as this would not have been suitable for a fast and reliable application of the DBTL cycle and would have prevented overall progress. Counterintuitively, they decided to focus on the magnets (i.e., the infrastructure) and considered the physics of the plasma (i.e., the core of fusion) as a given.

Third, similarly to the world of software, the role of the DBTL cycle in deep tech is also one of de-risking. But the kind of risk being retired is radically different. Instead of being used predominantly to reduce the market risk and increase the product-market fit, the deep tech DBTL cycle is the main de-risking instrument of a deep tech venture. Each of the associated MVPs represents a very important "certification" of the retired risk. Every successful iteration through the DBTL cycle is a milestone in the development of the venture, and is relevant for the venture as a whole, as well as for the investors, and all the stakeholders involved. That is why it is so important to have artifacts, concrete MVPs to share, like the silk tie of Bolt Threads or the ice cream of Perfect Day. It can, of course, be used to reduce the market risk as well, but its importance to the de-risking of the venture, particularly at the beginning of the journey, cannot be stated enough.

One of the best examples of the power of the DBTL cycle in deep tech is represented by Boom Supersonic. Because of the complexity of certifying new safety-critical fundamental technologies in aviation, and the challenge of building the first supersonic airliner since the Tupolev Tu-144, the Boom team decided to utilize only fundamental technologies with known certification paths and proven safety records. This strategy does not preclude significant IP, as Boom's IP is contained in protectable design innovations as well as material learnings from the DBTL cycle.

2. https://hello-tomorrow.org/bcg-nature-co-design-a-revolution-in-the-making/

Four Challenges for Deep Tech

Despite all its potential, there are still multiple challenges to deep tech deploying its full potential. Four challenges, in particular, stand out. They each affect all the stakeholders involved, not just the ventures:

- the need for reimagination
- the need for continuing to push science boundaries
- the difficulties in scaling up
- the difficulties in accessing funding.

The Need for Reimagination

Seeing the opportunities of science and technology as a way of reimagining processes and solving problems has been a constant struggle throughout history. A well-known example is the 20 years it took to rethink the shop floor, when electric engines replaced steam engines.

We have seen how deep tech ventures often start from a solution based on a technological breakthrough. For them, reimagining the right business framework may be challenging. Many ventures tend to struggle to find a compelling value proposition through a clear reimagination of value chains, and of business models.

For existing corporations, the challenge of reimagining products and processes comes from a very different place, and probably represents the biggest one in deep tech. It is also something they must necessarily deal with. In previous decades, 77% of industry-leading companies were still leading five years later; but today, in a more dynamic market where continuous innovation and reinvention is key[1] to success, this figure has almost halved to 44%.

To profit by the full potential of deep tech, the imagination machine in companies should focus on anomalies, on explicit mental models. It should draw upon counterfactual as well as factual skills, while cultivating playfulness, encouraging cognitive diversity, and ensuring that its members are regularly exposed to the unknown.

Instead, because of limited exposure to the outside world and as a result to innovation, big companies continue to commit to the exploitation of the status quo, driven by reinforcing metrics, with opposite results to those that would spring from fostering reimagination. Efficiency is the current dogma: to improve what the company has already. Possible sparkles of imagination are prevented by focusing on averages, rather than exceptions[2].

For big companies, competing on imagination is the key to the power of deep tech. Conversely, if utilized properly, deep tech can become a powerful tool for reimagination.

Pushing Science Boundaries

While science has made enormous progress in many fields, there are still many areas where we are only starting to scratch the surface of what is possible.

One example is biology. The complexity of nature is far from being fully understood. Understanding the link between genotype and phenotype, for instance; the biological structure and function, the interactions of the biological system. Meanwhile, 80-90% of species are still hidden from science[3] and we are still at the dawn of fully understanding the brain.

On the materials front, the chemical space is as vast as the universe, and we only know a fraction of it[4]. The complexity of nanoparticles as multi-component 3D structures is still a great challenge for design and engineering.

Despite the increasing interest in soft robotics, only a few prototypes have come to light. The behavior of soft materials today is way more difficult to seize than that of hard materials, and therefore more difficult to control and activate.

Quantum computing has enormous potential and promising results but is still in its infancy, given all the technical challenges that can hinder fast progress.

Similarly, AI and Machine Learning are subject to incredible and continuous progress, but many issues are still exposed and far from being resolved. Even the last and most promising developments, like transformers, pale in comparison to the brain. For instance, the "biggest" transformer available for text, Switch, has "only" 1.6 Trillion parameters, about 60 times less than the brain, which has about 100 trillion parameters (i.e., synapses).

Governments, universities and start-ups (should) work together to push the boundaries of science and deliver its economic impact through technologies. It is important for corporates and investors alike to learn the language of science and become proficient in it.

For more on the need to push science boundaries further, see the report "Nature Co-Design: A Revolution in The Making[5]"

1. https://bcghendersoninstitute.com/the-global-landscape-of-corporate-vitality-8a375428b946
2. https://www.bcg.com/publications/2020/why-companies-must-compete-on-imagination
3. BioGenome Project, 2018
4. Ball P. Navigating Chemical Space, 2015
5. https://hello-tomorrow.org/bcg-nature-co-design-a-revolution-in-the-making/

The Scaling Up Challenge

While finding the right MVP or the first artifact is in itself a big challenge, ensuring that it is scalable at higher volumes is an altogether separate one, particularly if compared to software.

Deep tech ventures operate at the convergence of technologies leading to fundamental innovation. This often results in a very "new" physical product for which no similar product has been scaled up before. It is therefore quite difficult to apply specific or existing scale-up experience to deep tech products.

Scaling up a deep tech physical product (and therefore a manufacturing process) can be much more complex and costly than software work (which has very low marginal cost to scale). It requires more physical facilities, as well as constraints on the testing methodologies. The scaling up phase is crucial to achieving the design-to-cost parameters. This puts additional pressure on scaling up. Not only do the engineering challenges need to be overcome, but they also need to be overcome at the right cost point.

Furthermore, scaling up biological products can also face inefficiencies. Large scale fermentation, for example, is constrained to a specific operating window based on physical & metabolic barriers. Scaling up for nanotechnology is similarly non-trivial.

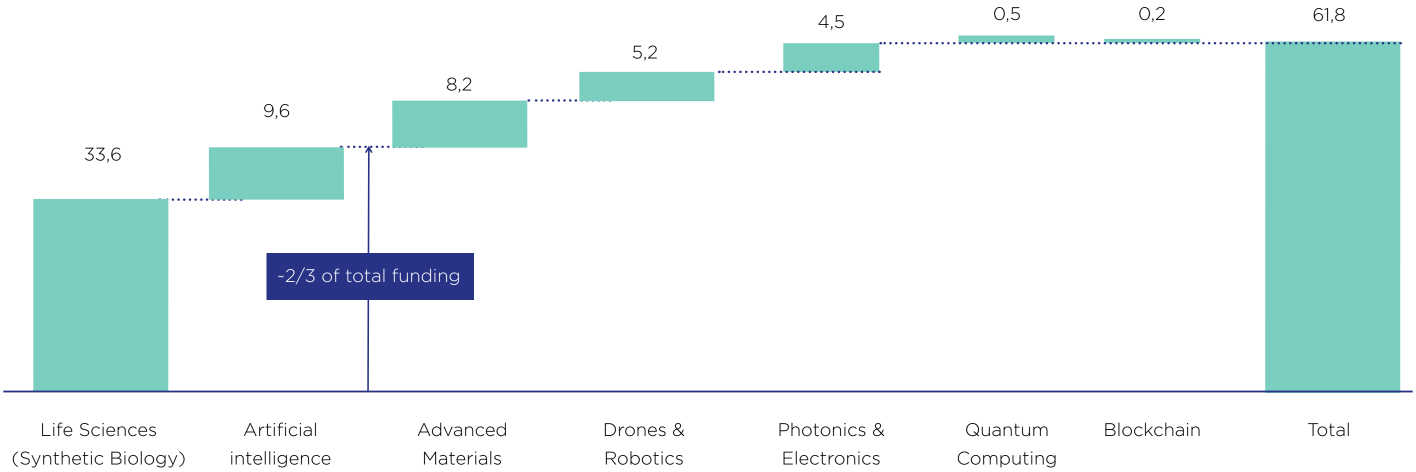
For more on the scaling up challenge in synthetic biology and nanotechnology, see "Nature Co-Design: A Revolution in The Making[1]"

The Funding Challenge

Despite investment growing up to more than $60B in 2020 (preliminary estimates), and its massive disruption potential, Deep tech is in fact hindered by the current overall investment model. It is particularly affected by the VC standard blueprint, which is insufficient and unevenly spread, and mostly directed towards AI/ML and Life Sciences (Exhibit 18). Even more challenging is shifting away from the laboratory (grant/subsidy-based) to venture funding for deep tech.

Exhibit 18: Investment is unequally spread with ~2/3 accounting for Artificial Intelligence and Life Sciences

Deep tech investment by technology in 2020 (preliminary estimates, $B)



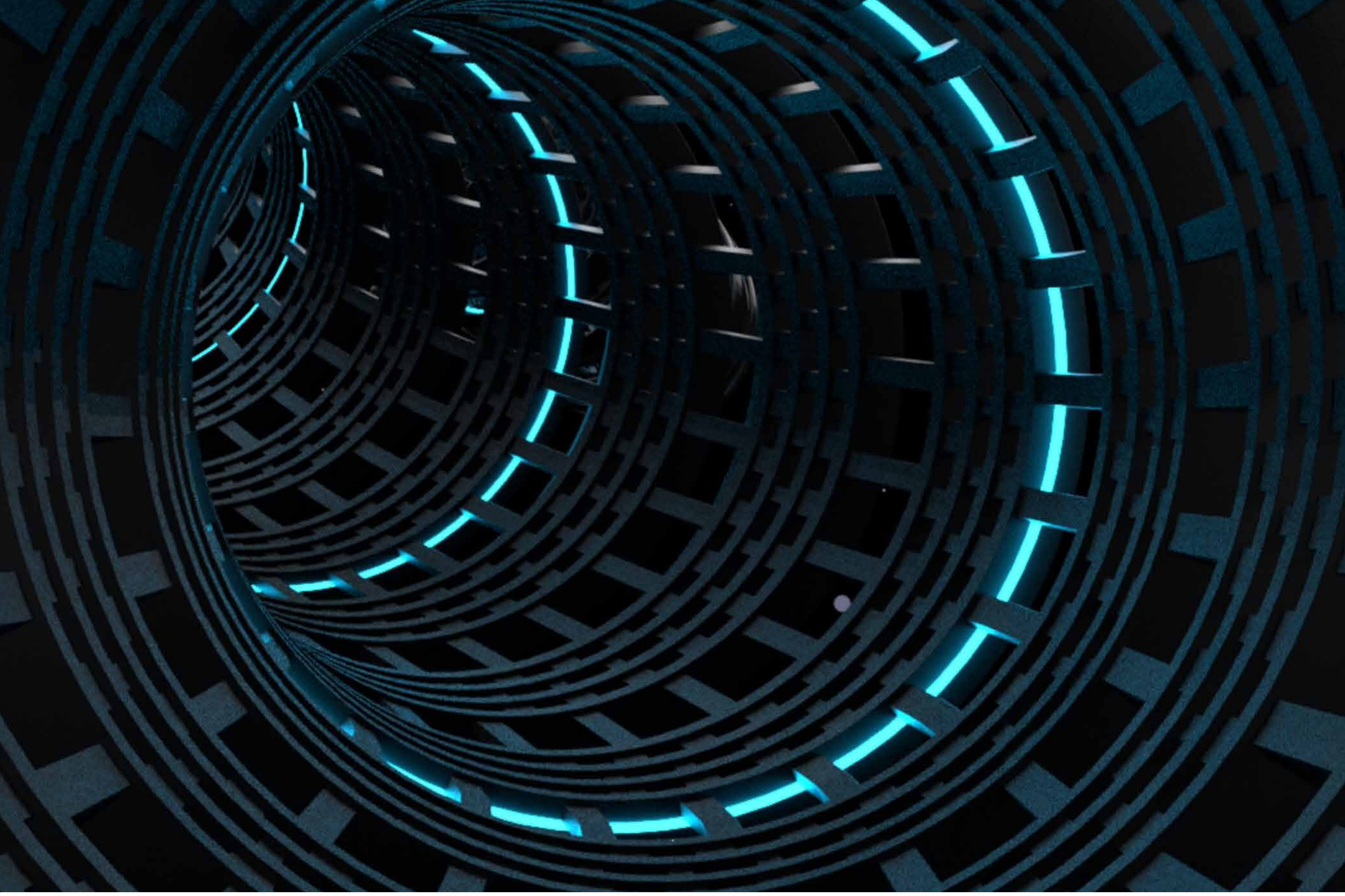
Note: Investments mapped of several technologies were split equally between these technologies; ~32% of 2020 investment amounts in deep tech start-ups and scale-ups remain undisclosed; 2020 figures are assumed to be incomplete
Source: Capital IQ, Crunchbase, Quid, BCG Center for Growth & Innovation Analytics, BCG and Hello Tomorrow analysis

Because of such frictions along the investment chain, fueled by mindset paradoxes and investment model biases, deep tech-based, supporting Sustainable Development Goals, progress, is prevented. PE and VC funds are structurally hindered (lifetime, size, incentives) from investing in deep tech, as they lack the necessary talent to understand science and technology risks and support ventures.

Furthermore, most VCs have lost the original "venture" mindset and, very often, end up relying instead on the power distribution law to get to their returns.

We address the deep tech investment challenge in further detail in "The Deep Tech Funding Paradox" upcoming report.

1. https://hello-tomorrow.org/bcg-nature-co-design-a-revolution-in-the-making/



Four Moments of Truth: The Deep Tech "Catechism"

DARPA, the US Defense Advanced Research Program Agency, is famous for having contributed some of the most important civilian innovations of the last decades, having been, namely, a driving force in the creation of weather satellites, GPS, personal computers, modern robotics, the Internet, autonomous cars, and voice interfaces.

Created in 1958, DARPA certainly predates deep tech, even though the kind of innovation it has been able to drive is comparable to the potential of deep tech. According to DARPA itself, they "operate on the principle that generating big rewards requires taking big risks". They use a set of questions, known as the "Heilmeier Catechism[1]", as a very important heuristic to determine the projects in which to invest and how to evaluate them.

1. George H. Heilmeier, a former DARPA director (1975-1977), crafted a set of questions known as the "Heilmeier Catechism" to help Agency officials think through and evaluate proposed research programs. What are you trying to do? Articulate your objectives using absolutely no jargon. How is it done today, and what are the limits of current practice? What is new in your approach and why do you think it will be successful? Who cares? If you are successful, what difference will it make? What are the risks? How much will it cost? How long will it take? What are the mid-term and final "exams" to check for success?

Questions like "How is it done today, and what are the limits of the current practice?", "What is new in the approach and why do you think it will be successful?" or "What are the mid-term and final "exams" to check for success?" are at the core of the Heilmeier Catechism.

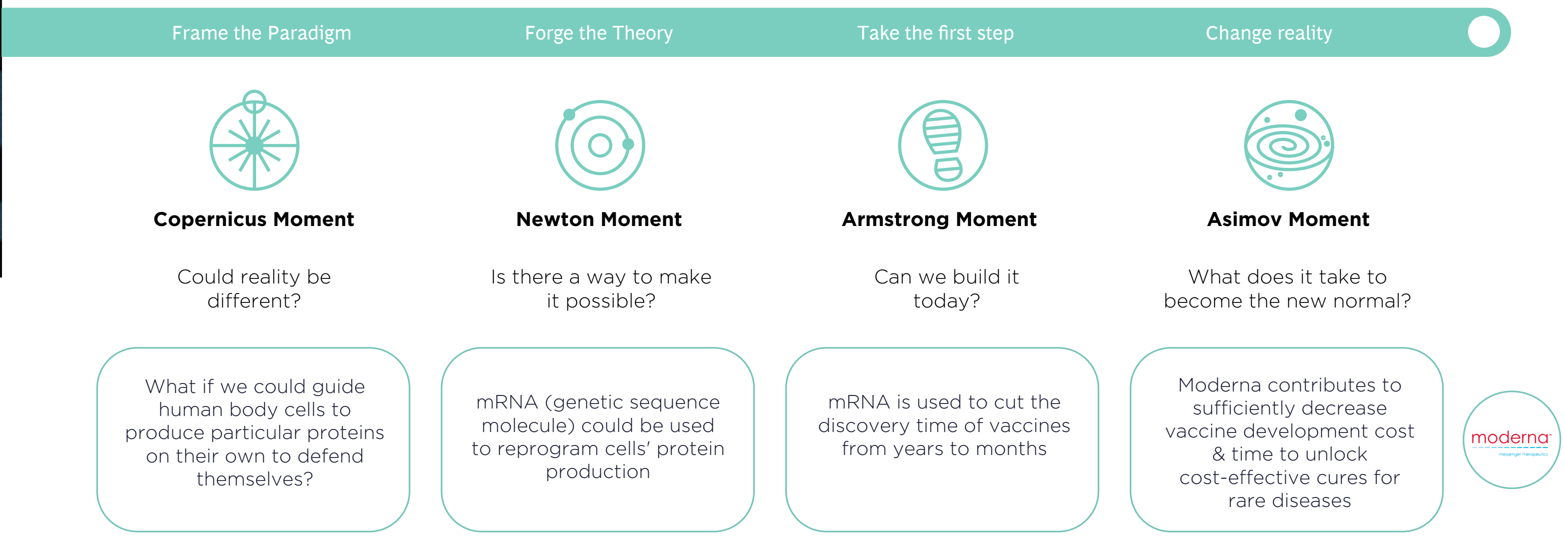
In a similar way, one could say that there is a set of questions that represent a very good heuristic for achieving breakthrough innovation; a kind of "deep tech catechism". The questions of the catechism also define what can be considered the 'moments of truth' for deep tech ventures; the moments when the future of the ventures is decided.

The four moments of truth of deep tech and the related questions are as follows (Exhibit 19):

- **The Copernicus Moment** on how to frame the paradigm. In other words, what is the problem, and could reality be different?
- **The Newton Moment** on forging the theory. In other words, how can we make this possible?
- **The Armstrong Moment** on taking the first step. Can we build it today?
- **The Asimov Moment** about changing reality. What does it take to become the new normal?

Exhibit 19: The deep tech principles are reflected in four moments of truth, taking place in parallel

Four moments of truth for a deep tech venture, each to be anticipated very early on in the venture creation. This chronology is an archetype but some steps can occur much earlier



Source: BCG and Hello Tomorrow analysis

The Copernicus Moment refers to framing the right question, identifying the right problem or the right business friction, in order to then derive the right approach. It is about generating the right hypothesis by using the imagination: seeing things not for what they are but for what they could be.

The Newton Moment lies at the core of the deep tech approach. It is when science and engineering meet to validate the hypothesis, and when technologies converge to make things possible that were not possible before.

The Armstrong Moment is when the different technologies and the DBTL cycle are applied to produce the first working prototype very fast, and in so doing, de-risk the venture.

The Asimov Moment is built, from the very beginning, around economics and business requirements. This is achieved by following a design to cost approach: by defining the value strategy and target costs in order to establish oneself in the market. One must also use another, important lean start-up instrument as the business model canvas[1].

Similar to what we saw for the convergence of approaches, the difficulty with the four moments of truth resides in the need to address all of them early on, at the same time – instead of sequentially, and from the very beginning. The relevance of the moment's question will vary over time, but addressing all of them is essential to de-risking the endeavor. Doing so will help anticipate friction points and adapt strategy and execution as needed. While the anticipation of frictions is of course not specific to deep tech ventures, it remains extremely important in this context. It is a key tool for retiring risks as early as possible – one of the core activities to lead deep tech ventures to success.

1. First origins of Business Model Canvas: Business Model Generation (A. Osterwalder, 2010)

Exhibit 20: Deep tech ventures development mirrored in their answers to the moments of truth

Source: BCG and Hello Tomorrow analysis

The four moments of truth are also a good instrument for evaluating the development of deep tech ventures in terms of milestones and achievements. (Exhibit 20)

The importance and potential of addressing the four moments of truth and their related questions from the start can be seen in the case of Seaborg Technologies. Seaborg is developing a fundamentally new type of nuclear reactor - a Compact Molten Salt Reactor (CMSR) - to deliver a scalable, inherently safe, cheaper-than-coal, dispatchable power source by 2025. Because they use molten salt, a fluid, as a fuel, instead of traditional solid fuel, the reactor cannot melt down or explode. A breach of the reactor will simply leak out the liquid fuel, which will then solidify without harmful release of radioactive gasses to air or water. Seaborg delivers their CMSR in a modular floating power plant, building Nuclear Power Barges, where the reactor can operate for 12 years without refueling. This allows them to deploy it with minimal logistics.

What is truly innovative and remarkable, together with some of the technical solutions, is how Seaborg has addressed the fourth moment of truth (or what it takes to change reality and become the new normal) from the get-go. By building floating power plants, Seaborg was able to take a completely new regulatory approach. A molten salt nuclear reactor in a concrete power plant would take years to get regulatory approval, which, in the case of countries with limited expertise in the field, would then be followed by equally lengthy processes to find a local competent regulator (a regulatory requirement).

Historically, the need for a local competent regulator has been a hurdle to delivering nuclear energy in some areas of the world, including South East Asia (a region where solar and wind energy as sources of energy are problematic, and cannot be widely used, rendering it difficult for those countries to decarbonize). Instead, Seaborg's nuclear power barge is following the regulatory framework of the American Bureau of Shipping (ABS) New Technology Qualification (NTQ) process, a five-phase process that aligns with product development phases. The power barge can thus be built in a country that approves its status as a local competent regulator and can then be shipped to a location overseas.

Seaborg is now going through the third moment of truth. For the Copernicus Moment, they identified the problem and framed the paradigm: How can we deliver safe, cheap, and clean nuclear energy? For the Newton Moment, they found a way of making it possible: A modular compact molten salt reactor. Now, they are approaching the Armstrong Moment, designing and building the reactor, with the ambition of deploying the first commercial power barge by 2025. But that does not mean that they are sequentially addressing the key moments of truth or that they will only 'worry' about the

Asimov Moment once they have passed the Armstrong Moment. On the contrary, their unique approach to regulatory approval, at the center of their venture, already constitutes a big part of the answer: Seaborg's power barge can become the new normal because it aims at providing safe, cheap, and clean nuclear energy that can be rolled out quickly, in many different places at once, unconstrained by regulatory processes.

The example from Seaborg's nuclear power barge also highlights an important element about deep tech ventures: The fission physics around molten salt reactors are already quite established, and Seaborg is not innovating through that path. They are choosing, rather, to innovate through the convergence of different disciplines and technologies: by combining neutronics and fuel dynamics with computational advances; looking at advanced materials to overcome corrosion and radioactivity resistance; and addressing the regulatory approval process in a completely novel way. Their approach is thereby fundamentally problem-oriented, focusing on bringing all the pieces together to achieve their goal. It is through problem orientation that they are able to frame the challenges from a completely new perspective and dream up innovative approaches.

Deep tech relies on a broader ecosystem, not only on start-ups like Seaborg. The ecosystem is made of corporations, investors, universities, institutions, and facilitators. The four moments of truth play an important role for them too. Each of the participants in the ecosystem must consider all the moments from the very beginning, and at the same time, just as Seaborg did. Each actor must be able to root the dynamics of the ecosystems in the context of the four moments, in order to be able to derive their specific implications. For instance, investors can use the moments of truth to either evaluate the maturity of the ventures or the progress made (Exhibit 20)

We will explore the new rules of engagement for each of the actors in the ecosystem in future articles. But it is safe to assume that in order to be able to engage successfully, all participants in this wave of innovation need to embrace the fundamental principles behind the rise of deep tech, embodied in the four moments of truth.

It's Still about the Ecosystem

In the second wave of business innovation, large companies developed ICT technologies and new drug treatments in small ecosystems composed mainly of government agencies and universities. In the third wave, individual entrepreneurs, start-ups, and venture capital funders joined the mix and redefined how ecosystems are formed and interact.

The fourth wave is witnessing yet another ecosystem metamorphosis, adding other types of participants and major capabilities. Information and knowledge are critical currencies of exchange. While most of the current generation of deep tech ecosystems are still in their infancy, their potential is enormous in both the near and long term.

Ecosystems are not new, but the economy's increase in modularization shows that new combinations that were not feasible before are possible now through ecosystems. Companies can now coordinate while remaining independent.

Also, ecosystems are powerful when there is a disruption in the market, which is exactly what deep tech companies are intending to bring. If the business is stable over time, an ecosystem is less necessary and rather counterproductive, given that innovation flexibility has an efficiency cost. "*Ecosystems are useful when there is a variety or there isn't a predictability of what you want*"[1].

Participants in the ecosystems should consider adaptive approaches rather than plan-driven approaches "*There's the belief that you can tell the ecosystem what to do, which is a little ironic because at the very point of having an ecosystem is that you are able to find a new trade-off between flexibility and control and ecosystems are not part of command chains*"[2]

1. Michael Jacobides in https://bcghendersoninstitute.com/dispelling-the-myths-of-ecosystems-with-michael-jacobides-a13ca9b77681

2 Peter J. Williamson in https://bcghendersoninstitute.com/book-interview-the-ecosystem-edge-with-peter-j-williamson-ad6c92274afa

Two characteristics stand out when looking at the current generation of deep tech ecosystems.

- **They are highly collaborative.** They grow and strengthen through the continual interaction of all stakeholders. The need for collaboration extends beyond what already exists in current industrial value chains, and even trumps traditional competitive considerations.
- **They are loose associations,** characterized by uncertain futures and paths of progress. Any given venture may or may not succeed. There is enough uncertainty that traditional top-down strategy often loses out to other influences in the ecosystem.

The win-win nature of deep tech ecosystems demands that participants have a shared vision with both short- and long-term goals; that they know how to advance a particular technology or market; and that they develop a 360-degree view of all stakeholders' priorities. All participants must have a clear vision of both what they bring to the ecosystem and how the ecosystem benefits them. They must leverage the power of the ecosystem, while acknowledging that today's deep tech ecosystems require different rules of engagement than past ones, for everyone. For instance, a cultural shift is required, both in corporations and in academia, to enable collaboration with ventures (especially around industrialization and commercialization).

Conclusion

A new and powerful wave of innovation is rising. One that could fundamentally reshape the economic and societal landscape.

Deep tech builds on more than a century of science and technology. Having now reached the level of manipulation of natural phenomena, and harnessing the power of computation and data, deep tech allows non-trivial recombination to address new problems or reframe existing ones, independently of century-old industries.

Deep tech is ultimately about problem framing (or reframing), which isn't easy for industries with sunk cost and inertia in the current paradigm. In fact, very often, deep tech ventures will end up reverting to the original problem and seeing it with fresh eyes. It is about questioning the basic barriers, obstacles, and blind spots of current approaches.

Deep tech ventures have more latitude and can "afford" to focus on the problem. They can build upon the shoulders of the 20th-century giants without assuming their burden. Riding this new wave of innovation comes naturally to them.

Conversely, established corporations must learn how to ride the wave or run the risk of being carried away by it. They need to understand how to operate in the innovation ecosystem: be clear about what they bring to the system (infrastructure, market access, engineering and regulatory...); about what they are looking for (innovation, new products, and processes); and about what they can get from the actors in the ecosystem; and how to go about it. The deep tech wave is not necessarily a zero-sum innovation wave – it is a unique opportunity to rethink the foundations of the business.

To ride this wave, all participants in the ecosystem must master the convergence of approaches and technologies: where design, science, and engineering come together to reshape solutions and remove constraints; where multiple technologies, emerging and non-emerging, can be combined to make new solutions possible. The necessary instrument for pulling all this off? The DBTL cycle.

The core message about deep tech is that it's not about technology, it is an approach. This approach is characterized by focusing on problems over solutions, building upon hypotheses, being cross-disciplinary, anticipating frictions, front-loading risk, shortening the engineering cycle, keeping the cost and economics front of mind — and leveraging the ecosystem.

The power of the 4th wave lies in its ability to massively broaden the option space at unprecedented speed and solve fundamental problems. Of all the innovation waves, it promises to be the most transformational. The greatest our world has ever seen. The great wave.

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