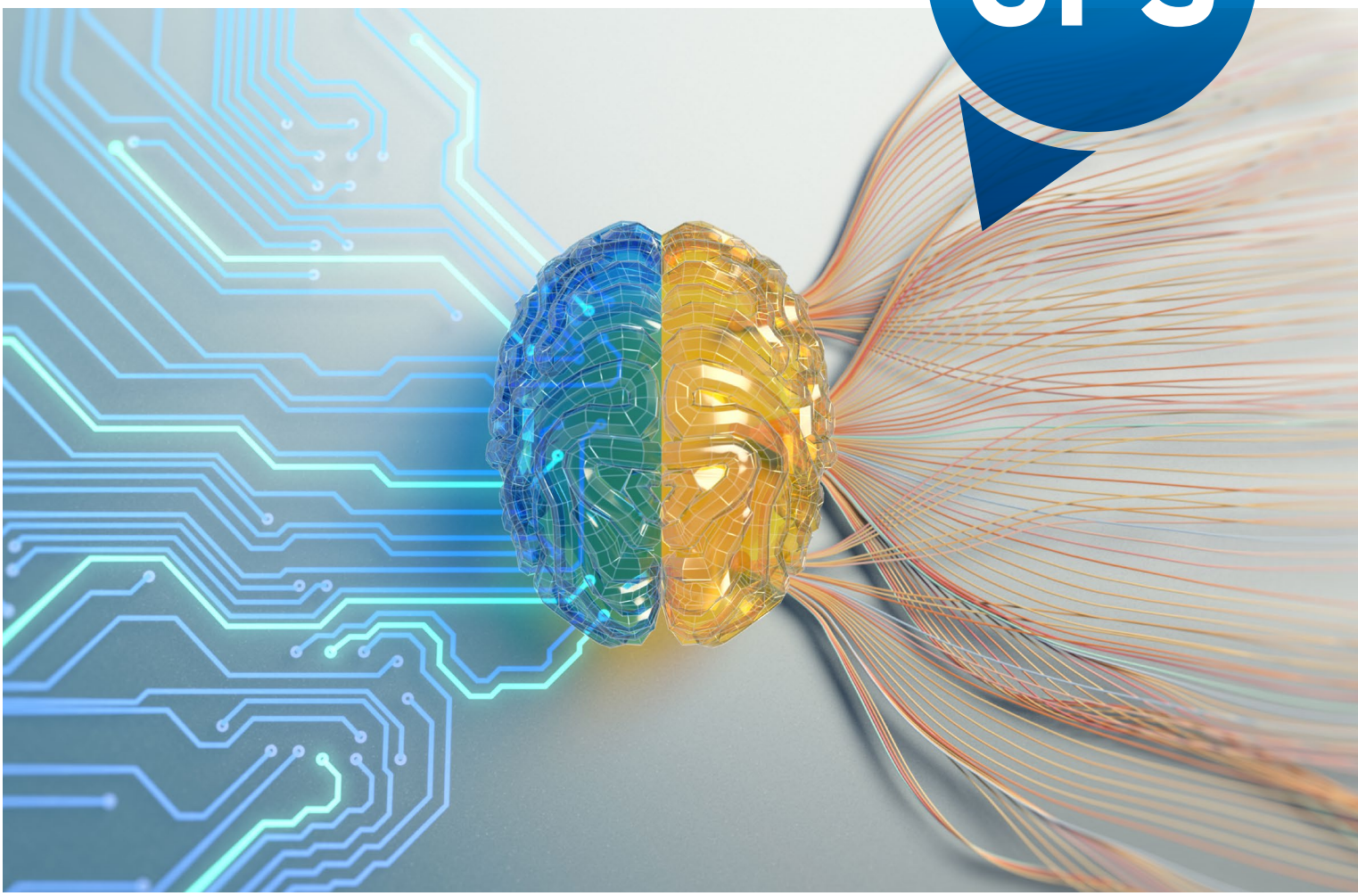

DISRUPTIVE INNOVATIONS IX

Ten More Things to Stop and Think About

Citi GPS: Global Perspectives & Solutions

December 2022

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DISRUPTIVE INNOVATION IX

Ten More Things to Stop and Think About

Kathleen Boyle, CFA
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In our new report, the ninth in our Disruptive Innovations series, we once again look at some of the leading-edge concepts across sectors and identify new products, which could ultimately disrupt their marketplace. A few of the "new" concepts are derivatives of innovations we have explored in the past. Technology-related concepts dominate the list this year and span across a range of sectors — from retail to education to farming.

We start by looking at the areas where innovation and financing are coming together through the amount of venture capital (VC) funding by theme. Although total growth in venture capital funding increased steadily between 2010 and 2020, investments roughly doubled in 2021 to $723 billion. Despite optimism these levels would continue, VC funding has pulled back in 2022.

On the sustainability front, we continue to highlight innovations to help reduce global greenhouse gas emissions. Vertical farming, where plants or crops are grown indoors in vertically stacked layers, use less water, fertilizer, and land than conventional farming, leading to lower emissions. The acceleration of automation capabilities in vertical farms has also improved its scalability and profitability. Advancements in sodium-ion batteries, which use sodium instead of metals such as lithium to generate charge, have lower material costs and lower supply chain pressures due to the abundance of sodium around the world than current battery technologies. These advantages could drive electric vehicle penetration rates. In terms of power generation, small modular nuclear reactors could be disruptive to global energy markets, stabilizing power prices and shifting incentives away from gas and coal power generation throughout the world.

Innovations in technology can potentially change the way we shop, access the internet, organize not only data but corporate structures, gain education, and produce high-performing computers. Social commerce is transforming the way shoppers interact with merchandise but also how retailers inform their product roadmaps. Households and small businesses may soon be cutting their fixed broadband cords for wireless broadband access that can also expand the addressable market for broadband services. Upskilling through online professional learning, qualifications, and credentialing could either disrupt universities or help them adapt to changes in learner preferences.

From an organizational perspective, the introduction of blockchain-based decentralized autonomous organizations, which are collectively owned and governed with rules set and executed through smart contracts, could enable more individuals to collectively work for themselves through digital community ownership. Data fabric can be used in an organization to simplify access to data across different platforms and high-NA extreme ultraviolet lithography (high-NA EUV) is expected to lower costs and reduce complexity in the manufacture of semiconductors.

Finally, in healthcare, allogeneic cell therapies, which source cells infused into a patient to treat or cure a disease from master cell banks instead of patients themselves, are must less invasive for the patient and can increase the availability of cell therapy.

Speeding Into The Digital Future

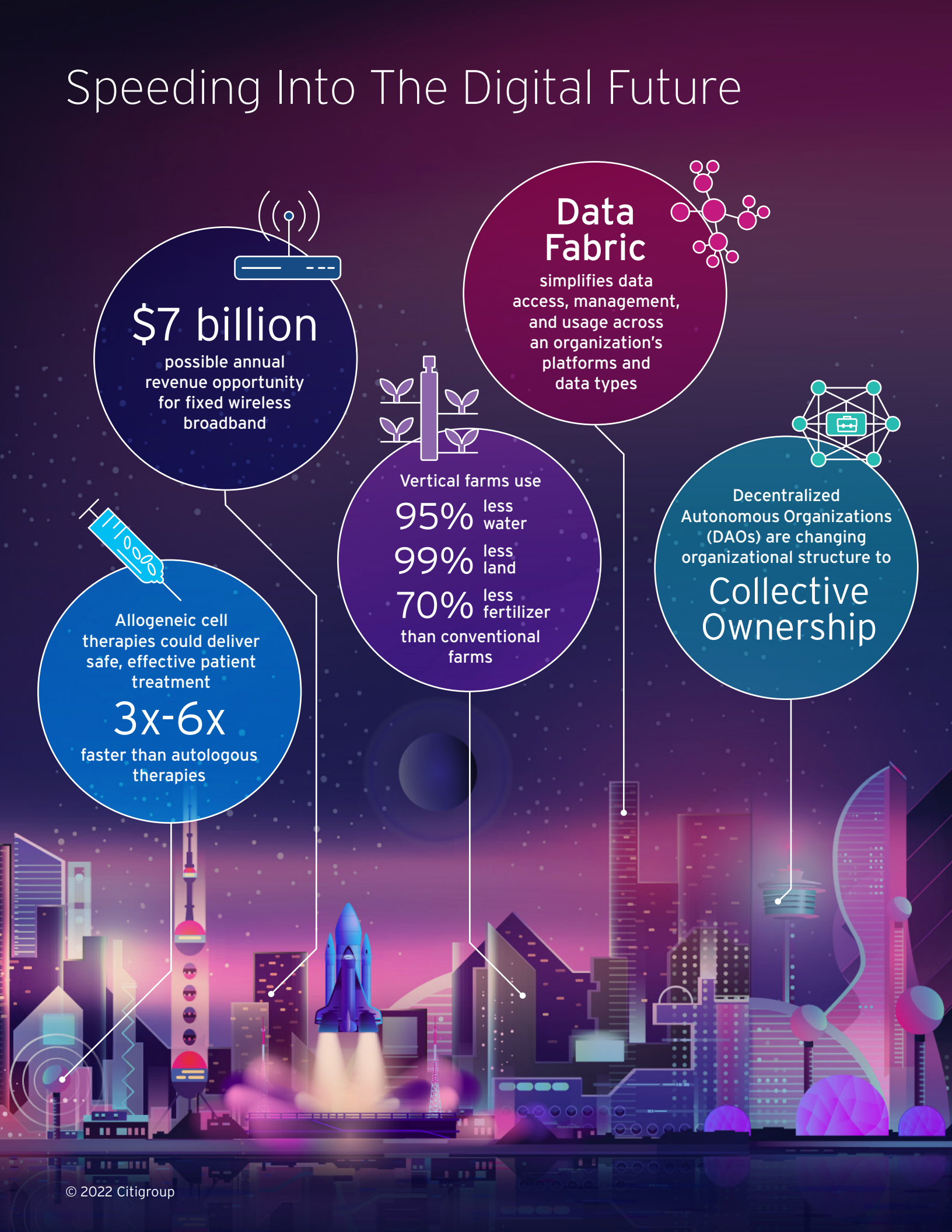
$7 billion
possible annual revenue opportunity for fixed wireless broadband

Data Fabric
simplifies data access, management, and usage across an organization's platforms and data types

Vertical farms use
95% less water
99% less land
70% less fertilizer
than conventional farms

Decentralized Autonomous Organizations (DAOs) are changing organizational structure to
Collective Ownership

Allogeneic cell therapies could deliver safe, effective patient treatment
3x-6x
faster than autologous therapies



The outsourced spend on professional e-Learning could show

18%

compound annual growth over the coming years

20%

possible overall market share of High-NA EUV lithography systems by 2030

61%

of U.S. social media users have made a social commerce purchase in 2022

285 GW

of new small modular reactor power plants are needed to offset retiring electricity generation assets in the U.S.

Sodium-ion batteries have a raw material cost

lower

than lithium-ion batteries

Contents

Adam Spielman
Citi Global Insights

Introduction

This is the ninth report in our Disruptive Innovation series, which means we have now published on a total of 90 areas. This raises the question: Which present the most significant opportunities, i.e., how, for example, does the opportunity in fuel cells compare to that in wearable tech?

This is a BIG question, and a brief introduction cannot possibly hope to provide all the answers. However, we sketched out an approach in a recent report, quantifying the outlook in 100 different areas, or themes as we call them.[1] We chose the 100 in the most objective way we could, leveraging a decade's worth of analyses from Citi Research. The final selection is listed in Figure 1. Of the 100 themes, 69% come from a Citi Research product called the Global Theme Machine, or GTM, and most of the rest come from the Citi GPS Disruptive Innovation series.

About two-thirds are types of technical innovation (mainly colored black in the table), but 40% also relate to sustainability themes (green), and 11% to growth and prosperity (blue). (This adds up to more than 100% because some of the innovation themes are also classified as related to sustainability and society and are shown in green.)

Figure 1. 100 Themes

Growth & Prosperity	
Theme	**Source**
1. Aging Demo Spend	GTM
2. Belt & Road	GTM
3. EM Consumer	GTM
4. Global Trade	GTM
5. Infrastructure	GTM
6. Luxury Spend	GTM
7. Medical Tourism	GTM
8. Services Offshoring	GTM
9. Tourism	GTM
10. Urbanization	GTM
11. U.S. Construction	GTM

Sustainability & Society	
Theme	**Source**
12. Agriculture Demand	GTM
13. AgTech	GTM
14. Alt Proteins	DI
15. Biofuels	GTM
16. Carbon Markets	DI
17. Clean Tech	GTM
18. Clean Water	GTM
19. Climate Change	GTM
20. Defense	GTM
21. De-Polymerizing Plastics	DI
22. E-cigarettes	DI
23. EdTech	GTM
24. Energy Efficiency	GTM
25. Energy Storage	GTM
26. Food Innovation	GTM
27. Fossil Fuels	GTM
28. Fuel Cells	GTM
29. Health & Wellness	GTM
30. Hydro Energy	GTM
31. Hydrogen	GTM
32. Indoor Farming	DI
33. Lightweighting of Autos	GTM
34. Net Zero	GTM

Sustainability & Society	
Theme	**Source**
35. Novel Biothreats	GTM
36. Obesity	GTM
37. Sharing Economy	GTM
38. Solar Energy	GTM
39. Sustainable Materials	GTM
40. Timber	GTM
41. Waste-to-Energy	DI
42. Wind	GTM

Technology & Innovation	
Theme	**Source**
43. 3D/4D Printing	GTM
44. 5G Network	GTM
45. Artificial Intelligence	GTM
46. Auto Electronics	GTM
47. Automation	GTM
48. Cannabis	Add
49. Cloud Computing	GTM
50. Contactless	GTM
51. Cybersecurity	GTM
52. Dark Kitchens	Add
53. Data Storage	GTM
54. Deepwater Drilling	GTM
55. Digital Identity	GPS
56. Digital Leisure	GTM
57. DNA/Genetics	GTM
58. eVehicles	GTM
59. eAircraft/ Air Taxi	GPS
60. Edge Computing	DI
61. Elder Care	Add
62. eSports	DI
63. Experiential Commerce	GTM
64. Femtech	Add
65. FinTech	GTM
66. Generics & Biosimilars	GTM
67. Healthcare IT	GTM
68. Hyperloop	DI

Technology & Innovation	
Theme	**Source**
69. Immunotherapy	GTM
70. Internet Biz Models	GTM
71. Internet-of-Things (IoT)	GTM
72. Internet Protocol (ILP)	GTM
73. IT Services	GTM
74. Last-Mile Delivery	GTM
75. Liquid Biopsy	GTM
76. MedTech	DI
77. Mental Health Tech	GTM
78. Metaverse	DI
79. Mining Capex	GTM
80. Mobile Device Demand	GTM
81. Mobile Network Transition	GTM
82. Mobile Payments	GTM
83. mRNA	DI
84. Nanomedicine	Add
85. Neurotechnology	DI
86. Non-Fungible Tokens (NFTs)	Di
87. On-Demand Media	GTM
88. Psychedelic Drugs	Di
89. Quantum Computing	Di
90. Remote Working	GTM
91. Robotic Surgery	Di
92. Software-as-a-Service (SaaS)	GTM
93. Sleeptech	Add
94. Smart Grids	GTM
95. Space	GTM
96. Telemedicine	Add
97. Video Games	GTM
98. Virtual Reality	GTM
99. Voice-Activated Systems	DI
100. Wearables	GTM
Total GTM	=69
Total Others	=31

Note: GTM = Global Theme Machine, DI = Citi GPS Disruptive Innovation Series, GPS = Other Citi GPS reports, ADD = Additional
Source: Citi Global Insights

[1] Citi Research, *Mapping Innovation: Innovation Is Everywhere; We Compare the Size, Growth, and Opportunities*, February 2022.

We started with all the themes in Citi's Global Theme Machine because they were chosen in a rigorous process involving Citi Research sector heads, strategists, and quantitative analysts. The team chose the first set of themes in 2012. Since then, they have re-examined them each year to ensure the list remains fresh, adding a handful most years, merging and renaming others, and occasionally deleting some (e.g., shale.)

We then looked beyond the GTM because it is designed for investors in public markets, and as a result, one of the criteria for choosing a theme is that there must be around 20 publicly listed companies that offer exposure to the theme. This means that many potentially interesting themes — for example, quantum computing — are not listed in the GTM. The Disruptive Innovation series fills this gap perfectly.

How Big Is the Market for Each Theme?

After finalizing our list of 100 themes, we sought estimates for each theme's global total available market (TAM) and potential growth using just over 100 third-party sources, as set out in Figure 2. For most themes we looked at several sources — up to nine in the case of Cloud Computing — but in a handful we were able to find only one source.

Figure 2. Sources for Total Addressable Market Data

360 Research Reports	Fortune Business Insights	MarketWatch	Research Nester
Absolute Reports	FutureWise Research	MarketsandMarkets Research	Restaurant Dive
Acumen Research and Consulting	Future Market Insights	MarTech Cube	Reuters
Adroit Market Research	Gartner	Marticulous Research	S&P Global Market Intelligence
All The Research	Global Industry Analysts	McKinsey	Statista
Allied Market Research	Global Market Insights	Medgadget	STL Partners
American Enterprise Institute	Grand View Research	Million Insights	Stockholm International Peace Research Institute
Baker McKenzie	Help Net Security	Mordor Intelligence	Stratview Research
BCC Research	Hosting Tribunal	National Retail Federation	SwissRe
BioSpace	Humanities & Social Sciences Communications	Nature	Technavio
Bloomberg	IDC	NeuroTech Reports	The Brainy Insights
Brand Essence Research	IMARC Group	NextBigFuture	The Business Research Company
Brookings Institution	Industry ARC	Oberlo	The Geneva Association
CCS Insight	Industry Europe	OECD	Transparency Market Research
Climate Policy Initiative	Infrastructure Outlook	Persistence Market Research	TVTechnology
Data Bridge	insight-intelligence	Power Technology	U.K. Parliament
Data Library Research	Institute for Mergers, Acquisitions and Alliances	Precedence Research	Valuates Reports
Esticast Research	International Energy Agency	Psychedelic Spotlight	Verified Market Research
Facts & Factors	KBV Research	PwC	Vision Research Reports
FemTech Analytics	Knowledge Sourcing Intelligence	Quartz	Wild Code School
Financial Times	Market Data Forecast	Quince Market Insights	World Resources Institute
Food and Agriculture Org (UN)	Market Insight Solutions	Ranking The Brands	Zion Market Research
Food Navigator	Market Reports World	Reports and Data	
Forbes	Market Research Future	Research and Markets	**n=97**
Forrester Research	Market Study Report	Research Dive	

Source: Citi Global Insights

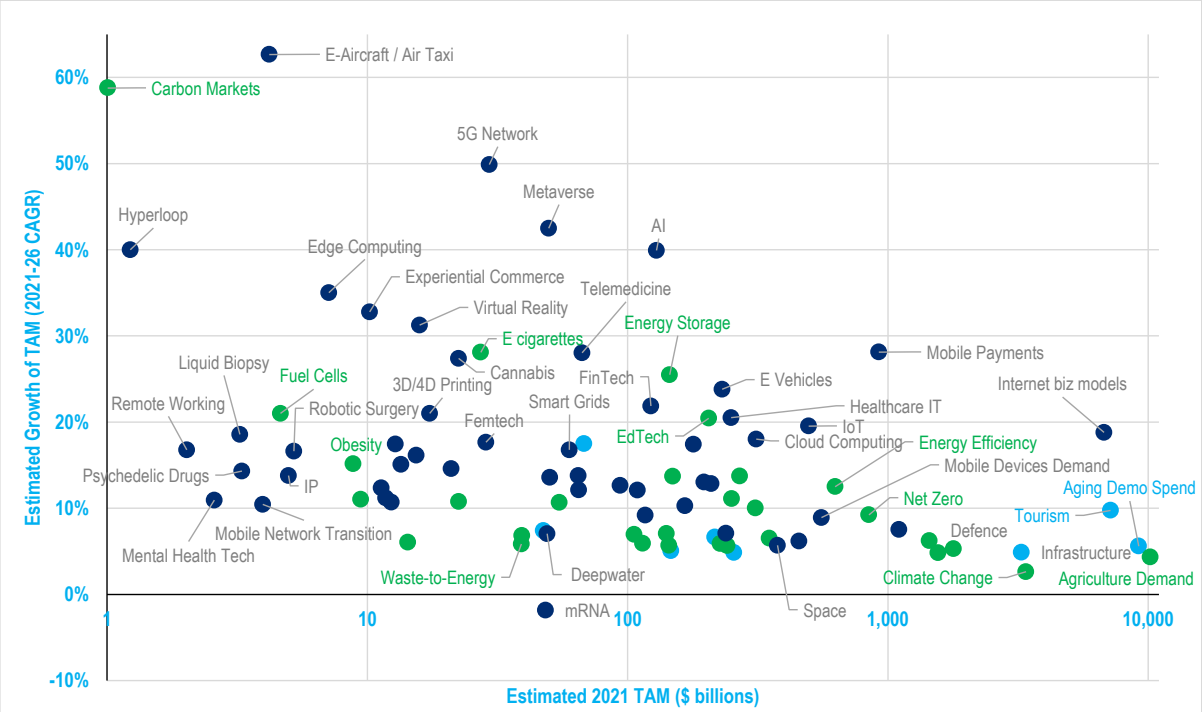
Figure 3 below summarizes the data. It shows both the average estimate for each of the total addressable markets (TAMs) for 2021 and the expected growth for the next five years.

What is immediately apparent is the huge variation in the TAMs for 2021: The chart shows that Agricultural Demand spending was about $10 trillion in 2021, whereas Quantum Computing had sales of $0.7 billion — more than 30,000 times less. Perhaps this is not surprising, as some themes are very broad and others refer to nascent technology.

There is a wide range of expected growth rates, varying from 50-60% compounded for some of the nascent industries — such as Quantum Computing and eAircraft/Air Taxis — to the low single digits for some of the big macro themes. It is no surprise that the big, macro-driven themes are growing more slowly. However, in our view, the inverse relationship, i.e., that smaller, nascent themes are growing faster, is surprisingly weak.

- **A large number of the themes are projected to grow in the single digits:** this is true for several macro themes that are already very large, such as Global Tourism and Net Zero, but also for many that are mid-size, like Deepwater Drilling technology and Waste-To-Energy plants.
- **Many of the themes with small TAMs in the single-digit and double-digit billions are projected to grow only in the teens:** Examples include Robotic Surgery, (legal) Psychedelic Drugs, and Remote Working. Consistent growth above 30% is rare.
- **By contrast, a handful of already-big innovations are expected to grow very rapidly in the next five years:** 5G Networks, the Metaverse, Artificial Intelligence, Mobile Payments, and Internet Business Models. These are the areas where the trillion-dollar market cap companies already play.

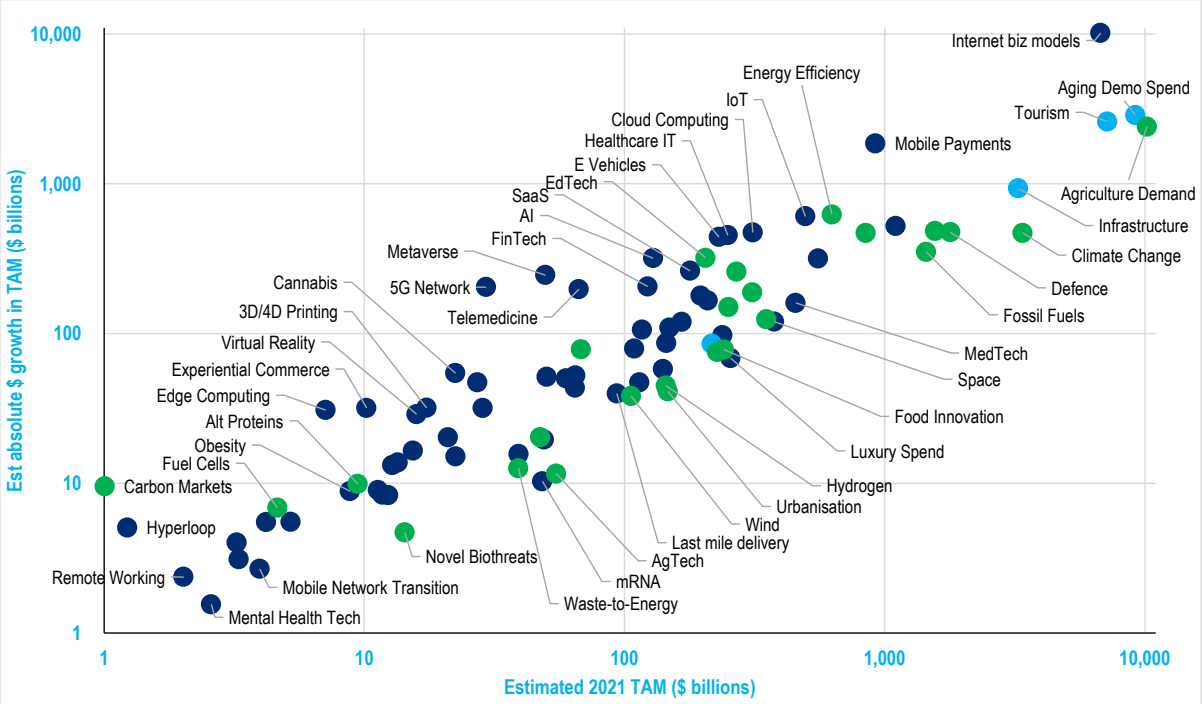
Figure 3. Predicted Growth for Themes vs. Current Size (%)



Note: Blue dots = Growth & Prosperity, Green = Sustainability & Risk. Total sources listed in Figure 2.
Source: Citi Global Insights

Figure 4 shows the same data but in a different way: The y-axis shows growth in absolute dollars, not percentages. This chart emphasizes that in absolute dollars, the largest growth will likely come from already-big sectors, which include some of the macro themes like Aging Demographic Spend and Global Tourism.

Figure 4. Predicted Growth for Themes in Absolute Dollars vs. Current Size



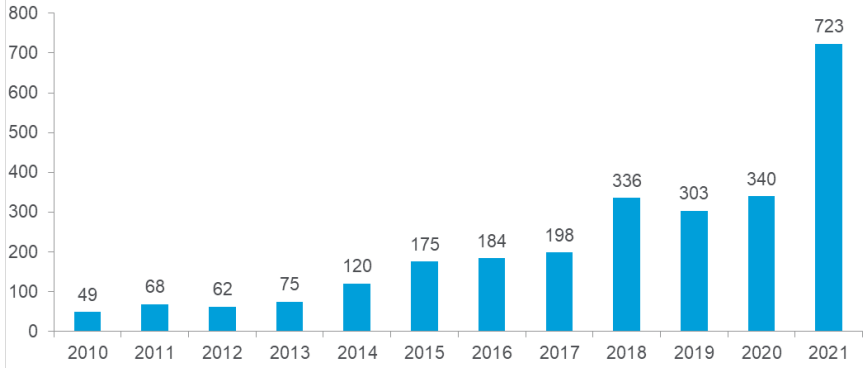
Note: Blue dots = Growth & Prosperity, Green = Sustainability & Risk, Black = Technology. See Figure 3 for growth and Figure 2 for all sources.
Source: Citi Global Insights

Falling Investment in Start-Ups

Another important issue is the decline in capital supplied to start-ups.

Between the global financial crisis and 2020, venture capital (VC) investment grew strongly, as shown in Figure 5. 2021 was a truly exceptional year, with investments roughly doubling from $340 billion to $723 billion.

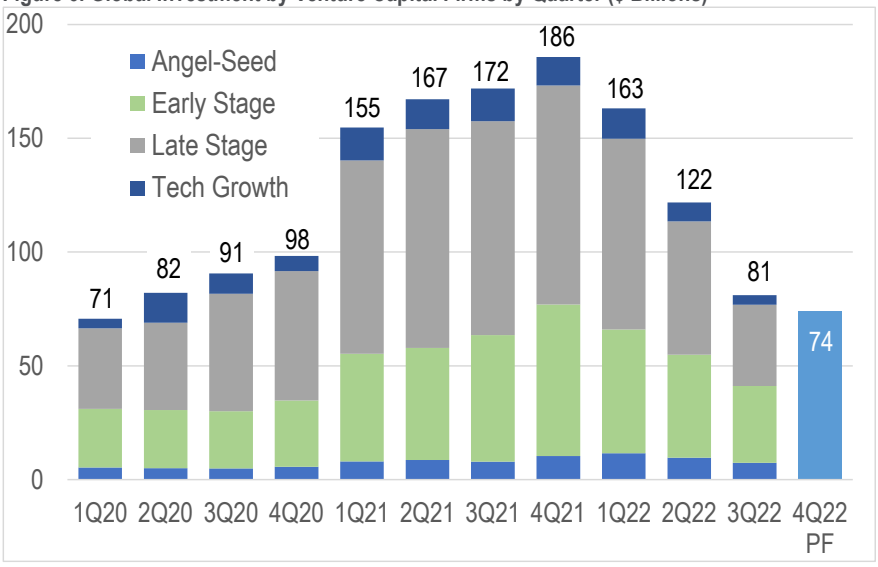
Figure 5. Global Investment in Private Companies by Venture Capital Firms and Similar ($ Billions)



Source: PitchBook Data Inc., Citi GPS

Recently, however, this trend has substantially weakened. In the first quarter of 2022, VC investment was roughly where it had been at the start of 2021. By the third quarter of 2022, it was substantially lower, as shown in Figure 6. VC funding in October and November of 2022 fell about 60% from 2021 levels, based on preliminary Crunchbase data. If this rate of decline is repeated in December, the total for the fourth quarter will end up at about $74 billion.

Figure 6. Global Investment by Venture Capital Firms by Quarter ($ Billions)



Source: Citi Global Insights extrapolations, Crunchbase

Clearly, the decline in VC funding makes life substantially harder for start-ups trying to bring innovations to market. We are not too pessimistic about the outlook, however, for several reasons.

First, it is important to remember that the data shown in Figure 5 and Figure 6 represent primary capital — in other words, cash handed over to companies' management for investment in developing and marketing new, usually disruptive, products. Companies have had to become much more careful about burning the cash they have, but they still have plenty of resources for innovating.

Second, VCs have close to record amounts of dry powder (i.e., available capital to invest). This suggests that good ideas are likely to receive backing, even if the valuations are likely to be less generous now than they would have been late last year.

Third, the Nasdaq composite has stabilized recently. It fell 30% in the first half of 2022 but has been effectively unchanged since then. VC funding is a trailing indicator, so it is not surprising to us that it fell in the third quarter. However, the column for pro-forma fourth quarter 2022 shows a much less steep decline. We are hopeful that unless tech stocks taken another leg down, the decline in VC funding will soon be over.

5G Fixed Wireless Broadband

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The broadband market for homes and small- and medium-sized businesses (SMBs) is facing a new risk of disruption from wireless firms that can now leverage their own networks to offer fifth-generation, or 5G, fixed wireless broadband access. Fixed wireless broadband service connects fixed locations, like homes, businesses, and farms, to the internet through airwaves. The competitiveness of fixed wireless broadband services (even using 5G) is often met with skepticism given the historical advantages of a fixed wired connection for both download and upload speeds. However, the combination of greater spectrum availability, ongoing network densification, and technological advancements is providing a new and compelling opportunity for wireless firms to take share from the $115 billion fixed broadband market and add to the current recurring annual wireless revenue base of over $200 billion. These new capabilities can also expand the addressable market for fixed broadband services for nomadic applications, especially in business use cases that include temporary work sites and (increasingly popular) pop-up retail locations.

By way of background, U.S. consumers and business users spend almost $550 billion annually — amounting to around 2.3% of nominal GDP in 2021 — on their communication needs for wireless, broadband connections to fixed locations, video consumption, and voice services. The home broadband market within the larger communications market represents over $90 billion of recurring annual revenue, while we estimate business spending on communication needs by SMBs represents at least another $25 billion.

Historically, broadband service to homes and SMBs was largely served by fixed wires (copper, coaxial, and/or fiber) and generally delivered by two competitors — a telecom incumbent and cable firm. The home broadband market was one of the last great duopolies in the communications category, and the absence of greater competition led to outsized annual revenue growth for the category that averaged about 7% annually over the past seven years, relative to the broader broadband category average of about 2%. Meanwhile, broadband adoption has soared, with U.S. household penetration reaching a mature 88% this year.

Fixed Wireless Access/Broadband Overview

Fixed wireless broadband and fixed wireless access (FWA) are used somewhat interchangeably to describe the opportunity to provide homes and SMBs with broadband service over a wireless network. While FWA can trace its roots as far back as AT&T's Project Angel in 2000, it was only recently, in conjunction with the deployment of mid-band 5G networks, that wireless firms have made more material strides in availability and penetration of the service.

By way of background, cable firms offer entry-level download speeds of 100 megabits per second (mbps) and can offer speeds as fast as one gigabit per second (gbps), with availability across 84% of the United States.[2] Telecommunications companies (telcos) that offer fiber-to-the-home services also offer entry level speeds of at least 100 mbps and can offer one gpbs or more, but the coverage is limited to about 36% of the U.S. In contrast, copper-centric digital subscriber line (DSL) services are available in the telco coverage footprints that do not have a fiber option, but the speeds for copper DSL tend to have limited peak download speeds, well below the current level of performance on cable and fiber connections.

[2] Based on previously published Form 477 data from the Federal Communications Commission (FCC)

While fixed wired connections can provide somewhat consistent user experiences, more factors can influence the wireless experience, especially as the capacity supplied to homes and businesses is often shared with mobile users. Historically, the balancing act between providing robust mobile service and competitive fixed wireless services was quite difficult to manage. However, the introduction of 5G services, new spectrum bands by the FCC, new software and network management techniques, and ongoing investments by the wireless carriers have opened the door to new and better service levels for fixed wireless applications.

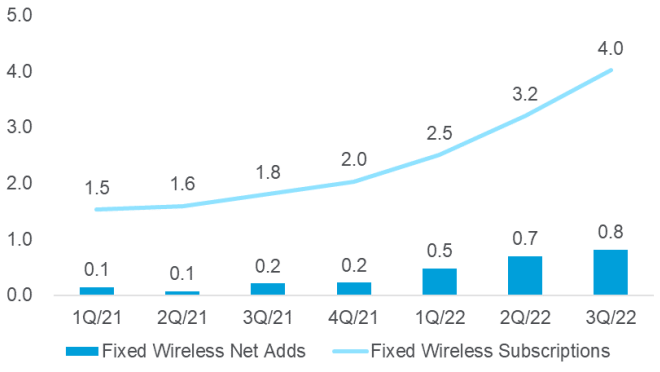
Wireless carriers are leveraging the incremental capacity gains from new spectrum and 5G technologies to offer a combination of services on the same platform: enhanced mobile, fixed wireless services, and emerging business-to-business (B2B) and Internet-of-Things (IOT) services that are anticipated to ramp in the future. By managing one network with several use cases, carriers are looking to fixed wireless services to accelerate utilization of the network.

Wireless carriers are now advertising download speeds of between 30 mbps and 300 mbps, with T-Mobile and Verizon each targeting over 100 mbps in urban and suburban areas (using mid-band spectrum). These speeds can be competitive with entry-level fixed broadband services offered by telcos and cable firms. The same wireless firms are also leveraging their networks in more rural areas to offer broadband download speeds of at least 20 mbps to 30 mbps that can be competitive or better than existing DSL services, especially if consumers do not have a competitive cable option.

Early Momentum Provides a Leading Indicator for Future Disruption

Fixed wireless broadband sales have accelerated since mid-2021 and reached over 100% of overall consumer broadband industry net adds during the second and third quarters of 2022, based on our industry analysis. We believe the new fixed wireless broadband services and the attractive value-based price points are helping to expand the broadband category overall, while also taking share from the broader ecosystem.

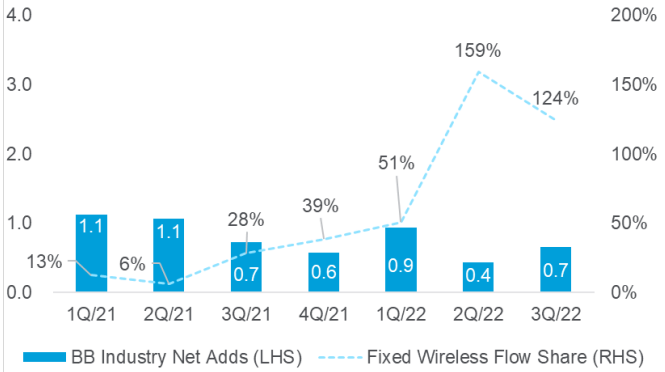
Figure 7. U.S. Residential Fixed Wireless Net Adds



Note: Residential Fixed Wireless subscriptions in 3Q 22 include AT&T (0.5M), Verizon (0.6M), T-Mobile (2.1M), and Other FWB/WISP providers (0.8M)

Source: Company Reports, Citi GPS

Figure 8. U.S. Residential Fixed Wireless Net Adds Flow Share



Source: Company Reports, Citi GPS

Cable firms and telcos have each acknowledged varying degrees of impact from the new fixed wireless competition, although cable firms remain skeptical of the sustainability of the trend, with one cable executive referring to fixed wireless as a “parking lot” from which cable will eventually grab share.

Capacity Constraints Need to Be Actively Managed

Wireless spectrum is a scarce resource, and the carriers that are deploying FWA need to actively balance the available capacity for the product against that of their core offering in mobility. In other words, the more FWA traffic is on the network, the less is available for mobile. Given this, skeptics of FWA are questioning whether fixed wireless broadband services using mid-band spectrum can handle a much larger number of gigabytes per month. To put this into perspective, monthly data consumption in the home is around 600 GB for broadband-only customers, according to the U.S. cable companies; this is 60 times the roughly 10 GB used monthly by wireless subscribers on the mobile network.

Through our analysis of wireless capacity and applying a framework previously published by the Federal Communications Commission (FCC), we find the bottleneck for capacity consumption is not gigabytes per month, but the minimum download speed (i.e., throughput) that is available to each user during the peak busy hour period of the network. As carriers can allocate more mid-band spectrum to fixed wireless applications, and as additional carriers participate in the opportunity, we believe carrier penetration for fixed wireless services can serve an average of 11%-22% of households within each cell site with advertised speeds of at least 100 mbps and applying an over-subscription rate of 5:1. To reflect the likelihood that average cell deployments are in denser areas than the average households per cell site in the U.S., we divide our results by a factor of three to be conservative.

Figure 9. Summary of Mid-Band Fixed Wireless Broadband Scenarios

		Mid-Band Spectrum Scenarios		
	Item	**60**	**100**	**140**
	Total Spectrum available	60	100	140
x	% downlink	80%	80%	80%
=	Downlink spectrum per sector	48	80	112
x	Average bits per Hz stream (Massive MIMO)	27	27	27
=	Data capacity per sector (mbps)	1,296	2,160	3,024
x	Sectors per cell site	3	3	3
=	Data capacity per site	3,888	6,480	9,072
x	Oversubscription rate	5	5	5
=	Effective data capacity per site (mbps	19,440	32,400	45,360
/	minimum data speed per user (mbps)	100	100	100
=	Maximum households per site	194	324	454
/	Households per cell site	1,723	1,723	1,723
/	Density multiplier	3x	3x	3x
=	Carrier penetration opportunity at peak capacity	4%	6%	9%
x	Number of wireless carriers	3.0	2.5	2.5
=	**Wireless industry opportunity at peak capacity**	**11%**	**16%**	**22%**

Source: Company Reports, FCC, Citi GPS

As we look forward, we expect fixed wireless opportunities and experiences to improve while carriers continue to satisfy demand from their core mobile users. Within this context, carriers are continuing to increase capacity across their networks by augmenting the amount of spectrum utilized, employing new technology that enhances the amount of available download speed on the network, and using software and new network management techniques to identify when the core mobile usage experience is at risk of underperforming from other demands on the network.

Marketing Scale Remains a Question

As carriers qualify service addresses for prospective customers, we identify two important questions:

First, can wireless firms successfully offer a self-installation that meets customer expectations for performance?

A self-installation option offers carriers a cheaper acquisition cost and a faster way to penetrate the market given that customers do not need to schedule and wait for an expert installation. The challenge with a self-installation option is that the antenna would generally need to be built into the wireless router, requiring the wireless signal to pass through walls and windows, which can degrade the quality of service relative to an installation that places the antenna on the outside of the home or building. An external antenna can also improve the capacity available for carriers to scale the fixed wireless service across a greater area, resulting in better performance for the customer.

We had thought the prevailing installation option for consumers would be a professional installation with an external antenna. However, the surprising strength of fixed wireless installations and customer base growth, even in this early stage, has been encouraging for the performance of self-installation options with antennas built into the customer premise equipment (CPE).

Second, will service availability consistently align with customer demand?

As wireless carriers are managing capacity within each cell site, the availability of homes for fixed wireless broadband is apt to be dynamic, especially in urban markets. Within a market or city, there are likely to be homes and locations that do not qualify for service until capacity is augmented. As customers adopt fixed wireless, carriers will also reach a level at which they no longer want to add homes within certain sectors of the market. This poses an interesting marketing question — will a customer's buying decision in a specific home or business location align with the availability of capacity in that specific location? We have anecdotally already witnessed addresses qualify for service upon a wireless carrier's announcement of the service's availability, but the service became unavailable months later as capacity utilization likely rose in that area, whether from greater mobile usage or fixed wireless adoption. The dynamic nature of demand within a market and the variability of capacity of supply may limit the scale of marketing. In response to the concern, carriers are looking at fixed wireless as an incremental and complementary use case to the core mobile service, rather than as a stand-alone business model.

Sizing the Market Opportunity

Wireless carriers are not setting overly ambitious targets for future FWA subscriptions, which reflects FWA's positioning as a value-based product with limited network capacity. The two largest U.S. carriers are collectively targeting up to 13 million subscriptions in the 2025-26 timeframe, which would represent about 10% of the broadband market and would be above our current industry estimate of 11.5 million in 2025.

Our base case outlook is that fixed wireless could be an annual revenue opportunity of at least $7 billion (at a monthly average revenue per user of around $50), which could add roughly 100 basis points to annual wireless service revenue growth over the next four years. With AT&T possibly entering into the category, wireless firms taking a greater focus on the SMB market, and carriers eventually deploying additional spectrum for fixed wireless broadband (including millimeter wave spectrum), we could see further upside to the fixed wireless revenue opportunity by 2025 and beyond.

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Allogeneic Cell Therapy

Cell therapy is a broad term referring to the infusion of living cells into a patient to treat or cure a disease. We believe allogeneic cell therapies — in which cells are sourced externally from master cell banks rather than being derived from patients — are the next major advance in the quest to treat and eventually cure cancer. We predict this novel category will surpass the approximately $8 billion global revenue projection estimated by 2025 for the predecessor class of autologous cell therapies. Allogeneic cell therapies will enable much broader adoption across the healthcare ecosystem than autologous methods and will yield threefold to sixfold faster treatment delivery to the patient without sacrificing efficacy or safety. Below, we outline the evolution in cancer care over the past 75 or so years culminating with the emergence of cellular therapies and explain why allogeneic cell therapies are poised to disrupt the oncology market over the coming decade.

Setting the Stage

Over the past 80-plus years, we have seen massive innovation in the development of therapies for cancer. Chemotherapy, a blunt and highly toxic tool that kills dividing cells, was introduced in the 1940s and was the mainstay of cancer therapy for much of the past century. Then, fast forward 40 years to the early 1980s, monoclonal antibodies, drugs that mimic the immune system's ability to fight off diseases like cancer, entered the scene and were heralded as the next great advance in cancer treatment. The first monoclonal antibody, Rituxan, was FDA-approved for blood cancer in 1997. In the early 2000s, we saw another wave of innovation in the fight against cancer with targeted small-molecule drugs reaching the market. The first targeted small-molecule drug, called Gleevec, received FDA approval in 2001. Ten years later, the field achieved yet another milestone, as the first antibody drug that leverages a patient's own immune system to fight tumors arrived with the 2011 approval of Yervoy.

But just in the last 10 years, novel ways to treat cancer have emerged that do not involve chemotherapy, antibodies, or targeted small molecules. This era ushered in an entirely new domain of treatment called cell therapy, where human cells derived from the cancer patient are extracted, modified, and re-introduced into the body to battle the tumor. The first such cell therapy — a "CAR-T" therapy called Kymriah that treats pediatric and young adults with a rare blood cancer, acute lymphoblastic leukemia — received FDA approval just five years ago. Kymriah and other cell therapies that have followed have revolutionized treatment of certain types of blood cancers and have been a disruptive force in the oncology therapeutic landscape, with the promise of a complete cure in the face of a devastating diagnosis with exceedingly high mortality. This sounds amazing, and it is, but it is still not enough.

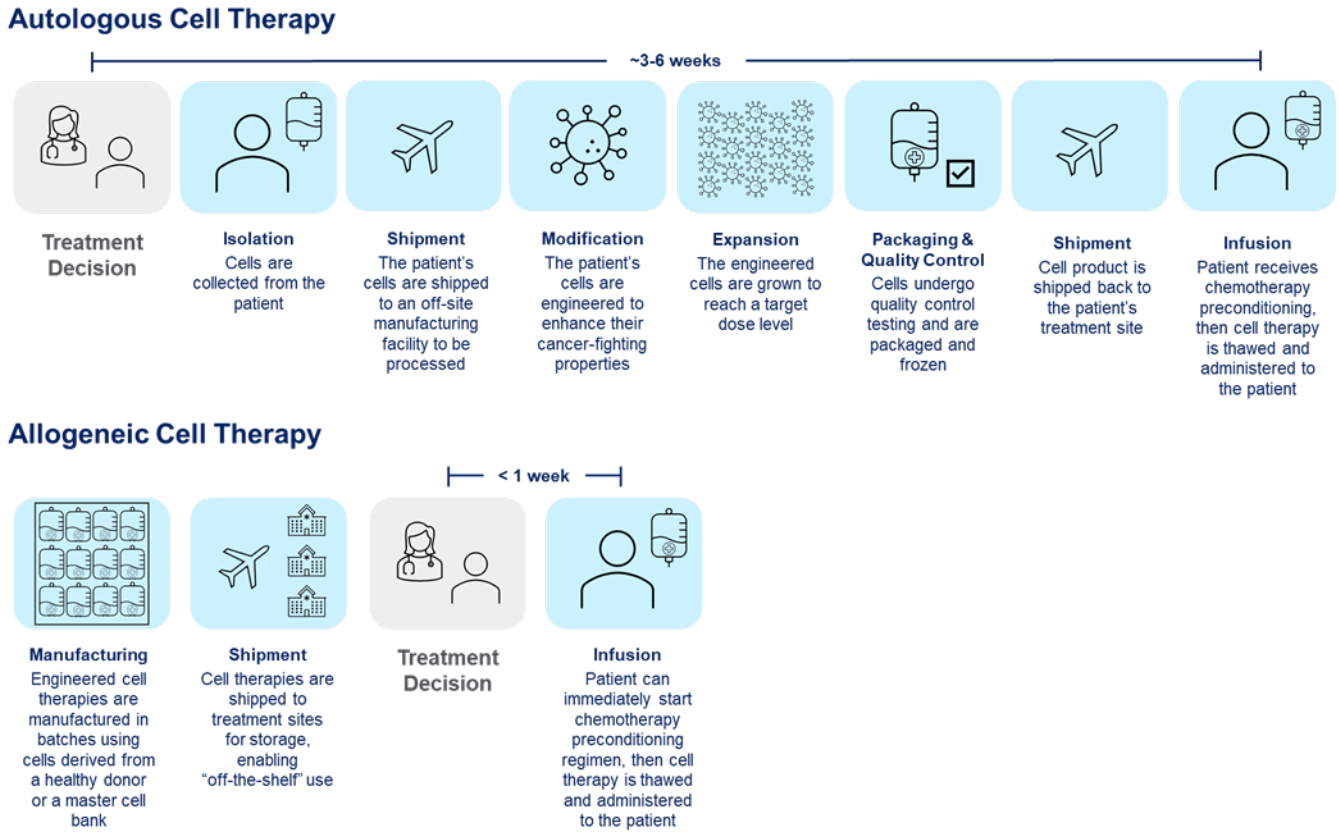
We are now in yet another era that is taking cell therapy further, beyond autologous cell therapy derived from patients themselves to the even more cutting-edge allogeneic cell therapy, where cells are sourced from master cell banks.

Allogeneic cell therapy has multiple advantages, including:

- **Much faster turnaround time:** The turnaround time — the harvesting, processing, and reintroduction a patient's cells — for autologous cell therapy can be as long as four to six weeks. An advantage of allogeneic cell therapy is that it can be manufactured at scale and stored on site for on-demand or "off-the-shelf" availability (see Figure 10 below). While autologous cell therapy is valuable, when patients are progressing quickly in their disease, oncologists often cannot wait over a month for the cells to be processed.

- **Healthier, more potent cells:** Unlike immune cells derived from the patient, allogeneic cells are derived from young, healthy donors, eliminating any co-morbidities associated with the patient's underlying disease.
- **Less chance of manufacturing failure:** Patient-derived cells may not meet manufacturing specifications given batch-to-batch variability, whereas allogeneic cells are derived from a uniform master cell bank, nearly guaranteeing adherence to manufacturing quality controls.
- **Much less invasive for the cancer patient:** With autologous cell therapy, cells must be harvested from the patient and then re-infused after genetic processing. This requires two invasive procedures. With allogeneic cell therapy, only one invasive procedure, infusing the cells, is needed.
- **Wider access to cell therapy:** Currently, autologous cell therapy is restricted to major academic centers in the U.S. given the complexities of the therapy. The adoption of allogeneic cell therapy, in view of its greater simplicity, would expand the market to second-tier urban and even community and regional hospitals.

Figure 10. Autologous vs. Allogeneic Cell Therapy Manufacturing Process



Source: Citi GPS

Cell Therapies Are "Living Drugs"

In our discussion, we will continue to focus on adoptive cell therapy, also known as cellular immunotherapy, which involves harnessing cells from the immune system to battle cancer. As noted above, the immune cells can either be derived from the individual patient (in the case of autologous cell therapy) or from a healthy donor (in the case of allogeneic cell therapy) and are often modified ex vivo (i.e., outside of the body) to enhance their cancer-fighting properties.

There are several types of adoptive cell therapy being evaluated in clinical trials, including:

- **CAR T-cell therapy:** T cells are a critical type of white blood cell that helps the body fight off infection. "CAR-T" cell therapy involves reprogramming T cells to enhance their ability to target cancer cells. The T cells are engineered to express specific proteins, called chimeric antigen receptors (CARs), on their surface. When the cells are re-infused into the patient, these new receptors help the T cells recognize, bind to, and attack cancer cells.
- **NK / CAR-NK cell therapy:** More recently, scientists have started engineering a different class of immune cells, called natural killer or NK cells, with CARs. This approach is known as CAR-NK cell therapy.
- **TIL therapy:** Tumor-infiltrating lymphocyte (TIL) therapy involves harvesting white blood cells directly from the patient's tumor by first obtaining a tumor biopsy. These cells are grown in very large numbers outside the body over several weeks and then re-infused back into the patient. Because TILs are extracted directly from the tumor, these cells have the natural ability to recognize and destroy the patient's cancer cells.
- **TCR T-cell therapy:** Engineered T-cell receptor (TCR) therapy is very similar to CAR-T. Both approaches involve modifying the receptors on T cells so they can recognize and attack cancer cells. The main difference between the two is the types of antigens the engineered cells can recognize. CAR T-cell therapy recognizes only extracellular targets on cancer cells, whereas TCR T-cell therapy also recognizes intracellular targets on cancer cells; hence, these two approaches are complementary.

Allogeneic Products Could Revolutionize Cell Therapy — but Are We There Yet?

Of the four approaches listed above, CAR-Ts are the only type of cell therapy on the market today. Since Kymriah's approval in 2017, five other autologous CAR-Ts have received FDA approval for various forms of blood cancer. However, complex and costly manufacturing has limited their commercial adoption.

Despite the appeal of allogeneic cell therapies, their development has lagged autologous approaches. Specific challenges in designing safe and effective allogeneic cell therapies stem from the immunological mismatch between the patient and the donor. For one, this mismatch creates a risk the infused, donor T cells could recognize the patient's cells as "foreign" and attack them, leading to a serious side effect known as graft versus host disease (GvHD). Second, there is the risk the patient's immune system may identify the allogeneic cells as "foreign" and rapidly eliminate them before they have had a therapeutic effect, also known as graft rejection. As a result, the allogeneic cell therapy field has been focused on strategies for improving persistence of the cells, as this should increase the likelihood of seeing durable responses.

Recent advances in gene editing tools, such as CRISPR and Cas9, have enabled development of allogeneic cell therapies designed to overcome the immune rejection and persistence challenges that have historically plagued the field. As shown in Figure 11 below, there are currently around 30 allogeneic cell therapies under evaluation in U.S. clinical trials for various forms of cancer.

Figure 11. There Are Around 30 Allogeneic Cell Therapies Currently in U.S. Clinical Trials

Company	Program	Cell Source	Target	Cancer Type(s)
Phase 3				
Atara	Tab-ce 1	EBV T cell	-	EBV + Post-Transplant Lymphoproliferative Disease
Phase 2				
Allogene	ALLO-501A	T cell	CD19	Non-Hodgkin Lymphoma
CRISPR	CTX110	T cell	CD19	Non-Hodgkin Lymphoma
Takeda	TAK-007	NK cell	CD19	Non-Hodgkin Lymphoma
Phase 1/2				
Precision	Azer-cel	T cell	CD19	Non-Hodgkin Lymphoma, B-cell Acute Lymphoblastic Leukemia
	PBCAR269A	T cell	BCMA	Multiple Myeloma
Phase 1				
Adicet	ADI-001	γƟ2 T cell	CD20	Non-Hodgkin Lymphoma
Allogene	ALLO-315	T cell	CD70	Renal Cell Carcinoma
	ALLO-605	T cell	BCMA	Multiple Myeloma
	ALLO-715	T cell	BCMA	Multiple Myeloma
Caribou	CB-010	T cell	CD19	Non-Hodgkin Lymphoma
CRISPR	CTX130	T cell	CD70	T-cell Acute Lymphoplastic Leukemia
Celyad	CYAD-101	T cell	NKG2D	Colorectal Cancer
	CYAD-211	T cell	BCMA	Multiple Myeloma
Celularity	CYNK-001	NK cell	-	Acute Myeloid Leukemia, Solid Tumors
Fate	FT516	NK cell	-	B-cell Lymphoma, Chronic Lymphocytic Leukemia
	FT538	NK cell	-	Acute Myeloid Leukemia, Multiple Myeloma, Solid Tumors
	FT596	NK cell	CD19	B-cell Lymphoma, Chronic Lymphocytic Leukemia
	FT576	NK cell	BCMA	Multiple Myeloma
	FT536	NK cell	MICA/B	Solid Tumors
	FT819	T cell	CD19	B-cell Lymphoma, Chronic Lymphocytic Leukemia, Acute Lymphoblastic Leukemia
Athenex	KUR-501	NKT cell	CD19	Non-Hodgkin Lymphoma, Acute Lymphoblastic Leukemia
Nkarta	NKX101	NK cell	NKG2D	Acute Myeloid Leukemia, Myelodysplastic Syndrome, Solid Tumors
	NKX019	NK cell	CD19	Non-Hodgkin Lymphoma, Acute Lymphoblastic Leukemia
Poseida	P-MUC1C-ALLO1	T cell	MUC1	Solid Tumors
	P-BCMA-ALL01	T cell	BCMA	Multiple Myeloma
Cellectis	UCART22	T cell	CD22	B-cell Acute Lymphoblastic Leukemia
	UCART123	T cell	CD123	Acute Myeloid Leukemia

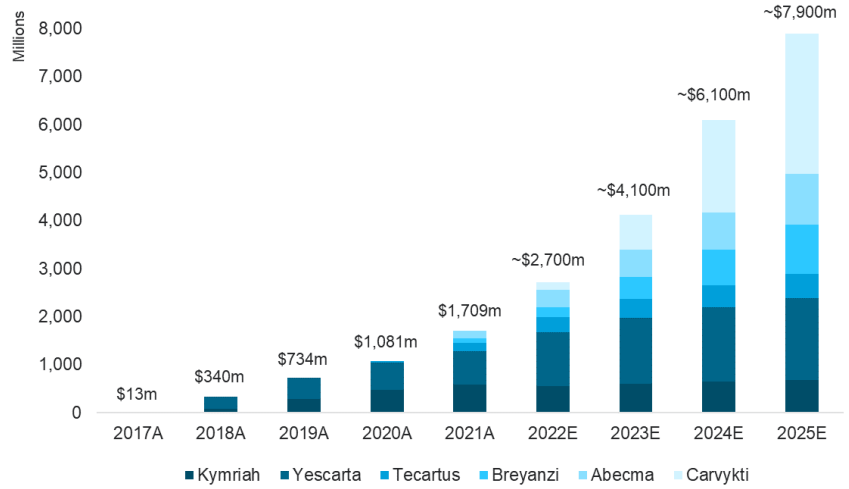
Source: clinicaltrials.gov, Citi GPS, Company Reports

Early clinical data for several allogeneic cell therapy programs appear promising, showing comparable initial response rates to benchmark autologous programs with manageable safety. The key outstanding question is whether the long-term efficacy (i.e., duration of responses) of allogeneic cell therapies will match that of autologous therapies thus far. To fully answer this question, we will need to see data from larger studies and with longer-term follow-up.

Approved Autologous CAR-Ts Alone Are Projected to Reach Nearly $8 Billion in Sales by 2025; Allogeneic Could Be Bigger

Despite the shortcomings of autologous cell therapies, annual sales for the six approved autologous CAR-Ts alone are widely expected to grow from around $1.7 billion in 2021 to nearly $8 billion by 2025 (see Figure 12 below).

Figure 12. Worldwide Autologous CAR-T Sales (Millions, 2017-25E)



Source: Visible Alpha, Citi GPS

With multiple allogeneic programs currently in late-stage clinical trials (Phase 2 or Phase 3), it is reasonable to expect that the first FDA approval of an allogeneic cell therapy could come in the next two to three years. If approved, allogeneic cell therapy could not only disrupt the existing autologous CAR-T market but could also expand the size of the pie given its multiple advantages over the autologous process. In other words, we believe allogeneic cell therapy could eventually be bigger than autologous cell therapy, which in its own right has been a major disrupter in the world of oncology over the past five years.

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Automation in Vertical Farming

The UN projects that the world population will grow from around 7.5 billion to around 9.7 billion by 2050, with two-thirds of the population concentrated in urban areas. According to OurWorldinData.org, about 50% of habitable land is used in agriculture, and the UN predicts that food production must increase by 70% by 2050 to feed the world.[3] Rising demand for farmland has led to dangerous deforestation and negatively impacted biodiversity, while soil erosion and the use of pesticides and chemicals in farming has degraded the environment further.

Climate change and a shortage of arable land are key structural challenges that could pose a serious threat to food security in coming decades. In addition, current supply chain issues and geopolitical instabilities have contributed to food supply uncertainties.

A Brief History of Vertical Farming

Vertical farming is the form of agriculture in which plants or crops are grown indoors in vertically stacked layers. Vertical farming incorporates controlled-environment agriculture (CEA) in which all parameters — such as light; nutrients; and heating, ventilation, and air conditioning (HVAC) — are controlled to optimize crop growth. Current techniques are often soilless, such as hydroponics, aquaponics and aeroponics, and instead use a variety of aqueous nutrient solutions or air as a base. Vertical farms generally grow inside buildings but can also be housed in containers, tunnels, and abandoned mines. As they are not dependent on weather, they can run year-round, bolstering their productivity. They also do not need pesticides, herbicides, or chemicals. The farms are generally built in urban centers close to where crops are consumed, thus reducing the carbon footprint of transporting crops while making fresher produce available to consumers.

Figure 13. Vertical Farms Grow Crops Indoors in Vertically Stacked Layers

Source: Siemens

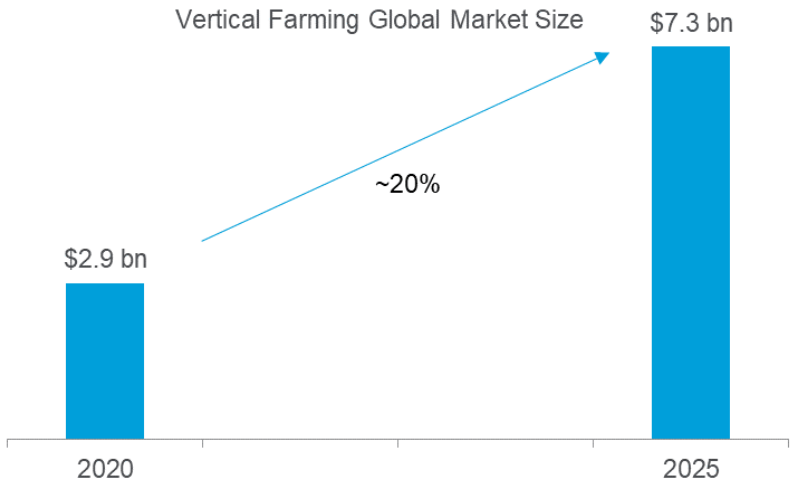
[3] Hannah Ritchie and Max Roser, "Land Use," Our World in Data, September 2019; Tim Searchinger, "*World Resources Report: Creating a Sustainable Food Future*," World Resources Institute, July 2019.

Advanced Automation Plays a Major Role in the Future and Sustainability of the Industry

Modern vertical farms claim to use 95% less water — in some cases even 99% less — than conventional farms, plus up to 99% less land and 70% less fertilizer

While the modern concept of vertical farming was first introduced in 1999, the acceleration of automation capabilities in the sector — such as robots, software, digital controls, Internet of Things (IoT), and artificial intelligence (AI) — has improved its scalability and profitability. Industry estimates suggest the industry's global market value stood at around $3 billion in 2020 and could reach $7.3 billion by 2025 and $25 billion by 2030, driven by the technological innovations in the sector. With automation innovations, such as those listed above, modern vertical farms claim to use 95% less water than conventional farms — in some cases even 99% less. As for land usage, some experts claim vertical farms could potentially use 99% less land compared to conventional farms, as well as around 70% less fertilizer.

Figure 14. Vertical Farming Is Expected to Grow Rapidly Due to Acceleration in Technological Advancements



Source: NASA, Citi GPS

Vertical farming technology can help with attaining many of the UN SDGs

New technology can help to attain many of the UN's Sustainable Development Goals, such as Goal 2 — Zero Hunger and Goal 3 — Good Health and Well-Being, by providing a means of producing sustainable and nutritious food. By using around 95% less water than traditional farming, vertical farming also furthers Goal 6 — Clean Water and Sanitation. It also produces much less food waste than traditional farming, contributing to Goal 12 — Responsible Production and Consumption. By reducing deforestation and soil usage, it can help achieve Goal 13 — Climate Action. Apart from these goals it furthers directly, vertical farming also contributes to Goal 11 — Sustainable Cities and Communities and Goal 9 — Industry, Innovation, and Infrastructure.

Advanced Control Systems Are Increasing Efficiency, Scalability, and Profitability

The most advanced vertical farms are fully connected and digitally controlled, just like an advanced automated manufacturing plant

Control systems, as the name suggests, control a vertical farm's growing conditions, monitor the environment, and leverage AI to make optimal decisions about conditions at various stages of crop growth. The more advanced vertical farms are fully connected and digitally controlled, just like an advanced automated manufacturing plant.

The control systems integrate hardware, software, automation controls, sensors, machine vision, machine learning, SCADA (supervisory control and data acquisition) systems, and manufacturing execution systems (MES) to gather data and make intelligent decisions. The systems are therefore comparable to current advanced manufacturing assembly lines, though managing the conditions for living organisms is more complex.

Current advanced control systems provide critical data on the health of the crops and optimize all the parameters ranging from lighting and nutrients to HVAC. The system controls the intensity of the light and knows the exact spectrum required for optimum growth at different stages. It also changes the course of the nutrient recipes and supplementary CO2 as the crop grows. In the next decade, next-generation vertical farms could be equipped with these integrated control systems, which could further improve energy efficiency and crop yields and drive unit economics and profitability, which is very important for the future of the industry.

Due to technological advancements over the last decade in lighting, HVAC, and automation systems, vertical farming has rapidly evolved and has become commercially viable for certain crops like leafy greens.

Notable Practical Developments and Initiatives

In July of 2022, Dubai opened the largest vertical farm in the world, covering 30,000 square meters and set to produce 900 metric tons of leafy greens annually. It can grow crops ranging from lettuces and mixed salad greens to spinach and arugula. The system uses 95% less water compared to the same crops grown in fields. In addition, crops harvested via vertical farming need no washing, as there is no use of chemicals, herbicides, or pesticides.[4]

A consortium of four British companies is exploring a series of sites between Dumbarton and Dundee as the location for Scotland's next generation of vertical farms. The farms would use 100% renewable power and would provide fresh foods like salad and fruit to over 60% of the Scottish population. The Scottish government aspires for the country to produce more fruits and vegetables domestically, and one hectare of vertical farm can provide fresh produce to a town of 10,000. Each site would also host wind, solar, and energy storage apart from vertical farming to maximally utilize the available land.[5]

Many other governments want to ensure locally produced, fresh food for their people. For example, in 2015 Qatar announced plans to grow 50%-70% of the country's vegetables locally by 2023 via vertical farming as part of its National Food Security Strategy.[6]

[4] Victoria Masterson, "*Dubai Has the 'World's Largest' Vertical Farm — Is This the Future of Agriculture?*" World Economic Forum, May 13, 2022.
[5] Vertical Farm Daily, "Consortium Plants to Build New Vertical Farms in Scotland," April 21, 2022.
[6] Jason Lemon, "*Qatar Will Grow 50 to 70 Percent of its Own Vegetables by 2023*," stepFeed, August 26, 2015.

How Much Does It Cost to Automate a Vertical Farm?

Research conducted by CambridgeHOK estimated the average cost of a level-one vertical farm, which is reliant on manual labor for watering and harvesting, would be around £1,200-£1,400 (approximately $1,500-$1,700 as of December 9, 2022) per square meter for total size of up to 500 square meters. A level-two operation, which uses manual labor for sowing and harvesting but automation for watering and cultivation, would cost £1,400-£2,000 per square meter for a total size of 500-2,000 square meters. Meanwhile, a level-three, fully automated vertical farming operation would cost £1,750-£2,250 per square meter for a total size of 2,000-10,000 square meters.[7] Thus, an industrial-sized 10,000-square-meter vertical farm would cost around $2.6 million for level-three full automation. These are indicative costs and vary from case to case.

Different Business Models Blooming in the Sector

Complementary business models to vertical farming include technology providers, Farming as a Service (FaaS) companies, and contract-based R&D services

- **Vertical Farming Technology:** Many well-known vertical farming companies use their own proprietary technologies to produce their own crops to sell to the market. To do this requires investment in R&D and innovation, as well as capital expenditure. Other companies provide the technology to farmers to operate their own vertical farms, eliminating the need for farmers to invest in innovation and R&D themselves.
- **FaaS (Farming as a Service)** is a service framework offering a suite of agricultural management solutions for controlled environment agriculture (CEA) facilities. Services range from providing experts and systems to start a vertical farm, to fully managing onsite farm operations, including providing control systems. Using a service model allows farmers to swap fixed upfront costs to variable costs while gaining access to the latest technology.
- **Contract-Based R&D Services:** Some companies offer contract-based R&D services that provide information on plant-growth optimization and software for optimizing conditions and collecting plant-growth data.
- **Customization and Premiumization:** A survey from Forager found that over three-quarters of respondents were willing to pay a 20% premium for locally grown food, which allows for differentiation premium.[8] Innovation in lighting enables customization in texture, crispiness, and flavors, qualities for which premium retailers and restaurants are willing to pay. Thus, even if unit economics in many crops are not yet comparable to traditional farming, customization and premiumization could hold the keys to success.

[7] Cambridge HOK, "*How Much Does Vertical Farming Cost*," Accessed October 23, 2022.
[8] Isabelle Gustafson, "Consumers Increasingly Value Local Food," CStoreDecisions, January 30, 2020.

Vertical Farming Automation Is Still in Its Infancy

Though many vertical farms claim to be fully automated, most are not and still need human labor, which forms an important part of the cost. Many vertical farms are still not profitable.

But as vertical farming technology advances and more operations are automated, their scale is widely expected to increase, and their costs are expected to fall. While many investors focus on the financials of vertical farm companies, they underappreciate the technology providers and original equipment manufacturers given the current size of the market compared to other industrial automation markets. Lighting and lighting controls play an important role in increasing the efficiency and productivity of vertical farms. For many industrial lighting companies (outside of startups in agri-lighting), the vertical farming market is a relatively small piece of their businesses, but rapidly growing.

Barriers to Adoption: Unit Economics and Number of Crops Need to Increase

- **Automation enables profitable vertical farming but requires capital expenditure.** Many vertical farms, barring a few, are still loss-making. Vertical farming is a high-growth industry but needs initial capital and incentivizing policies in place to support sustainable growth.
- **There are only a small number of crops with commercially viable vertical farms based on unit economics**. Crops such as herbs and salad leaves have high plant density and short turnover, leading to lower required resources during cultivation. Currently, vertical farming only serves a small portion of traditional crops.
- **Vertical farms are energy intensive.** If the energy used comes from fossil fuels, the carbon footprint of vertical farms is greater than that of conventional farms. Using energy-efficient LEDs and cleaner energy sources can help vertical farms operate more efficiently.
- **Crops that can be stored for many days are much more economical to grow via field farming.** Vertical farms, which operate closer to urban centers where most consumers live, are more valuable for growing more perishable crops.

Sectoral Impacts of Advanced Automation in Vertical Farming

Sectors that will benefit include:

- **Automation, software, and robotics providers:** Traditional industrial automation players also have a presence in this field.
- **Lighting:** LED lighting is a very important part of vertical farming. Reduced LED prices and an increase in LED lighting efficiency has been a driver of the vertical faming sector's growth. Unlike conventional lighting, LEDs can be effectively controlled with automation, and research is ongoing to increase the efficiency of LED lighting. Specifically, researchers are trying to determine which particular spectrum of light is most efficient at each stage of crop growth; this knowledge could help further reduce the energy consumption of vertical farming.

Sectors that may suffer include:

- **Pesticides, herbicides, agricultural chemicals, and fertilizers:** Though we do not think vertical farming can replace traditional farming, it has the potential to be an important part of the mix. However, as it increasingly takes share from traditional farming in the future, the demand for pesticides, herbicides, fertilizers, and chemicals will decrease.
- **Farm equipment:** The manufacturing of traditional farm equipment, such as tractors, could be at risk if vertical farming becomes a meaningful percentage of the farming industry.

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Data Fabric

Data fabric is a unified architecture of services that standardizes the way data on a multi-cloud, multi-location, and multi-platform environment is managed.

Most organizations today deal with large amounts of data across several business units. A key problem any organization that stores and uses large amounts of data on its servers will face is accessing that data in a multi-platform architecture. Further complicating the problem is the fact that over the last decade, both structured data sources (i.e., those with clearly defined data types) and unstructured data sources (i.e., those that are not typically easily searchable) have increased significantly in number. This has led to the creation within organizations of many data repositories (entities storing large amounts of data for the purposes of data mining, reporting, and analytics) that are not readily accessible to more than one team.

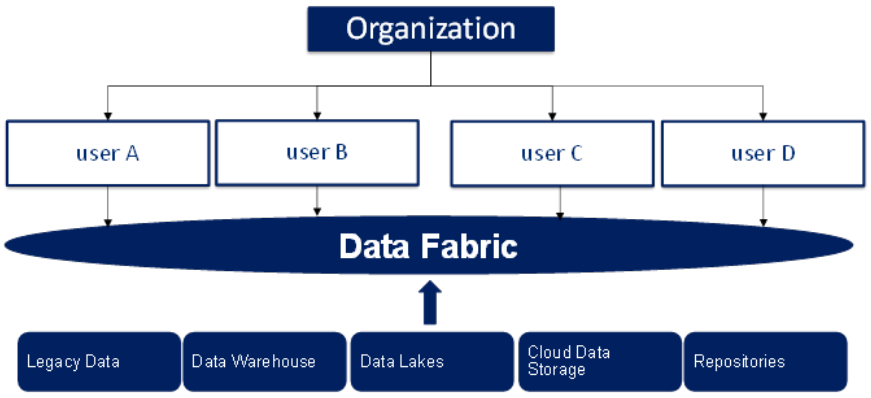
Most legacy systems are built in such a way that each line of business in a large organization has its own way of storing and accessing data. But today's systems are more integrated and highly data intensive, making such an approach infeasible and too costly to maintain. They are also extremely time-consuming considering how quickly the overall amount of data and number of data repositories have increased in businesses over the last few years.

Data fabric simplifies access to data across platforms, irrespective of data types

What organizations need is to simplify access to data and its management in a heterogeneous way, avoiding duplicating storage and making all data available across the entire organization. That is where data fabric comes in.

Data fabric is an architectural approach that breaks down the data repositories; enables access to data by users across the organization; and allows mining, integration, and usage of that data across multiple platforms irrespective of the location of the users or the data itself. Data fabric helps with the automation and integration of data from various departments, its delivery, and at times even its analysis.

Figure 15. Typical Data Fabric Architecture



Source: Gartner, Citi GPS

Moreover, different organizations have different sets of platforms where they store and access data. Therefore, a "one design fits all" solution does not apply to data fabric, as the data must be customized per the needs of the business. The purpose of data fabric is to expand the scope of data usage beyond the initial intended use.

Key Components

As outlined by multiple data fabric solution providers, including IBM and ScaleFresh, data fabric architecture consists of the main components in Figure 16. These components work together not only to integrate the data and make it accessible, but also to ensure its security and the data's alignment with its expected end use.

Figure 16. Key Components of Data Fabric

Source: IBM, ScaleFresh, Citi GPS

- **Data Aggregation and Access:** The most important function of data fabric is making data easy to access — i.e., ensuring it is available from all different sources and platforms without the need to copy terabytes of data. Data fabric sits above all the data sources, aggregates access to them, and helps people use the data without moving it from its original source. Even if data copying is necessary, depending on the intended application, data fabric architecture can do it robustly. Moreover, this architecture works with all data types across all sources that store the data — structured and unstructured.
- **Data Processing:** This component provides users with a set of applications that help make data available to them for analysis across different platforms, such as Python or Power BI.
- **Data Management:** Another aspect of data fabric is ensuring the right users have access to the right data. Not all data should be accessible to all users, and regulatory breaches should be avoided. Metadata can help automate these requirements.
- **Data Orchestration:** This involves taking data from different locations, organizing it, and making it available to end-users across the organization.

- **Data Discovery:** This lets users seamlessly identify and mine data from multiple sources, integrate it, and derive patterns from it that they otherwise could not.

Data Automation

Data fabric architecture can be further expanded by adding in artificial intelligence and machine learning tools to help automate the fabric and minimize human interference and errors.

Status Quo

Most organizations are still using legacy systems

Most organizations globally are still using multiple repositories, including data warehouses, legacy systems, and cloud data stores, among others. These existing systems tend to work well with the specific platforms they were designed for, but not across systems. This makes them not only difficult to use, but also costly and slow to work with.

Therefore, the need for increased awareness around data solutions, like data fabric, is essential considering the ever-increasing amounts of data companies deal with and the availability of provider-based data fabric solutions.

In addition, many businesses are starting to realize the long-term benefits of such architecture and planning to invest in data fabric upgrades in the coming years. Data is at the forefront of almost every industry, making this a must-adopt technology for companies around the globe.

What Can Go Wrong?

There are a few concerns regarding the implementation of data fabric.

There is no ready-made, one-size-fits-all solution

One is the lack of a one-size-fits-all solution. Every organization has its own challenges around the method, location, and format of data storage. Therefore, implementing data fabric solutions requires meticulous planning that can be complex and time-consuming depending on how the existing systems are built. Data fabric solutions are not implemented overnight, and implementation requires a deep understanding of an organization's existing data.

Data security concerns make data fabric more complex

Another concern is around the security of company data. In existing legacy systems, datasets are spread across different platforms, making breaching the protection for the entire data set difficult. However, in the case of data fabric, all data is exposed to a single source, necessitating significant investment in upgrading the data fabric security layer. That said, a data fabric solution, if efficiently implemented, can potentially make data more secure.

Failures can cause a cascading effect

If a data fabric architecture fails for any reason, the issue will have a cascading effect across businesses in the organization. The more complex a system, the more fragile it is. This makes monitoring a data fabric difficult, and failure is a risk if it is not properly monitored.

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DAOs, Capitalism, and Employment

We live in a digital world. Internet-driven business models and communities have reshaped media, communication, shopping, commuting, money, banking and finance, art, and now, virtual worlds.[9]

These same technological advances are now calling into question the fabric of ownership and employment: How should capital and labor be organized in an internet- and blockchain-driven world?

What Are DAOs?

A decentralized autonomous organization (DAO) is collectively owned and governed by its members, with rules set and executed through code (smart contracts). As public limited companies (PLCs) were to the industrial era of the 19th century, DAOs may be to the 21st century internet and blockchain economy.

A DAO is enabled by distributed ledger technology (i.e., blockchain), cryptocurrencies, and smart contracts (self-executing contracts with the terms of the agreement directly written into lines of code). At the technology's core, community members propose and vote upon decisions on-chain to ensure decentralization and transparency.

Proposals that achieve consensus are enforced by smart contracts. Profits generated by the DAO are distributed to token holders, either via airdrops to governance token holders or through a staking mechanism.

Figure 17. DAO Primitives

Note: Heterarchy is an organizational structure where the elements of the organization are unranked (non-hierarchical) or potentially ranked in a number of different ways.
Source: Medium, cdixon.org, Citi GPS

The first DAO was built on the blockchain and launched in May 2016 through a crowdfunded token sale, raising around $150 million. The DAO's mission was to fund projects, similar to a VC fund but voted on by its token holders.

This first ever DAO quickly ran into problems. In June 2016, a hacker found a flaw in the smart contract code and began to drain funds from the DAO. This was the beginning of the end of the so-called genesis DAO.

[9] Citi GPS, *Future of Money: Crypto, CBDCs and 21st Century Cash*, April 2021; Citi GPS, *Metaverse and Money: Decrypting the Future*, March 2022

Since then, DAOs have proliferated. The exact number of DAOs today is unclear, but estimates suggest close to 5,000 exist, with more created but inactive. Their cumulative value, including governance tokens, is almost $10 billion.[10]

At their core, DAOs are organizations. But unlike traditional ones controlled by a select few leaders, DAOs are much more decentralized in decision-making. Key features of DAOs versus traditional organizations are summarized in Figure 18.

Figure 18. Decentralized Autonomous Organization (DAOs) vs. Traditional Organizations

Decentralized Autonomous Organizations	Traditional Organizations
Usually flat and democratized	Usually hierarchical
Members need to vote to implement any changes	Depending on structure, changes can be demand from a sole party or a group
Votes tallied, and outcome implemented automatically without need for a trusted intermediary	Votes are tallied internally, and the outcomes of voting are handled manually
Services offered are handled automatically in a decentralized manner	Requires human handling or centrally-controlled automation
All activity is transparent and fully public	Activity is typically private and limited to the public

Source: Citi GPS

DAOs are different, but not an entirely new concept

Community-based models have existed for millennia. Early humans worked in groups to hunt and fish animals or forage for vegetation.

Modern co-operatives date back to the 18th century as people moved from farms to cities. By the mid-19th century, several formal co-operatives started out as local community-led groups in Western Europe, North America, and Japan.[11]

Borrowing the broader community framework from modern co-operatives, DAOs build on the concept of collective ownership by leveraging distributed ledger technology (DLT) to allocate decision-making, management, and ownership.

The funds of a DAO are stored in its own treasury and governed by smart contracts, which means DAOs, unlike co-operatives, do not need to rely on banks or external financial institutions to store funds.

DAOs also differ from traditional co-operatives in governance, as they usually implement a “one token, one vote” mechanism as opposed to the one member, one vote system found in most traditional co-operatives.

Why Do We Need DAOs?

Decentralized governance offers the possibility for thousands or even millions of individuals to make decisions collectively at scale, resolve the agent-principal problem (i.e., a conflict in priorities between a group and the representative authorized to act on their behalf), and improve transparency.

- **Resolves Agency Problem:** DAOs introduce community governance, where stakeholders do not need to trust agents working on their behalf. The

[10] DeepDAO, “Organizations,” accessed September 20, 2022.
[11] International Cooperative Alliance, “The History of the Co-Operative Movement,” accessed September 27, 2022.

organizations distribute collective risk and rewards based on programmatically executed rules.

- **Infuses Transparency:** All transactions in a DAO occur on-chain and are trackable and observable. The community can review spending, funding allocations, and fulfillment of plans, for example.

Figure 19. Prominent Real World Use Cases of DAOs

Protocol DAOs

Focused on governance of decentralized protocols, such as borrow/lending applications and decentralized exchanges. Prominent protocol DAOs include MakerDAO, Uniswap and Yearn Finance.

Philanthropy DAOs

Focus on supporting social responsibility initiatives and other community-driven projects. For examples the Big Green DAO focuses on food justice and gardening initiatives.

Investment / Venture DAOs

Pools capital to invest in early-stage start-ups, protocols, off-chain investments and other DeFi projects. Helps democratize & decentralize investment processes. Popular investment DAOs include MetaCartel Ventures, BitDAO etc.

Grant DAOs

Fund innovative new DeFi projects, based on applications received from start-ups. These DAOs depend on community-based donations to the grant pool, which are then allocated to different projects based on collective votes. E.g., Aave.

Collector DAOs

Aimed at NFTs & artists to support ownership of art and content. ArtsDAO represents the largest NFT community in the Middle East, composed of investors, artists, creators, collectors, and Web3 developers.

Metaverse DAOs

Metaverse will be able to operate autonomously, creating a new ecosystem built around tokens. Metaverse could be governed by a DAO, members of which will vote on proposals that affect the metaverse's future.

Social DAOs

Foster communities and personal connections by bringing like-minded people together and coordinating activities via tokens. Many crossovers from Collector DAOs to Social DAOs such as Board Ape Yacht Club.

Other DAOs

In addition to the prominent DAOs discussed above, other variants could include Media DAOs, Service Guild DAOs, Entertainment DAOs, Gaming DAOs, Operating System DAOs etc.

Source: 101 Blockchains, Alchemy Blog, Ledger Academy, Citi GPS

DAOs: Remaking Shareholder Capitalism into Digital Community Ownership

Critics view the shareholder model of capitalism as providing less power to creators, users, and employees, while maximizing the value for uninvolved shareholders. While this form of capitalism may lead to growth, it can also lead to problems of inequality, social and economic instability, and corruption.

DAOs can facilitate inclusive access, providing small investors and contributors with access to the DAO's content and a voice in organizational decisions. DAOs can also potentially help unlock access to private investment opportunities previously available only to wealthy investors. But what, specifically, are DAOs best suited to building and operating?

DAOs and Ownership-Embedded Employment

DAOs enable more individuals to collectively work for themselves as employment styles and structures change: Examples include the rising popularity of portfolio careers, the digital nomad lifestyle, and virtual corporations, which were all accelerated by high-speed internet as well as greater acceptance of the work-from-home model that COVID-19 turbocharged.

In a DAO, members vote on the work to be done, unlike in traditional organizations where a manager allocates team tasks. DAOs can help align employee skillsets better with work — if a member is not interested in a project, they can choose not to do it and somebody else can pick it up.

- **More Autonomy, Better Monetization:** Increased lifestyle flexibility and control have enabled today's creator economy of artists, vloggers, podcasters and the like to flourish through short-term contracts.

  As DAOs proliferate, instead of having one employer and a defined working week, individuals may be able to contribute several hours a week to multiple DAOs, resulting in more autonomy in the monetization and scheduling of work hours.

  DAOs are likely to attract self-motivated individuals who share an organization's specific vision. Thus, DAOs are well-suited to strengthen workers' engagement by rewarding them with ownership in projects, mitigating the agent-principal dilemma. ***DAOs could grant more autonomy over where, when, and how an employee works.***

- **Freedom to Pursue More Fulfilling Work:** According to a report by Gallup, 85% of the global workforce today is not engaged or actively disengaged at work.[12] DAOs could offer employees freedom to choose projects where: (1) they share the company's mission and vision, (2) the role aligns with their core competences, and (3) talented and like-minded co-workers are present.

  The technology-centric nature of DAOs may also help automate trivial tasks using smart contracts that could further free up employee time for more critical and creative work.

- **Different Compensation Streams and Structures:** DAOs could enable ownership and governance in an Open Metaverse, driving newer monetization methods for contributors. For instance, a DAO employee can contribute to content moderation of the virtual world where kids play, learn, socialize, and earn native DAO or Metaverse tokens, thereby making the employee the owner and aligning their interests with that of the DAO and the Metaverse. See our Citi GPS report *Metaverse and Money: Decrypting the Future* for more on the Metaverse.

Risks and Challenges of DAOs

DAOs are still in their infancy and issues related to their effectiveness, governance and technology still need to be addressed. In addition, mainstream adoption of Web3 (a third iteration of the internet based on blockchain where individuals have the potential to monetize their own data) — which may drive DAO growth — depends on the successful resolution of questions related to user experience, security, scalability, and regulatory clarity.

- **Limited Purpose, Short-Lived:** Most DAOs tend to be short-lived, focusing on a specific task or project (e.g., raising funds, agreeing on a proposal) and then ceasing to exist. Unlike traditional companies, DAOs rarely operate with a very long-term view, transcending generations of employees, management, and shareholders.

- **Decentralized Leadership and Execution Challenges:** Although DAOs flatten certain hierarchies and make it easy for members to switch their contribution

[12] Gallup, "State of the Global Workplace: 2022 Report," June 2022.

across projects and tasks, making decisions on transformative ideas in a decentralized community can be challenging. Critics of DAOs may argue that disruptive innovation is often driven by just a handful of visionary leaders.

- **Nascent Technology and Code Vulnerabilities:** Smart contracts running a DAO are prone to hacks and exploits. This can result in breakdowns of the mechanism needed to run the DAO efficiently. For instance, the very first DAO launched in 2016 via a token sale and was hacked for $50 million in the same year via the exploitation of vulnerabilities in its code base.[13]

- **Risks From Too Much Transparency:** DAOs are fundamentally transparent and public, allowing anyone to see their on-chain activities. While this can be good for building trust, it also reveals details of ongoing projects and activities. This makes DAOs vulnerable to unfair competition practices, and DAO members may be prone to increased risk of social engineering schemes from malicious actors.

> The question of whether DAOs are efficient enough to compete with centralized service providers can be answered by the view that DAOs are very good at managing treasury globally. I think it really depends on what a DAO is doing, what objective is, and what it tries to achieve. In my opinion, DAOs are very good at governing public goods or infrastructure that have a greater base than one particular company. But when it comes to actually building something efficient, a DAO might not be very suitable. However, we're still in the early stages. We might see a very efficient way of building things through DAOs soon.
>
> – STANI KULECHOV, FOUNDER AND CEO OF THE AAVE COMPANIES[14]

- **Potential for Low Voter Turnout, Minority Holding Majority of Tokens:** DAOs assign one vote to each token, not one vote to each token holder. This has led to ongoing debates around the use of other voting methods such as relative quorum voting, which requires a certain number of members to participate in the voting process. Low voter participation is another concern: On popular decentralized protocol platforms like UniSwap, Decentraland, and Compound, it is often under 5%.[15]

[13] Nathaniel Popper, "A Hacking of More than $50 Million Sashes Hopes in the World of Virtual Currency," *The New York Times*, June 17, 2016.
[14] Citi GPS, *Metaverse and Money: Decrypting the Future*, March 2022.
[15] DeepDAO, "Organizations," accessed September 19, 2022.

- **Shadow Voting and the Rise of Dark DAOs:** Shadow voting occurs when an individual borrows a governance token, exercises the right to vote without any economic stake in the protocol, and then returns the tokens to the lender. The rising number of Dark DAOs, which buy on-chain votes opaquely, facilitates the purchase of user votes to overwhelm governance systems or engage in market manipulation.
- **Identity and Know Your Customer (KYC) Risks:** DAO members often choose to remain pseudonymous and are known only by their avatars, posing a challenge for anti-money laundering and KYC policies.
- **No Arbiters:** DAOs often do not have an arbitrator or a Human Resources department to resolve employee conflicts.
- **Lack of Regulations:** There is a general lack of regulations around DAOs. So far, only the state of Wyoming in the U.S. formally recognizes DAOs and gives them the same legal power as a limited liability company. The draft Responsible Financial Innovation Act proposes a change to section 7701(a) of the Internal Revenue Code of 1986, adding a section on DAOs in an attempt to define them, but there is currently no mature regulatory framework on how to deal with DAOs.
- **Imperfect Decentralization and Autonomy:** The September 2022 Commodity Futures Trading Commission (CFTC) enforcement action against a DAO called Ooki DAO and its founders, Tom Bean and Kyle Kristner, calls into question the degree to which DAOs are truly decentralized and autonomous. The founders of the DAO were charged as controlling active participating members of the entity and given a $250,000 penalty and a cease-and-desist order.[16]

Future of DAOs as a Foundation of the Creator Economy

DAOs operate on an economic model that grants individuals the flexibility to rent their talent and time to specific projects in order to earn rewards by leveraging fractional ownership in a community-governed ecosystem.

DAOs could also play a crucial role in the Open Metaverse. Using DAOs, content creators can own their original creations and monetize them, and the value can be manifested as NFTs (non-fungible tokens) or tokens. DAOs can also be used to govern the Open Metaverse, or parts of it.

The Metaverse combines the physical and digital worlds in an immersive manner. While the centralized vision of the Metaverse would likely resemble today's current Web2 internet with platform gatekeepers, user data monetization and embedded advertising, the Open Metaverse would be community-governed and, over time, freely interoperable.

> "The Open Metaverse will encapsulate composable DeFi protocols and programmable NFTs governed by DAOs. The economic value of the Open Metaverse could be at least $5 trillion by 2030."
>
> – IOANA SURPATEANU, WEB3 AND DEFI INVESTOR, ADVISOR, AND ENTREPRENEUR[17]

[16] Commodities Future Trading Commission, "Release Number 8590-22," September 22, 2022.
[17] Citi GPS, *Metaverse and Money: Decrypting the Future*, March 2022.

As Web3 infrastructure proliferates and offers the possibility of redefining traditional paradigms of gaming, social media, money and finance over the next five to 10 years, we are likely to see more of these communities being governed by DAOs.

In the coming years, DAOs could challenge the way we think about organizations by putting emphasis on self-governing businesses. And even if existing corporate structures do not wither away, DAOs represent a mindset and an ethos that may influence existing structures to become more participatory.

High-NA EUV Lithography

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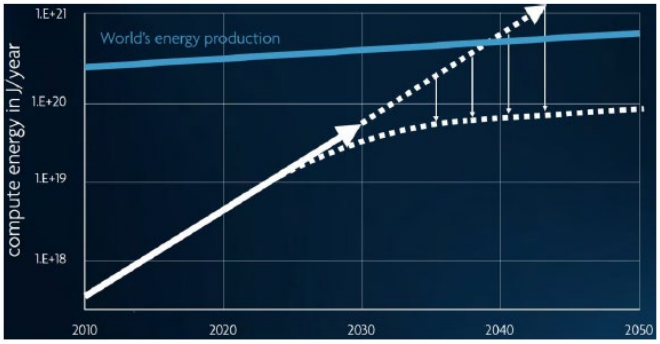
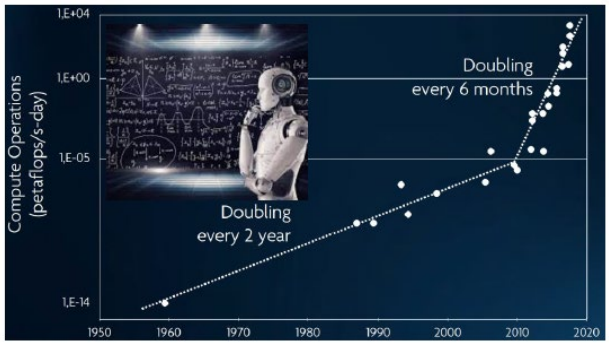
The total energy consumption by general-purpose computing continues to grow exponentially, doubling every three years. As a result, in the absence of innovation, computing energy needs are predicted to exceed energy production in 15-20 years. The rapid emergence of artificial intelligence (AI) over the past decade and its associated computational power requirements are only making this challenge tougher. In our view, a mission-critical piece of solving this innovation puzzle will be the adoption of a semiconductor process technology referred to as high-NA EUV lithography (high numerical aperture extreme-ultraviolet lithography).

Figure 20. More Energy Efficient Computation Required



Source: Imec, Semiconductor Industry Association, Citi GPS

Figure 21. Computational Power Needs Accelerating



Source: Imec, Semiconductor Industry Association, Citi GPS

For more than 50 years, Moore's law, which is the observation that transistor density in integrated circuits (ICs) tends to double every 18-24 months, has set the pace for progress for the semiconductor industry. The associated shrink of feature sizes for ICs has resulted in performance leaps and cost declines at the same time, leading to semiconductors playing integral roles today in virtually every aspect of modern life.

Lithography creates the features of a chip during fabrication and hence is a mission-critical enabler of Moore's Law

This shrink of feature sizes has been thanks to advances in overall semiconductor production technology and, in particular, the continuous resolution improvements of each generation of lithography systems. Lithography (or more precisely, photolithography) refers to the process of transferring patterns to the surface of a silicon wafer during the semiconductor fabrication process using light. Hence, it defines the size and shape of all chip components, connections, and contacts.

EUV is the leading-edge lithography technique today, and High-NA EUV is the next step on the roadmap

Extreme ultraviolet (EUV) lithography has firmly established itself as the patterning technique of choice today for high-performance computing. High-NA (numerical aperture) EUV refers to the next step on the EUV roadmap. (Numerical aperture describes the range of angles over which the system can accept or emit light.) High-NA EUV uses larger optics (i.e., mirrors), or optics with high NA. We believe that successful commercialization of high-NA EUV lithography will ensure that Moore's law remains relevant beyond the end of this decade.

High-NA EUV lithography is expected to lower costs and reduce complexity for both major types of semiconductors: logic and memory

Analysis so far points towards significant benefits from the transition to high-NA EUV lithography across both major types of integrated circuits: logic and memory.

- **Logic:** Logic chips are the "brains" of electronic devices — they process information. Through adoption of high-NA EUV at advanced nodes in the future, Intel anticipates savings of around 20-50% in the relative cost of patterning, as well as a reduction in complexity (measured in terms of process steps) of around 35-60%.

- **Memory:** Memory chips store information. There are two types: DRAM (working or performance memory) and NAND (persistent storage). In the case of DRAM chips, ASML's simulation of volume production in 2026 suggests that adoption of high-NA EUV could potentially translate into average savings of around 30% and cycle-time reduction of around 10.5 days across all layers.

In the subsequent sections, we first take a step back to explain the science behind lithography in general, before zooming in on high-NA EUV. We follow this up with an overview of ongoing ecosystem developments. We conclude by outlining our views on the technology's introduction and adoption over the medium-term and the roadmap beyond.

Introducing Lithography

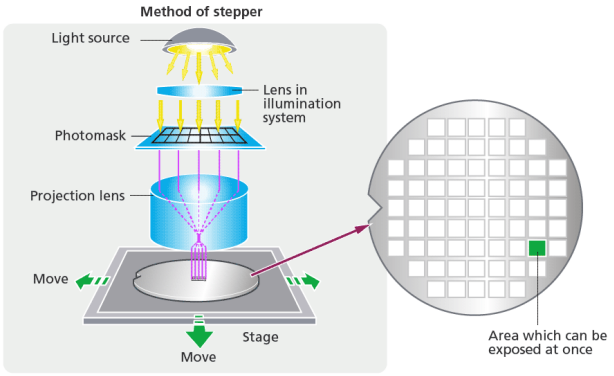
A lithography system is essentially a projection system

A lithography system involves the projection of light through a blueprint of a pattern that will be printed. With the pattern encoded in the light, the system's optics shrink and focus the pattern onto a photosensitive silicon wafer. After the pattern is printed, the system moves the wafer slightly and makes another copy on the wafer.

The resolution — essentially, the level of miniaturization that can be achieved using a lithography system — depends on the wavelength of the light source and the numerical aperture of the optics

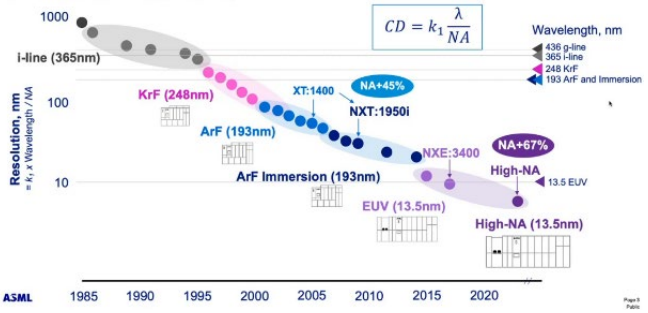
The level of shrink or miniaturization that any lithography system can achieve depends upon the resolution of that tool. Resolution is defined as the minimum feature dimension that can be transferred with high fidelity onto the silicon wafer. It is a function of wavelength of the light source used for imaging and the numerical aperture (NA) of the optics used, based on an equation called the Rayleigh criterion. In optics, the NA of an optical system is a dimensionless number that characterizes the range of angles over which the system can accept or emit light. As illustrated in the roadmap of lithography systems below, the resolution of these systems has steadily come down over the years.

Figure 22. Lithography Process



Source: Semiwiki, Citi GPS

Figure 23. Immersion Lithography System



Source: ASML, Citi GPS

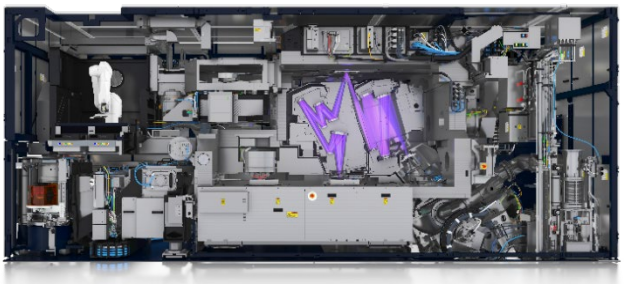
EUV lithography systems today already use mirrors more precise than those used in space telescopes

Extreme Ultraviolet (EUV) lithography has firmly established itself today as the leading-edge technique of choice today and represents a significant feat of engineering and science. For example, the production of EUV "light" involves firing 100,000 laser pulses per second to hit tiny droplets of tin twice, heating them to a temperature around 40 times hotter than the surface of the sun. A collector mirror collects this radiation and directs it onto the wafer via several highly precise mirrors – more accurate than even those used in space telescopes.

Figure 24. First Generation EUV System — NXE:3400 (Front closed)

Source: ASML, Citi GPS

Figure 25. First Generation EUV System — NXE:3400 (Front Open)



Source: ASML, Citi GPS

High-NA EUV involves pushing the precision of optics further, aiming ultimately to produce transistors smaller than a strand of DNA

High-NA EUV will take this precision of optics even further (with the NA specification moving to 0.55 from 0.33 in case of EUV today, or an increase of around 67%) when it enters volume production, which is currently targeted for the middle of this decade. To provide some context, if you were to enlarge the high-NA EUV mirrors to the size of planet Earth, the biggest aberration would be the diameter size of a human hair. The aim is to ultimately produce transistors smaller than a strand of DNA.

Ongoing Ecosystem Developments

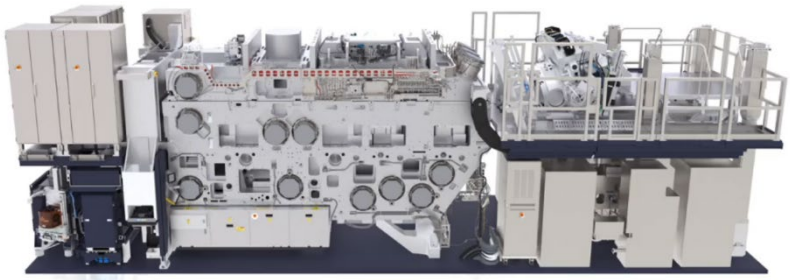
The first high-NA EUV prototype is expected to be operational in 2023

Nanoelectronics research center Imec and lithography systems provider ASML have jointly set up a research laboratory in the Netherlands to further the development of high-NA EUV technology. The integration of the first nigh-NA prototype system in the world is already underway at this lab, and this system is scheduled to be operational in early 2023 and made available to customers.

High-NA EUV pre-production systems are targeted to ship in 2023 or 2024

This will be followed by shipments of the pre-production (or pilot) high-NA EUV lithography system (EXE:5000) to customer locations around the world in the late-2023 or early-2024 timeframe. We note that four orders for these pre-production systems were first placed and announced back in 2018.

Figure 26. High-NA EUV System — EXE:5000



Source: ASML, Intel, Citi GPS

We see five broad categories of ongoing development across the ecosystem

In our view, these initial systems will be used to further understand and focus on improvements across the five broad categories below ahead of the introduction of volume production:

- **Computational Patterning:** This involves the study of enhancement techniques to compensate for errors during the imaging process in high-volume production.
- **Scanner Imaging:** This involves refining imaging itself, including minimizing the difference between the intended and the printed features of an IC layout.
- **Masks:** Masks refer to the templates used to print the patterns on wafers. The work here revolves around reducing defects and adapting masks to high-NA EUV optics.
- **Materials:** The migration to high-NA EUV involves the development of new materials, particularly photoresist materials, which are used to provide the photosensitive coating.
- **Metrology:** Simply put, metrology is the art of measuring structures patterned on the wafer. It intuitively gets harder as high-NA enables further shrink.

Adoption Over the Medium Term and Roadmap Beyond

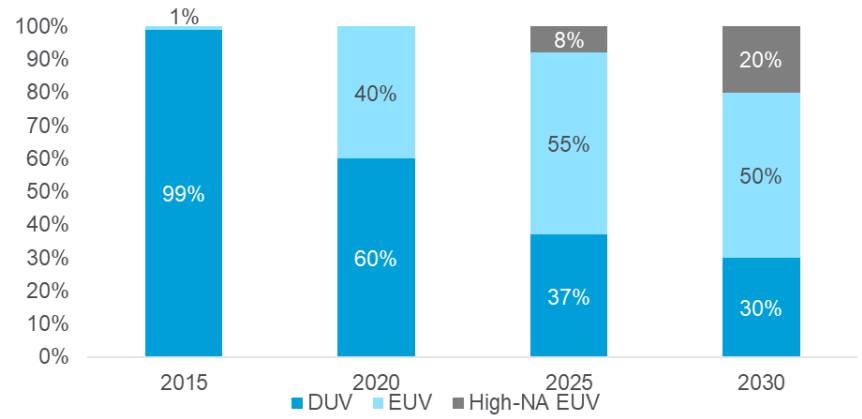
High-NA systems are scheduled to be introduced in volume production in 2025

Assuming the prototype and pre-production systems are made available as scheduled, leading semiconductor manufacturers intend to introduce the subsequent high-NA EUV lithography system, EXE:5200, in high-volume manufacturing (HVM) starting in 2025. We note that leading chipmakers have already placed multiple orders for these EXE:5200 systems in 2022.

High-NA EUV could potentially account for around 20% of the market by 2030

As high-NA EUV technology matures in the latter half of this decade, ASML anticipates a potential annual shipment run-rate of up to 20 systems per year and is working with its supply chain to assess the feasibility of this. On our estimates, this implies high-NA EUV lithography systems potentially accounting for around 20% of the overall lithography system market by value by the end of this decade.

Figure 27. Lithography Systems Market Evolution (By Value, 2015-30)



Source: Citi GPS

We see two most likely options beyond high-NA EUV: enhance k1 or increase NA

Lastly, as we look at the lithography roadmap beyond high-NA EUV, we see two options that could emerge as the likely next steps to lower the resolution of lithography systems further:

- **Enhance k1:** As noted earlier, the resolution of a lithography system is subject to the Rayleigh criterion and primarily depends upon wavelength and numerical aperture. However, a third factor exists within this criterion that describes the process capabilities of the system; it is represented as “k1.” In the past, the industry successfully lowered k1 by transitioning from dry systems to immersion systems. The same option is already being evaluated in research projects today.
- **Increase NA:** NA could be increased further yet, from 0.55 in the case of high-NA EUV to 0.70. However, in this process, the masks, which have always been rectangular, might instead be round. That would possibly entail a major upheaval for mask manufacturers, but it could bring benefits by increasing throughput anywhere from 15%-40%, according to Intel.

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Head of European Media Research
Citi Research

Professional Qualifications and Credentialing

At first glance, it may seem strange that we are including Professional Qualifications and Credentialing as a potentially disruptive innovation in 2022. It is true that the core purpose of professional qualifications — namely, to serve as a third-party validation of an individual's acquired skillset — is no different than it has been at any point over the past 50 years.

This said, how credentialing is undertaken — increasingly online — and the purpose it serves — to validate membership in a community as much as to act as a corroboration of skills — is rapidly evolving and has the potential to significantly disrupt industry, and even the global economy, much more broadly than the market thinks.

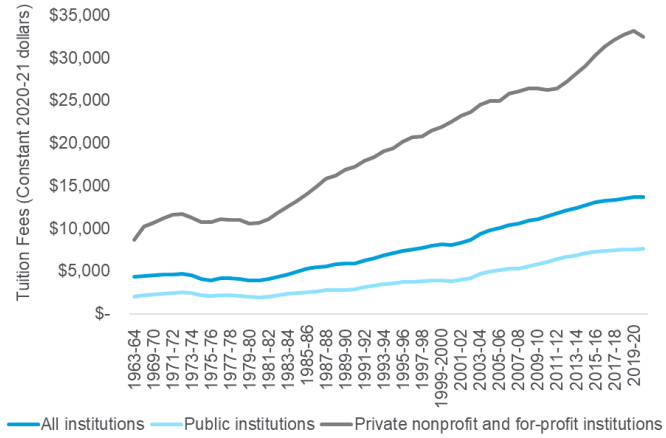
Aside from upskilling learners, which is what it is conventionally used for, accrediting promises to create indirect disruption as employers use professional learning, qualifications, and credentialing as a benefit to attract and retain the best talent in ever-tighter labor markets. Alongside this, accreditors benefit from the creation of professional communities who then promote usage of — and innovation around — their products. This then drives a myriad of opportunities for companies that do the mechanics of assessment and credentialing, as well as for platforms that provide learning services, both physical and online.

Background: Diminishing Returns for Learners and Employers from Traditional Higher Education

Over the past two decades, the cost of attaining a tertiary education in both the U.K. and U.S. has risen significantly. Tuition fees in the U.K. rose ninefold to a current maximum of £9,250 ($11,361 as of December 12, 2022) from £1,000 in 2000-01. The U.K. government's student loan forecasts expect students starting in 2020-21 to accumulate an average debt of £45,800; this compares to an average amount owed by the 2009 cohort of £11,800, a 288% increase.[18] The U.S. is no exception, with the Consumer Price Index (CPI) index for U.S. college and tuition fees increasing exponentially since the 1980s in comparison to the All Items CPI index, as demonstrated in Figure 29. The average cost for undergraduate tuition in the U.S. for the 2020-21 academic year was $13,677 per year, a 70% increase since 2000-01.[19] For every graduate in the labor force, over $28,000 is owed in student loan debt, compared to $11,504 in 2006.[20]

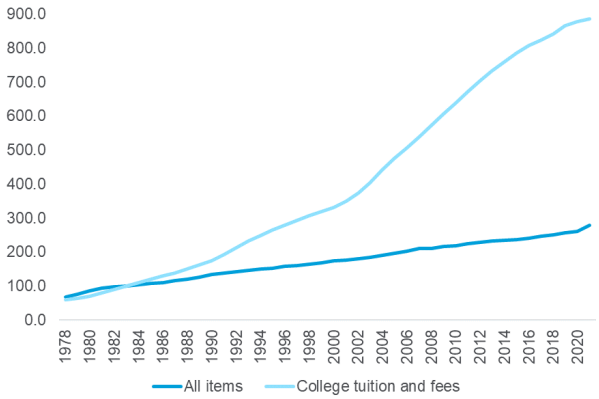
[18] Paul Bolton, *Student Loan Statistics*, House of Commons Library, July 2022.
[19] National Center for Education Statistics, "Digest of Education Statistics," accessed October 5, 2022.
[20] Federal Reserve Bank of St. Louis, "Is College Still Worth It?," July 9, 2018.

Figure 28. Cost of Undergraduate Tuition in the U.S. (Tuition and Required Fees Only)



Source: U.S. Department of Education, Citi GPS

Figure 29. CPI For All Items vs. CPI For College Tuition and Fees



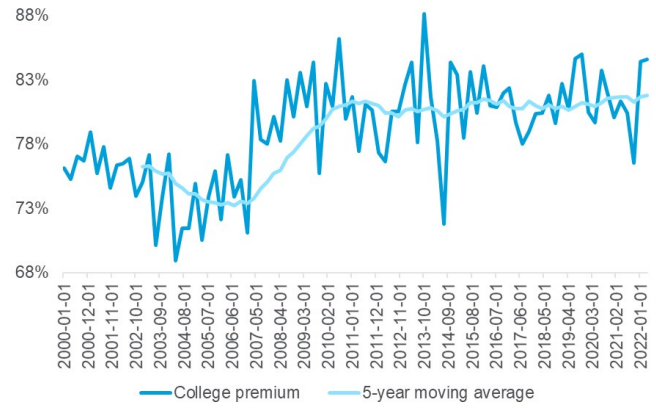
Source: U.S. Bureau of Labor Statistics, Citi GPS

Just as the cost of access to education has gone up, the net benefit of a tertiary education has diminished in the U.K. In 2007, graduate workers could expect to earn a median salary that was 50% more than that of non-graduate earners.[21] This premium has eroded to only 38.5% in 2021. The reality is not as bleak in the U.S., where graduate workers can expect to earn around 80%-82% more than non-graduate workers. However, this premium has remained flat despite rising costs since 2010.

As a consequence of costs outpacing the net benefits of a tertiary education, we see reduced participation in higher education. The U.S. has experienced a fall in enrollment from 20.1 million in 2010 to 17.1 million in 2021, reversing decades of increasing participation.[22] Although there are potential cyclical reasons for falling student numbers — including tight labor markets reducing the numbers of adult learners, as well as some regulatory changes in the market, such as gainful employment regulation that has impacted access to funding — we suspect some of the reduction in participation is structural in nature.

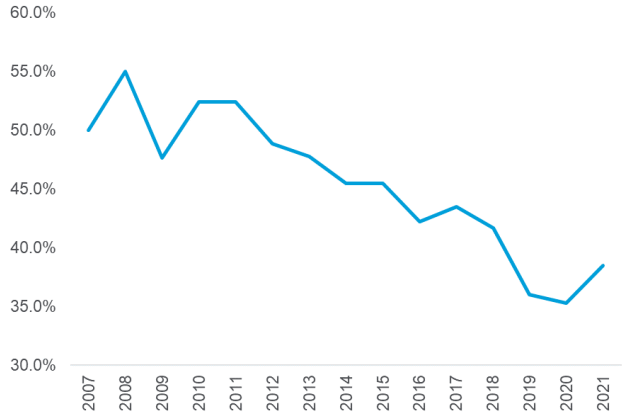
[21] Gov.uk, "Explore Education Statistics," accessed September 23, 2022.
[22] National Student Clearinghouse Research Center, "Current Term Enrollment Estimates," retrieved September 23, 2022; National Student Clearinghouse Research Center, "Current Term Enrollment Estimates," Fall 2012.

Figure 30. U.S. College Income Premium



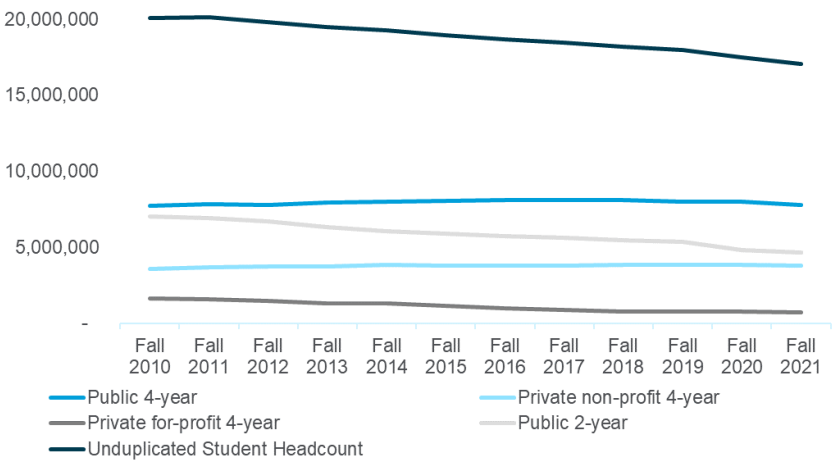
Source: Federal Reserve Bank of St Louis, Citi GPS

Figure 31. U.K. University Earnings Premium



Source: U.K. Government Graduate Market Statistics, Citi GPS

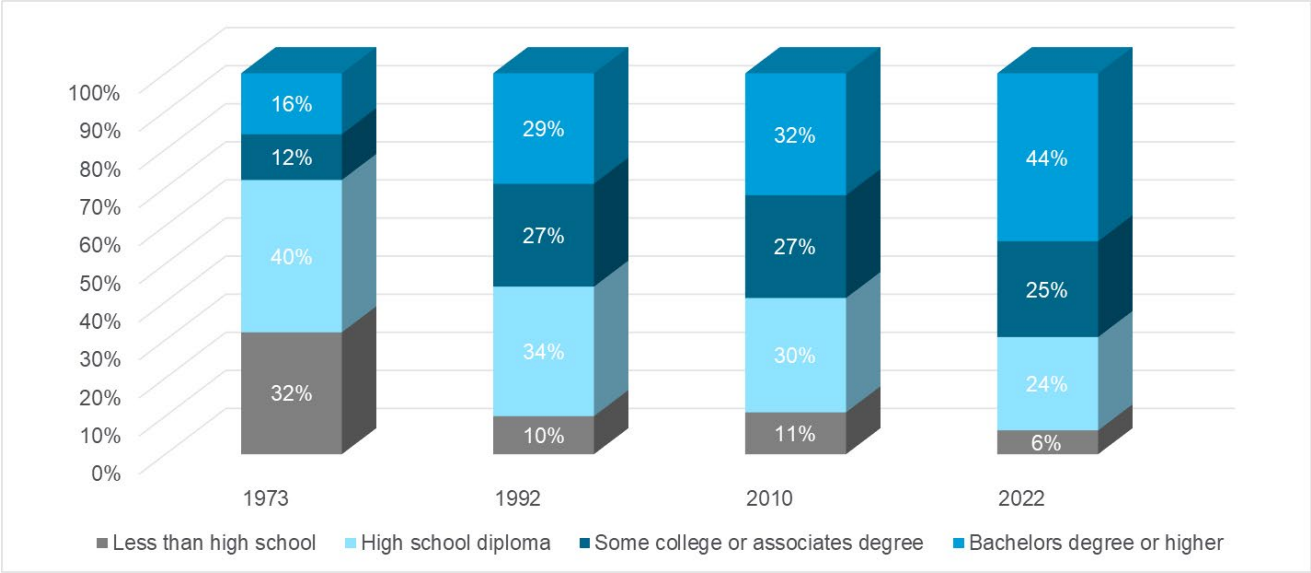
Figure 32. U.S. Enrollment Estimates



Source: National Student Clearinghouse Research Center, Citi GPS

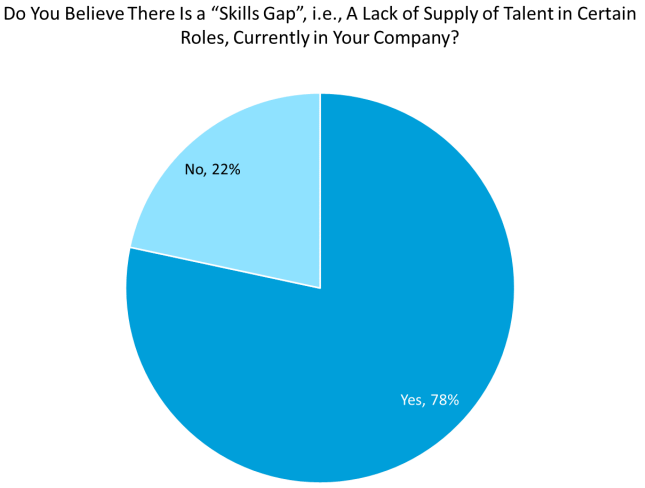
A separate but important phenomenon is the concept of “degree inflation.” During the 2007-09 financial crises, four-year degrees became more attractive. As unemployment in the U.S. subsequently rose, there was an accumulation of degreed individuals unable to attain employment. As a response to the surplus of qualified candidates within the job pool, employers raised the minimum requirements for open listings. This drove “degree inflation,” with more and more jobs over the last decade requiring a bachelor’s degree as a minimum requirement — a phenomenon that has remained remarkably persistent even in the face of tight labor markets. The irony here is that even with higher requirements, many corporates are still not finding recruits with the skills they need to do their jobs, something that is often referred to as the “skills gap.” In our own survey of over 300 corporates worldwide, 78% indicated that there was a lack of supply of talent in certain roles within their organizations.

Figure 33. U.S. Workforce by Educational Attainment[23]



Source: Georgetown University, Center on Education and the Workforce, Citi GPS

Figure 34. Skills Gap[24]



Source: Citi GPS

[23] Anthony P. Carnevale, Nicole Smith, and Jeff Strohl. (2021). *Recovery: Job Growth and Education Requirements Through 2020,* Georgetown University Center on Education and the Workforce, June 2013.
[24] Citi GPS, *Education: Learning for Life*, November 2021.

The combination of higher minimum requirements, diminishing returns on higher education, declining enrollment, and the rate of technological change outpacing skill development has resulted in a "skills gap" — a fundamental mismatch between the skills required to do open jobs and the skills the candidate pool possess. The skills gap drives labor market inefficiency — in the context of the current tightness in the labor market, there is a talent shortage of 10.7 million workers in the U.S., and employers are struggling to attract and retain talent.[25]

The financial consequence is sizeable; the International Data Corporation predicts that the loss resulting from the skills gap will reach $775 billion by the end of 2022.

It is against this backdrop that the popularity of professional qualifications has grown in recent years as a way to address the skills gap.

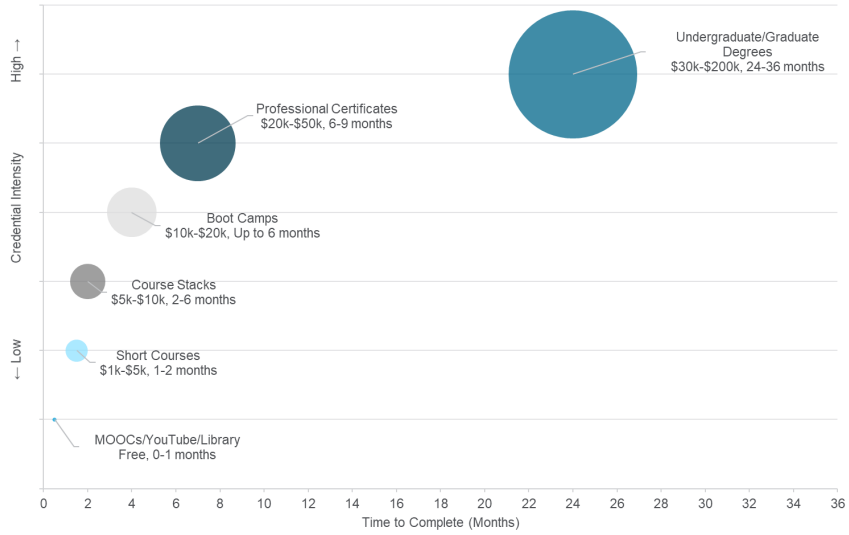
Technology as an Enabler; COVID-19 as a Catalyst

Traditionally, a barrier to adoption of professional qualifications was the direct and opportunity cost of spending time in a classroom. This mode of learning acted as a deterrent for many learners due to its perceived inflexibility. The global pandemic acted as a gamechanger in this respect, disrupting the education sector and driving change in three main ways.

- **Firstly, worldwide lockdowns meant that much in-person classroom learning moved to a virtual format.** The flexibility and convenience of this model has clearly resonated with some learners, and the cost is much lower. In a post-pandemic world, the total number of enrollments in Coursera online learning has increased by 2.5x from 2019-21.[26] According to Cengage's Spring 2022 Digital Learning Pulse Survey, which is based on community college responses from more than 1,200 students, 76% of respondents agree that they prefer the option to take fully online courses, up from 68% in fall 2021. We see that since the pandemic, the education sector is experiencing what appears to be a structural shift in mode of consumption.[27]

[25] U.S. Bureau of Labor Statistics, "Job Openings and Labor Turnover Summary," accessed November 23, 2022.
[26] Coursera, *2021 Impact Report*, November 2021.
[27] Citi GPS, *Education: Fast Forward to the Future*, October 2020.

Figure 35. Degrees vs. Credentials: Looking at the Payoff Between Cost, Intensity, and Time to Complete



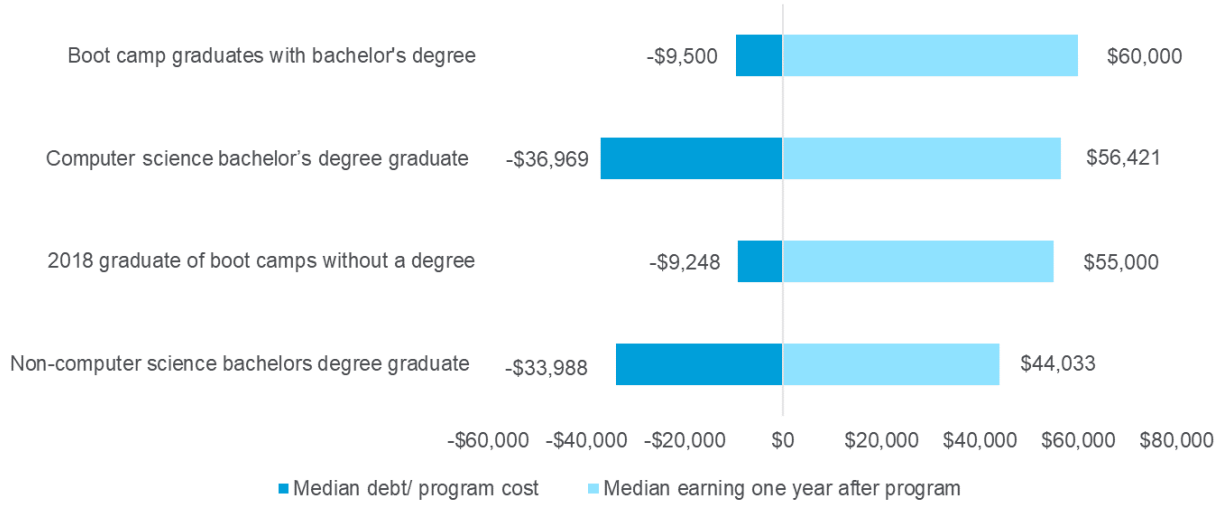
Source: 2U, Citi GPS

- **Secondly, the pandemic prompted an almost unprecedented churn in the U.S. labor market, which has become known colloquially as the "Great Resignation."** The U.S. "quit rate" reached a 20-year high in November 2021 and, according to PwC research, one in five workers say they are planned to quit in 2022.[28] The most cited reason for quitting and changing roles is unsurprisingly wage stagnation against rising living costs.[29] Professional qualifications and credentialing are a useful way to accomplish a change in role or career. FutureLearn's Future of Learning Report reveals that 81% of respondents who have changed careers since the start of the pandemic state that an online course helped them make their move.

- **Lastly, as companies continue to focus on productivity** (which, again, has arguably become more acute post-pandemic), **the drive for automation has accelerated.** According to KPMG research, over 40% of companies were actively looking into automation, self-service, machine learning, and AI solutions prior to the pandemic.[30] This increased to over 59% after only a few short months into the pandemic. Amid the more than 40 million jobs shed at the pandemic's peak, the University of Chicago estimates that 42% of COVID-induced layoffs will be permanent. This leaves a wealth of previously employed individuals needing to upskill or reskill to compete for a job in the current environment. It is in this context that professional qualifications have grown in popularity post-pandemic, as they provide relatively inexpensive reskilling options for learners. Credly reports that the number of companies issuing workforce and industry credentials has increased by 83%, demonstrating their growing popularity.

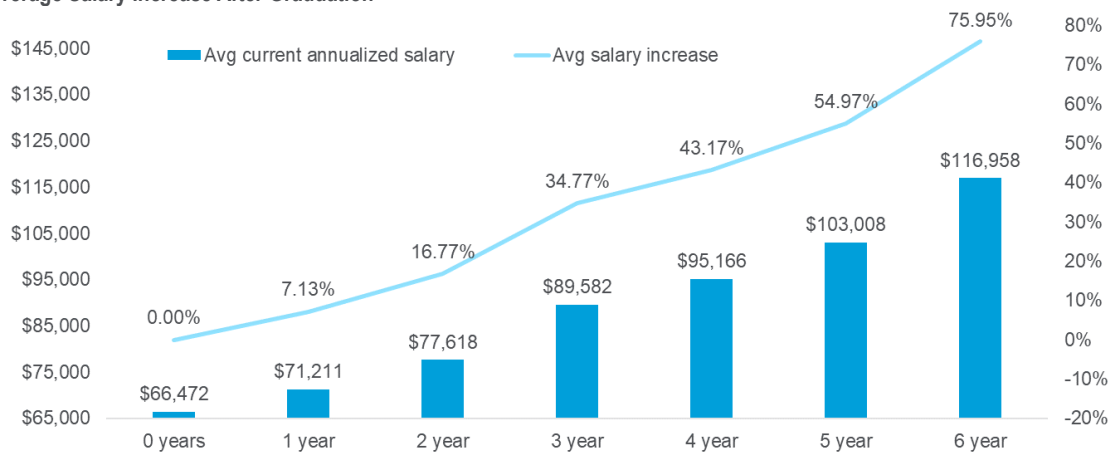
[28] PwC, Global Workforce Hopes and Fears Survey 2022, May 2022.
[29] Pew Research Center, 2022 Pew Research Center's American Trends Panel, March 2022.
[30] KPMG, "Applying Automation to Increase IT Call Center Capacity," accessed September 23, 2022.

Figure 36. Program Cost and Post-Graduation Earnings: 2U-Powered Boot Camp Graduates vs. U.S. Bachelor's Degree Holders



Source: 2021 Gallup-2U Boot Camp Graduates Study, Citi GPS

Figure 37. Average Salary Increase After Graduation[31]



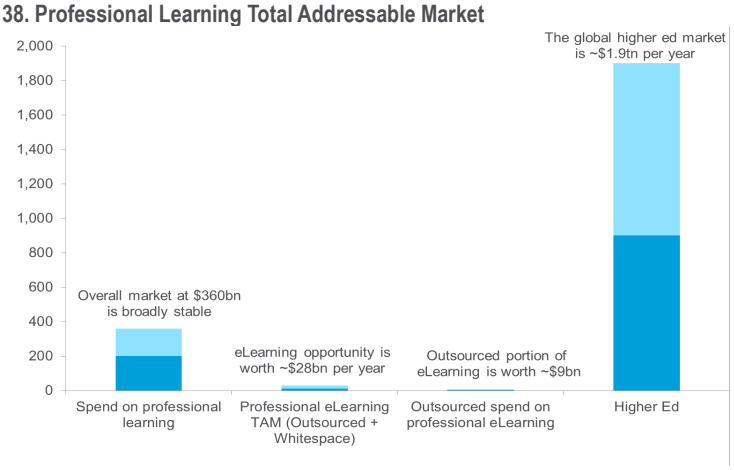
Source: Tech Elevator 2022 Annual Alumni Status Report, Citi GPS

Sizing the Market: A $28 Billion Opportunity That Could Grow Five to Ten Times, or More, Over Time

Sizing the market is made somewhat easier by the fact that the base professional learning market already exists and is fairly easily quantified. As per Figure 38, industry experts place the current professional learning market opportunity at around $360 billion. Within this, the current e-learning portion (including whitespace opportunity, which is the component of the addressable market that is yet to be addressed by an external provider, as it is typically done in-house) is $28 billion. In that market, about one-third of the e-learning spend, $9 billion, is currently outsourced. We think this element of the market could expand at upwards of an 18% compound annual growth rate over the coming years.

[31] Tech Elevator, *2022 Annual Alumni Status Report,* July 2022.

Figure 38. Professional Learning Total Addressable Market



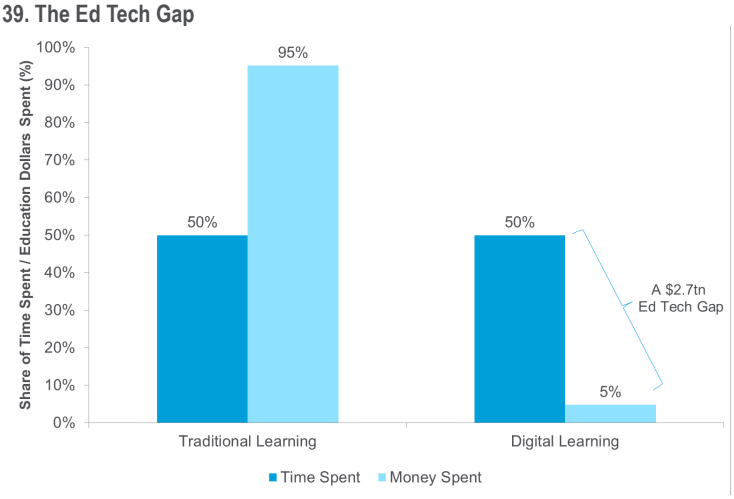
Source: Company Reports, Training Industry, Citi GPS

Even this, though, may prove conservative. There are two dimensions to the possible upside. The first is whether, over time, professional qualifications can begin to cannibalize the global higher-ed market, which is substantially larger, both in the U.S. and internationally, at around $1.9 trillion per year.

The second is whether online learning platforms can command a larger share of the market. Although the proportion of the professional learning market that is delivered via online channels is higher than that of the education market as whole (around 7.8%, versus our forecast of around 5% for the broader education market by the end of 2023), we note that the "ed-tech gap" could be much more significant.

As per Figure 39, if the proportion of industry revenues from online channels were to match how learning is done (close to 50% of learning occurs on these channels), the broader ed-tech market could be worth almost $3 trillion per year. For the professional eLearning market, this could mean the total addressable eLearning market reaching $180 billion-$200 billion over time without even considering its potential to take share from higher ed.

Figure 39. The Ed Tech Gap



Source: HolonIQ, Citi GPS

We See a Three-Sided Benefit

We see the three main beneficiaries of professional qualifications as learners, employers, and accreditors.

Learners, the most obvious winners, benefit from acquiring an apposite skill set, increasing their chances of landing a new role or achieving targeted career advancement in a current role at a reasonable cost, with a limited timeframe required for learning. Pearson surveyed 29,000 candidates who earned IT certifications within a 12-month timeframe and found that 36% attained new jobs, 28% received pay raises, and 21% received job promotions. These outcomes are achievable at a relatively low cost. The 2021 Gallup-2U Boot Camp Graduates Study found that the median graduate who worked full-time both during and after completing a 2U tech bootcamp could offset 59% of the program cost with additional income earned within one year. This allowed for a relatively quick return on investment, especially in comparison to a traditional four-year degree. Employers increasingly recognize such alternative qualifications, with a prominent example being Google, which now accepts a professional qualification in place of a four-year degree for entry-level roles, widening the pool of potential candidates.

Employers not only benefit from a higher-quality candidate pool with relevant job-ready skills, but can also use professional learning, qualifications, and credentialing to upskill and retain the best talent in ever-tighter labor markets and begin to plug the skills gap. More proficient employees provide value added above the cost of certification. Global Knowledge's 2021 IT Skills and Salary report estimates the return on investment per certificated employee to be $10,000 or more.[32]

Lastly, the benefit to the accreditors comes from creating professional communities for individuals who are experts in the accreditor's technology or processes. Examples are those who have completed Microsoft Azure, Google Cloud, or Amazon Web Services certifications. This not only provides the accreditors with direct access to talent with a skill set specifically tailored to their product, but also promotes awareness and use of the products within different organizations. Alongside the clear benefits for the owners of the credential, we also note the significant opportunity for the platform businesses that host the learning programs, as well as the certification businesses that run the assessments and verify qualifications.

Will Universities Be Disrupted or Will They Adapt?

Arguably, the emergence of professional qualifications has already disrupted universities, as enrollment in higher education has come under pressure progressively in recent years. This pressure has been particularly acute at community colleges as more adult learners shift from degrees to alternative credentials. The question in the future is whether traditional undergraduate degrees may in turn be disrupted as high school graduates seek alternative pathways to employment without incurring the cost and time of attending a full-time university. This could result in meaningful further contraction in student numbers and, potentially, even in the number of universities.

The disruption of universities, however, assumes that they choose not to "course-correct" — in this case, both figuratively and literally. In practice, what we are seeing is universities adapting by evolving their offerings to keep up with changes in learner preferences.

[32] Global Knowledge, *2021 IT Skills and Salary Report*, November 2021

In recent years, universities have been partnering with various ed-tech platforms, not only to bring their traditional courses online, but also to offer stackable learning. This represents a modular approach to attaining a Bachelor's or Master's degree whereby smaller, independently recognizable certificates can be "stacked" together to form a larger credential. It allows employees already in the workforce to upskill or reskill more flexibly and cost-effectively. Those wanting to pursue a degree can also rest assured that certificates attained along the way are recognized irrespective of degree completion. This provides flexibility to learners, as they can configure their studies around both pre-existing commitments and unexpected life events.

Another innovation emerging in the education sector is the integration of professional certificates into degrees through college credits. This approach allows learners to attain job-relevant skills while studying toward a degree and demonstrating post-graduation job-readiness to employers. We show some examples of universities becoming more competitive in Figure 40.

While these innovations do not directly compete with professional certificates as a stand-alone credential, they provide a more modular and efficient alternative to traditional degrees. For universities dealing with the potential disruption caused by the growing focus on professional qualifications and credentials, it may be a case of subscribing to the old maxim: "If you can't beat them, join them."

Figure 40. Institutes and Partnerships

Date	Institution	Details of Partnership
September 2022	edX	The London School of Economics announces the launch of two MicroBachelors® with edX
October 2021	Coursera	Those who complete Google Professional Certificates on Coursera are eligible to receive up to 12 college credits from participating colleges and universities, such as the University of London, the University of North Texas, and Northeastern University
October 2021	edX	edX launches the first MicroBachelors Program® with IBM
March 2021	edX	Rochester Institute of Technology (RIT) accepts all edX MicroMasters® Programs for credit towards its Masters of Science in Professional Studies

Source: Coursera, edX, Citi GPS

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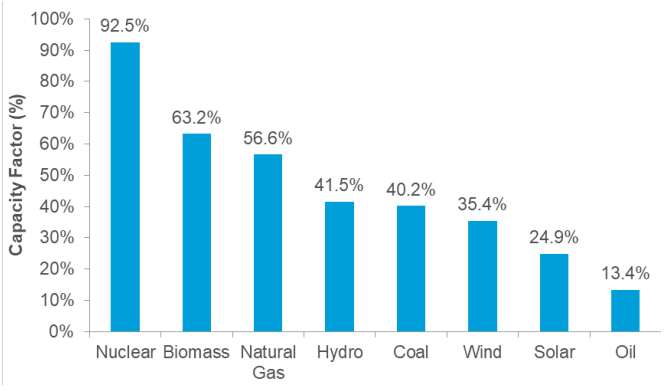
Small Modular Nuclear Reactors

With global power prices at historic highs amid a confluence of geopolitical forces and the world continuing to prioritize lowering greenhouse gas (GHG) emissions, nuclear power is coming back in favor. This is the case in the U.K. and Europe in particular, but also in the U.S. and globally. During the last several decades, we witnessed the retirement of many nuclear power plants, and companies abandoned plans to build new nuclear plants amid rising costs and low gas prices, especially in the U.S. and Europe. However, China and a number of emerging-market countries have persisted in the expansion of nuclear energy. Meanwhile, companies around the world have been advancing new technologies for small modular nuclear reactors (SMRs) that have the promise of producing reliable around-the-clock electricity for a price cheaper than gas, coal, and biomass and more reliable than solar, wind, and batteries under different weather conditions.

The advancement of SMRs could be very disruptive to global energy markets, as it could stabilize power prices and shift incentives away from gas and coal power generation throughout the world. It could also suppress global demand for solar, wind, and batteries. It would advance the electrification of the global economy over time, including transportation, industrial activity, and hard-to-abate sectors. With increased use of a cheap zero-carbon fuel source, the outlook for GHG emissions would materially improve.

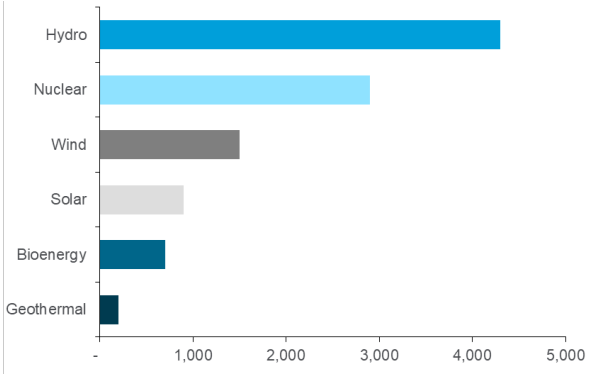
Nuclear energy has a lot of advantages that differentiates it from other sources of electricity. Nuclear power is one of the world's largest low- or no-carbon sources of electricity; however, aging nuclear reactors and the cost of installation of new reactors are hurdles to overcome. Nuclear power plants have some of the lowest land requirements of all low-carbon energy sources. For each 1,000 megawatt electric (MWe) of electricity per year, a nuclear power plant requires at most one to three square miles, while solar and wind farms require much larger footprints. Nuclear power plants are the most reliable sources of electricity and considered to be the safest source of electricity based on recent developments in the sector.

Figure 41. Electricity Baseload Based on Type of Energy



Source: EIA, Citi GPS

Figure 42. Low Emissions Electricity Generation by Source Worldwide, 2020



Source: IEA, Citi GPS

During this era of energy transition and renewed focus on energy security, nuclear energy looks ripe for future growth due to new, state-of-the art technologies such as SMRs in combination with existing technology. Developments in the creation of more advanced reactors (ARs) and/or mobile reactors for producing energy are an emerging source of discussion and excitement in global power markets.

However, there has been uneven progress across the world in the development and regulatory approval of such technologies. In this regard, we investigate the future role of SMRs in the energy mix and how soon their adaptation and commercialization could take place. The disruptive nature of SMRs in nuclear energy is very explicit, but it is still a number of years before the technology becomes scalable around the world.

What Are Small Modular Reactors?

SMRs, in short, refer to nuclear reactors with power outputs below 300 MWe, while typical present-day reactors' power output ranges from 1,000 MWe to 1,600 MWe. Underlying technology for SMRs can vary and may include Gen III/Gen III+ reactors — including light water reactors (LWR) — as well as Gen IV reactors, such as fast neutron reactors, graphite-moderated high temperature reactors, molten salt reactors, and other reactors that have higher efficiency for decarbonized energy production and industrial heat cogeneration. LWR technology has been already tested and is currently in use by modern large plant reactors, while Gen IV reactors are still in the prototype stage. SMRs can be deployed for both on-grid applications and off-grid remote sites, and they have the flexibility of being able to operate with various intermittent renewable energy-generation systems.

SMRs are similar in design to Gen III/Gen III+ and Gen IV reactors, but the smaller cores enable a more integrated design, with all components of the nuclear steam supply system incorporated into one piece. Another key feature of SMRs is that they are inherently safer. Having a lower overall power output and smaller size increases the efficiency of passive safety systems, both under normal and extreme conditions. SMRs also have lower core inventories (meaning a lower probability of an accident occurring due to lower levels of radiation) and are relatively mobile and easy to transport. SMRs can be installed on land or in marine settings, including in difficult-to-build large plant infrastructure locations. Additionally, SMRs are expected to cost less to build compared with large reactors, as well as to feature potentially cheaper generating costs. Some SMR concepts could be added incrementally to large grids to keep up with growth in electricity demand, as well as to provide energy services other than electricity, including but not limited to desalination, energy for hydrogen processes, and district heat. Finally, once SMRs are commercialized, their buildout could potentially occur in well under a decade, depending on the regulatory framework in the given country. This is compared to multiple decades for construction for some of the larger plants.

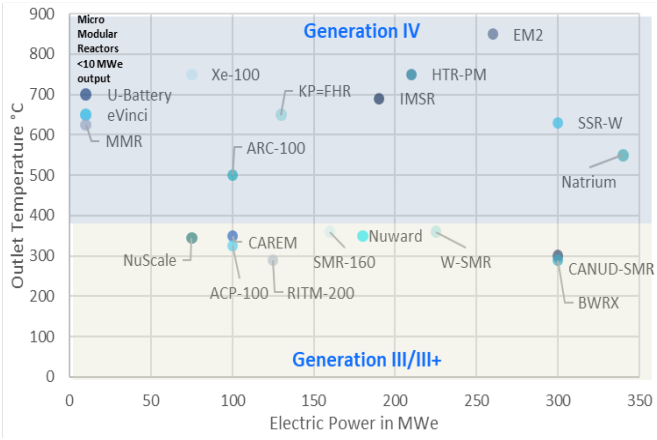
While SMRs by nature vary significantly based on their design and concept, those that use Gen IV technologies could create even greater disruption in the industry than the better-known modular LWR reactors. Gen IV SMRs have been explored and developed in recent years and vary in their specifications. The majority of Gen IV SMR designs improve upon Gen III reactors in terms of safety by operating at higher temperatures without the need for significantly pressurized containment vessels. Certain designs aim to provide industrial heat of up to 1000°C, allowing the reactor to be used more effectively. Through high-temperature electrolysis, Gen IV reactors can also produce green hydrogen that is usable directly in the transportation industry, as well as to produce synthetic fuels and ammonia. For example, in December 2021 in China's Shandong province, a high temperature gas-cooled reactor — which uses a pebble-bed module and is known as HTR-PM — became the first-ever Gen IV design to be connected to the grid.

The most mature Gen IV designs include fast neutron reactors, which have no moderator, operate with higher neutron flux, and are cooled by liquid metal (such as sodium, lead, or lead-bismuth). These reactors are smaller and simpler than LWRs, achieve better fuel performance (using the full energy of uranium rather than 1% of it), and have up to 20 years of refueling intervals (versus three to five for LWRs). Russia operates the only commercial-scale fast neutron reactors, called BN-600 and BN-800, while continuing to invest in similar projects. Research into fast neutron reactors is also ongoing in the U.S., South Korea, China, India, Japan, and Europe.

Graphite-moderated high temperature reactors, a type of Gen IV technology, use graphite as a moderator and can use helium, carbon dioxide, or nitrogen as primary coolants. High temperature gas-cooled reactors are designed to deliver high temperature helium of 700°C-1000°C, which can be directed to industrial applications or used to make steam conventionally in a secondary circuit via a steam generator. EM2 SMRs use helium cooling with gas-cooled fast reactors.

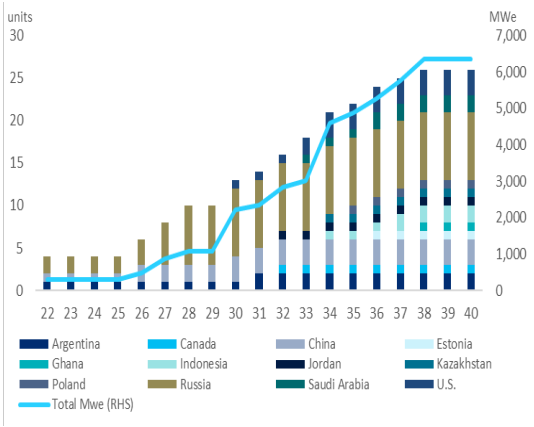
Additionally, molten salt reactors are another well-known Gen IV technology that, for primary cooling, uses molten fluoride salts under low pressure. Conceptually, any reactor requires fuel to be dissolved in the coolant as fuel salt and ultimately to reprocess that salt online. Molten salt reactors typically operate at much higher temperatures (around 600°C-700°C) compared to LWR types. China is currently leading the global research in molten salt reactor development. **Finally, micro modular reactors typically generate less than 10 MWe power output.** These reactors use tristructural isotropic (TRISO) fuel, which consists of three coatings applied to spherical uranium fuel particles. TRISO fuel maintains its structural integrity even in extreme conditions due to its spherical shape. The temperature for the operation varies from 650°C- 800°C.

Figure 43. Range of Sizes and Temperatures for Heat Applications for SMRs



Source: Citi GPS

Figure 44. UxC High Case Forecast for New AR/SMR Builds to 2040



Source: UxC

Challenges for SMRs

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Regulation continues to be the largest obstacle to commercializing SMR technology faster across the world. The U.S. Nuclear Regulatory Commission (NRC) has a very comprehensive and lengthy regulatory process, prioritizing security of operations. Approval for a 50 MWe reactor design granted to NuScale, a company that designs and markets SMRs, is a big milestone for the industry, with more reviews and approvals to come as the company is now uprating its design to 77 MWe. The U.S. Department of Energy (DOE) has also provided funding for research and development efforts in this space. Included in the recent U.S. Inflation Reduction Act (IRA), where direct funding of $369 billion is allotted for reducing emissions, is a $250 billion loan guarantee program that is available for DOE use and extended until 2030. This kind of loan program would be available for companies with innovative clean energy technologies currently in development. It is safe to assume that companies involved in the development of advanced nuclear reactors will be beneficiaries of this program. Additional financing allowed the DOE to select two SMR designs — TerraPower's 345 MWe Natrium plant and X-energy's 80 MWe pebble-bed unit — that are due to be fully operational by 2029. The DOE awarded each company $80 million in initial funding for testing, licensing, and building prototypes.

Sustainable procurement of fuel (i.e., uranium) for advanced reactors could be at risk, with supplies exclusively coming from Russia into the U.S. in recent years. The IRA identifies such dependency and allocates $700 million to the DOE's effort in developing an alternative source for it.

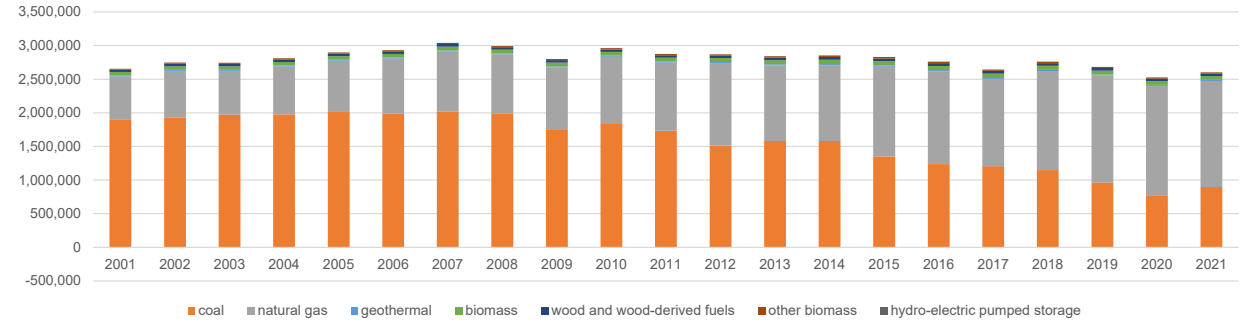
Other countries, including the U.K., Canada, South Korea, Argentina, China, Russia, Poland, and Romania, are working on either updating their regulatory requirements, operating within their existing regulatory frameworks, or introducing new regulations to commercialize SMRs. China, Russia, and Argentina have been recently able to adapt their current regulatory requirements to connect SMRs designs to the grid — specific examples include CAREM 25 in Argentina, Akademik Lomonosov in Russia, and HTR-PM in China. Further adaptation and streamlining of relevant licensing and regulatory frameworks will be essential in developing a global market for SMRs.

Overall, active buildout and adoption of SMR technology is widely expected on an enhanced larger scale across the world after 2028 (refer to Figure 44Figure 45). While the regulatory environment is more flexible in some countries then others, the adoption of SMRs in the U.S., Canada and Poland should be unfolding after 2030. Nevertheless, the global picture is not one of one-sided optimism, as there are still many obstacles to wide-scale AR and SMR deployment. Some of the obstacles are internal hurdles — such as usage of these reactors in a commercial setting and economic feasibility — while others are external headwinds, such as broader trends, global macroeconomics, and overall policy environments.

How Big Could the SMR Market Be?

In this U.S., the size of the non-nuclear baseload generation market is around 2.5 million GWh per year. As these generating assets start to retire, there is a potential for a meaningful portion of the generation to be replaced with SMRs if this technology advances. If every asset were replaced, the market would need to build around 285 GW of new SMR power plants. Over time, the market could even grow larger, as electricity demand will continue to increase and grid operators will want to keep the lights on.

Figure 45. Non-Nuclear U.S. Baseload Generation (in GWh)

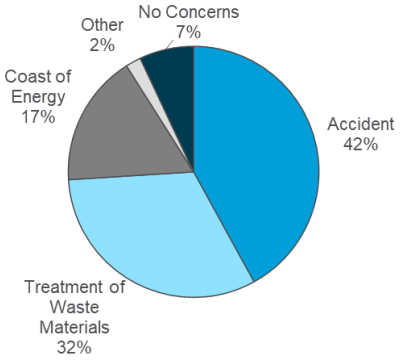


Source: EIA, Citi GPS

Barriers to Adoption

There are a few key barriers to widespread SMR adoption, including: (1) a strong "Not in My Back Yard" (NIMBY) public attitude, (2) technological advancements, (3) timing of regulatory approval, and (4) costs of competing forms of resource adequacy. Citi's survey of about 3,000 Americans demonstrated that 42% of people were concerned about a nuclear accident, which likely drives the NIMBY attitude. The nuclear industry also has a history of projects costing more than the initial guidance and taking longer than expected, given their complexity. The outlook for nuclear does not involve the energy source in isolation — competing forms of power generation are also innovating and looking to drive their costs lower.

Figure 46. Top U.S. Concerns About Nuclear



Source: Citi Innovation Lab

The industry implications are substantial:

- **Utilities:** The utility industry will generally be a winner of disruption from SMRs, as the technology could create material capital expenditure opportunities for new power plants and energy transmission and distribution while letting utility companies shrink their carbon footprints. In power markets, there will be winners and losers, as the growth of SMRs could flatten and lower power price curves and take market share from other forms of generation.
- **Industrial Companies:** Industrial companies will generally benefit from the lower costs, lower carbon emissions, and more stable energy bills resulting from SMR adoption. There could be shift in the power supply chain from certain forms of generation such as gas, coal, solar, wind and others to nuclear.

- **Real Estate:** The shift in generation buildout could create winners and losers as stakeholders address NIMBY issues, and a different type of land resource is needed for the evolving power generation mix as different sources of energy require different land resources.
- **Environment and Health:** If SMRs grow as a proportion of the generation mix, GHG emissions could go down and air quality could improve. This has benefits, but we note that nuclear assets have historically had large risks associated with their buildout, e.g., radioactive material.

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U.S. Internet Analyst
Citi Research

Social Commerce Changes Product Discovery

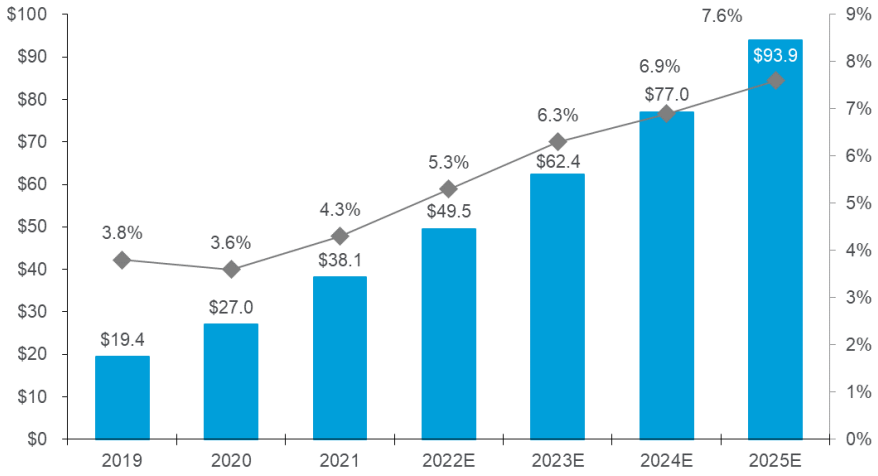
Although it constitutes only around 4% of U.S. eCommerce today, we believe social commerce — wherein brands and products can leverage the scale of social networks to directly target specific users — can significantly alter the broader eCommerce experience going forward.

Currently, the majority of product searches occur either directly on Amazon — where about 60% of U.S. consumers begin their product searches — or on Google. Social commerce changes this paradigm, in our view, as the eCommerce experience evolves from primarily users searching for products on search and eCommerce sites to social platforms suggesting products based on users' interests, actions, and followed influencers — who users increasingly view as a key part of their social networks as well as trusted brand ambassadors.

Ultimately, we see the social commerce experience evolving to be a more natural way to shop that better emulates the more traditional shopping mall experience as merchandising improves online. And as virtual dressing room try-ons ramp while augmented reality (AR) and virtual reality (VR) technology improves, we believe the bottom line with social commerce is greater discovery, increased conversion rates, and lower return rates for retailers, as well as improved overall satisfaction among users. As such, we would not be surprised to see more social-like offerings across eCommerce websites, such as virtual storefronts, short-form video (SFV), shoppable ads and product-tagged videos for brands (retail media), personalized shopping recommendations, livestreaming, and augmented reality (such as virtual try-ons), among other innovations. This comes as transactions on social sites create more first-party data, including payment information that improves personalization and targeting, creating a virtuous cycle.

To be clear, Social Commerce is likely to take some time to change user habits and behavior and alter the broader eCommerce landscape, but we believe it could reach around 7.5% of U.S. eCommerce sales by the end of 2025, equating to $94 billion of total gross merchandise value (GMV) and growing at a 2021-2025 compound annual growth rate (CAGR) of 25% (see Figure 47). This compares to eCommerce growth of 9% over the same period, altering the broader eCommerce landscape somewhat.

Figure 47. U.S. Retail Social Commerce Could Grow to 6.5% of eCommerce Sales by 2025 ($ Billions, %)



Source: eMarketer, Tinuiti, Citi GPS

China Leads the Way in Social Commerce

Social commerce appears to be more commonplace in China, with social buyers representing just under 50% of internet users compared to around 40% in the U.S., per eMarketer. This 10-point delta is likely due to greater overall eCommerce penetration in China (around 30% in China versus 20% in the U.S. in 2021, per Euromonitor), a larger share of key social buying apps (WeChat is used by 78% of China's mobile phone users and facilitated $250 billion of purchases in 2020); and greater overall acceptance of live commerce (SFV and live shopping are the strongest growth trends in Chinese social commerce).

The net impact is that the social commerce market in China represents 15.9% of the country's total 2022 retail eCommerce sales, with around 467 million social buyers versus 5% projected penetration in the U.S. in 2022. And while not all of the social commerce tools popular in China and the Asia Pacific region are likely to be adopted in the West — for example, live shopping has yet to catch up in the U.S. and Europe — we expect global users to see a similar secular evolution towards social commerce as well.

Social Networks Lead the Evolution Given Their User Bases and Tech Integration…

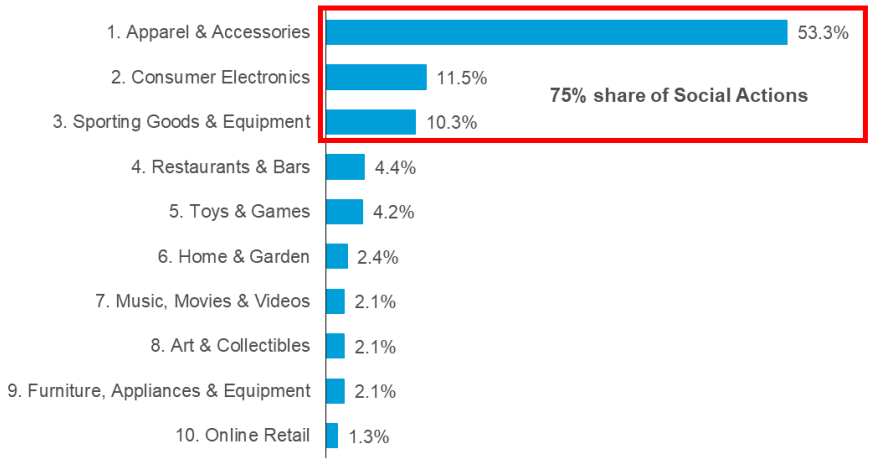
In our view, the benefits of social networks are the scale and engagement across billions of users the platforms provide, as well as the potential opportunities from the integration of newer technology like AR and VR. As a baseline, Meta reports 2.9 billion global monthly active users (MAUs) across Facebook and Messenger and 3.65 billion MAUs across its total platform, TikTok has over one billion global MAUs, and SNAP has 347 million global daily active users (DAUs). This global size and scale creates an opportunity for product discovery based on interests. Per Tinuti, 84% of Instagram users want to discover new products or services, and as a result, brands and products are increasingly testing these social networks as an incremental eCommerce channel.

#TikTokMadeMeBuyIt: Consumers increasingly turn to social platforms for commerce. Videos using the hashtag #TikTokMadeMeBuyIt now have 23.4 billion views as of September 2022, doubling since March 2022, which we view as evidence of increasing adoption of social commerce on the platform. Around one-fifth of global social buyers reported purchasing on TikTok "all of the time," while 72% of Pinterest users suggested that "Pinterest inspires them to shop when they aren't actually looking for anything," per Pinterest. We also note that in 2020, per eMarketer, 35% of U.S. social buyers reported their social commerce purchase was an impulse purchase and that they were unaware of the product or service before, which speaks to the power of discovery. Fast-forwarding two years, we believe even more users are turning to social networks for product discovery especially when adding in augmented reality (AR) interactions, we are reported by Tinuiti to increase purchase conversation rates by 94%.

…as More Brands and Retailers Adopt Social Tools

Across retail categories, Apparel & Accessories accounts for 53% of total social interactions, with Consumer Electronics second at 11.5%, and Sporting Goods & Equipment at 10.3% (see Figure 48). While Apparel & Accessories currently account for the majority of retail social actions, we believe all other retail categories can gain share here as more brands adopt the tools to increase discovery. Another interesting development is companies engaging in and monitoring social fashion trends to inform their product roadmaps as on-demand manufacturing improves. The benefits of this approach include minimizing the risk and capital needed to launch newer products.

Figure 48. Top 10 U.S. Retail Categories by Share of Social Actions, July 2021



Note: Social actions represent consumer reactions — comments, shares, retweets, likes, and dislikes — to retailers on social platforms (Facebook, Instagram, and Twitter).

Source: eMarketer, Shareablee, Citi GPS

Social Commerce in Action: Comparing eCommerce Features Across the Major Social Platforms

Social commerce is changing the front end of purchasing by increasing product awareness and creating a direct relationship with consumers that we believe fundamentally changes the shopping experience. That is, social platforms are embedding commerce functionality directly into the user experience via a more native approach while offering more tools to complete the transaction, creating a relatively friction-free product experience.

Product features drive social commerce efficacy. Facebook and Instagram have launched and integrated the largest commerce feature set, surpassing those of YouTube, TikTok, Snap, and Pinterest (see Figure 49). The leading firms notably emphasize product discovery and, to a lesser extent, newer innovative features like AR Try-On and, increasingly, monetization. That said, Meta's Instagram recently announced it plans to focus more on the discovery side, achieving monetization via its traditional advertising focus rather than through actual transactions.

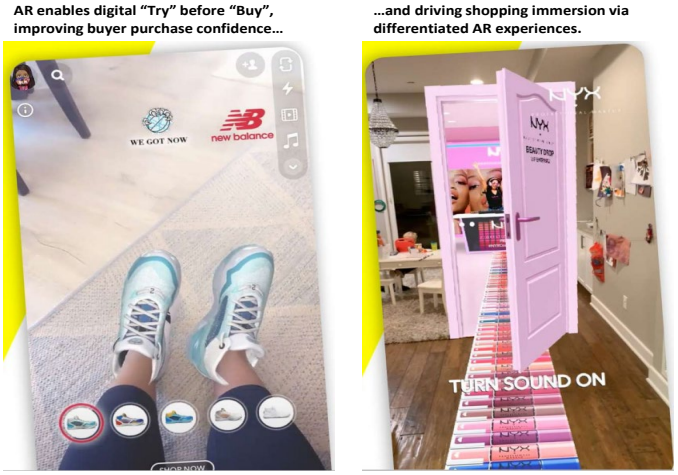
Figure 49. Social Platforms Boast a Wide Array of Social Commerce Features, but Adoption Is in the Early Days

Social Commerce Features	Facebook	Instagram	YouTube	TikTok	Snapchat	Pinterest
Product Discovery						
AR Shopping Ads	X	X			X	X
Online Storefront	X	X	X	X	X	X
Short-Form Video	X	X	X	X	X	X
Live Commerce	X	X	X	X		X
Dedicated Shop Tab	X	X				X
Online Marketplace	X					
Enhancing the Buying Experience						
AR "Try-On"	X	X			X	X
AR Lenses	X	X			X	X
Checkout via Merchant Website	X	X	X	X	X	X
Native Checkout (on-platform)	X	X			X	X
Monetization Tools						
Shoppable Ads	X	X	X	X	X	X
Shoppable Creator Content	X	X	X	X	X	X
Shoppable User-Generated Content		X		X	X	X
Conversational Commerce	X	X				

Source: Company Reports, eMarketer, Citi GPS

Social Commerce Features in Action: (1) Shoppable AR & VR and (2) Short Form Video

Figure 50. Shoppable AR Reinvents the Trying and Buying Experience

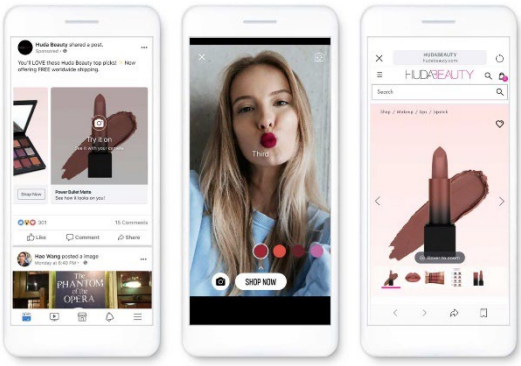


Source: Citi GPS

The integration of AR into social and shopping is a key evolution within commerce, in our view. AR tools offer consumers a differentiated product experience and allow them to interact with products in real-time. For example, **Snap's AR "try-on" experience has resulted in a 25% decrease in returns and an 84% higher conversion rate.**

The left-hand image shows the try-on experience of a New Balance shoe on Snap. The right-hand image showcases NYX Cosmetics providing an immersive experience by allowing customers to walk into and explore a virtual store.

Figure 51. Meta's Virtual Try-On Embedded in Facebook and Instagram



Source: Meta, Citi GPS

According to Snap, four out of five brands that use AR say it helps them drive sales, acquire new customers, and improve performance metrics, and 84% of consumers are interested in using AR to interact with a product before buying.

Meta operates similar AR ads, lenses, and try-on tools. The image to the left highlights a Facebook makeup ad that allows users to try on makeup virtually. The key to this type of offering is to increase engagement as more users interact with Meta's AR products, which we view as the precursor to the broader Metaverse. Per Gartner, by 2026, around 25% of people are likely to spend at least an hour a day in the Metaverse for work, shopping, education, social media, and entertainment, unveiling a new medium for social commerce over time.

Figure 52. Short-Form Video as a Key Unlock to Drive Inspiration

Monetizing SFV and supporting the creators that do so though new commerce offerings is another tailwind to social commerce adoption, in our view. Meta's Reels, TikTok, YouTube Shorts, and Snap's Spotlight, among others, stand out as SFV platforms benefiting from increased engagement, greater product discovery, and improved commerce conversion rates.

TikTok videos on the "For You" feed, trending videos, and videos from popular creators and influencers respectively drove 27%, 31%, and 34% of luxury product discovery on the platform in 2021, per eMarketer. The image on the left shows Instagram Reels with sponsored links to a retailer's product page.

Interestingly, we believe many of these tools are seeing adoption outside of social platforms. Retailers are increasingly leveraging and testing SFV to drive impressions, engagement, and ultimately conversion of products and services.

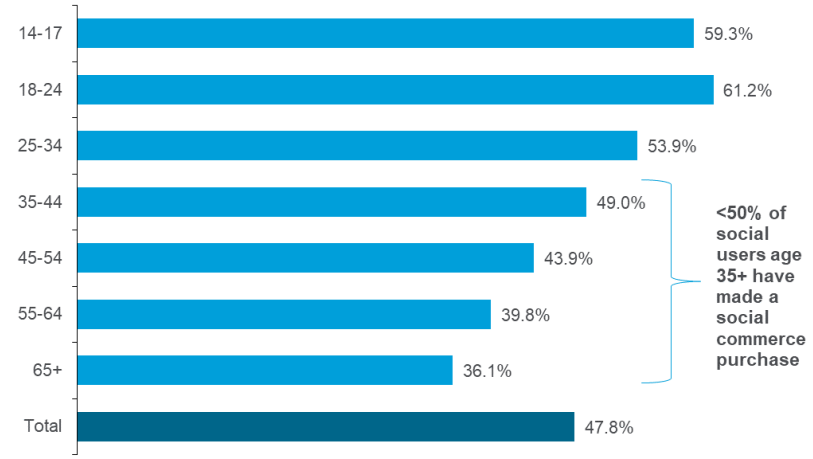
Source: Instagram, Citi GPS

Key Risks and Barriers to the Adoption of Social Commerce

While we believe social commerce could change the product discovery paradigm, adoption requires consumer and retailer buy-in. We highlight some of the key risks below:

Consumer Preferences Are Still Evolving, With Older Users Lagging in Adoption: It remains early in terms of the broad adoption of social commerce, and while it is encouraging that over 60% of 18- to 24-year-olds have made purchases via social networks, fewer than 50% of 35- to 44-year-olds have (see Figure 53 below). Users cite a lack of comfort and security as reasons for lagging adoption: Among U.S. social media users, 43% who had not purchased a product via a social network named entering payment information as a key friction point, and 31% were reluctant to share any personal information through social platforms, per a 2021 eMarketer survey.

Figure 53. 61% of U.S. Social Media Users Have Made a Social Commerce Purchase in 2022



Source: eMarketer, Citi GPS

It Remains Early in the Game for Retailers: While we believe the key benefits of social commerce will be greater product discovery, potentially higher conversion rates, and lower return rates, retailers are still in the early stages of testing commerce across social networks. That said, we are encouraged by early retailer adoption of AR and VR tools and forays into the Metaverse — for example, Gap launched a virtual Gap Teen store in May 2022 within Club Roblox; J. Crew has filed trademark applications for branded NFTs, virtual goods, and virtual retail stores; and other retailers, including Adidas, Nike, Gucci, and Samsung, have purchased virtual real estate to set up their own shops. In our view, these early moves into Social Commerce and the Metaverse signal a growing interest in social commerce and an appetite to engage directly with customers on the platforms where they may increasingly spend their time in future.

Social Platform Differentiation — Size, Scale, and CX: In an increasingly competitive social field, social platforms must provide retailers with easy-to-use ad and shop creation tools; a highly engaged, intent-driven, and scaled user base; and localized creators to more natively support retailer product offerings. Additionally, to provide a differentiated user experience, social platforms likely need to invest in AR and VR tools to engage users and allow retailers to create unique advertising journeys for them. Meta, TikTok, YouTube Shorts, Snap, and Pinterest are relative leaders in this arena, both on the placement of the ad and the measurement of the ad, offering AR tools for user engagement (i.e., lenses and Metaverse experiences) and advertising (i.e., try-on or product visualization capabilities).

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Sodium-Ion Batteries

To sustain today's growth in electric vehicle (EV) penetration rates, new battery technologies are vital. Sodium-ion batteries could be a game changer in the continual transition towards a decarbonized world. Global EV penetration rates are likely to grow from less than 10% in 2021 to around 50% by 2030. Lithium-ion batteries are currently the main power source for EVs and energy storage applications, but they have several well-documented disadvantages. To sustain such high EV penetration rates, competing battery technologies are necessary to avoid overdependence on lithium-ion batteries, but new battery technologies remain in research and development. Most are still in their infancy, and some are decades away from adoption. Examples of alternative technologies under consideration include sodium-ion, potassium-ion, calcium-ion, and vanadium-flow batteries. Sodium-ion battery technology, which functions similarly to lithium-ion battery technology chemically but offers advantages in several key areas (see Figure 54), could be adopted the soonest, with pilot-stage testing underway.

Rapid battery sector growth is critical not only to increasing EV penetration, but also to ramping up batteries' energy storage and grid applications. However, the availability of vital raw materials such as lithium, nickel, and cobalt for lithium-ion batteries remains a key challenge. Lithium-ion batteries are an established technology and have been in use since the early 1990s in devices such as camcorders, portable electronics, and mobile phones. However, the rapid growth in EV sales (6.6 million units in 2021, up 110% year-over-year) has driven strong demand for some battery materials, resulting in multi-year deficits. This has driven up battery component prices. Indeed, lithium prices are up around 200% year-over-year and 64% year-to-date. Higher battery component pricing is being felt across the supply chain, and persistent increases could raise the price of EVs, especially in the lower-end segments. This could put negative pressure on demand, delaying the decarbonization transition. The scientific community is looking at alternatives to lithium-ion batteries as a potential way to alleviate constraints from lithium's affordability, availability, and environmental impact.

Sodium is globally abundant compared to lithium. Its use could reduce supply-chain risks, especially in smaller countries. Sodium-ion batteries have garnered significant interest as an alternative to lithium-ion batteries due to their lower cost and the abundance of sodium in the natural environment. Sodium is 1,000 times more abundant than lithium and is available across most geographies. It is the sixth-most common element on Earth and makes up 2.6% of the Earth's crust. Some battery metals such as lithium, nickel, and cobalt are concentrated in certain geographies, exposing them to geopolitical and supply chain risks. Given sodium's global abundance, using it offers smaller countries another avenue to adopt EVs more widely and improve stationary energy storage (i.e., storing energy to be released as electricity when needed) to meet their net-zero targets.

Sodium-ion batteries function similarly to lithium-ion batteries, minimizing the technology jump. The operation and structure of sodium-ion and lithium-ion batteries is similar, but instead of lithium ions that shuttle between the anode (positive side) and cathode (negative side) during charging and discharging, sodium ions can fulfill this role. Another difference is that lithium-ion batteries currently use graphite as the anode. Sodium has a larger ionic radius (i.e., the size of a sodium atom's ion in a crystal lattice), so it requires an alternative material such as hard carbon — a solid form of carbon that cannot be converted to graphite by heat — as the anode.

Figure 54. Sodium-Ion Cells Have a Similar Operating Principle and Components to Lithium-Ion Batteries, Making Them Easier to Adopt Compared to Other Battery Technologies

	Anode	Cathode	Separator	Electrolyte	Current Collectors
Lithium-ion	Graphite - Natural or Synthetic	Lithium Nickel Manganese Cobalt (NMC) Lithium Nickel Cobalt Aluminum (NCA) Lithium Cobalt Oxide (LCO) Lithium Iron Phosphate (LFP)	Porous polymer	LiPF6 compound (Lithium hexafluorophosphate)	Anode - copper Cathode - aluminum
Sodium-ion	Hard carbon (HC)	Prussian white cathode (Material containing sodium, iron, carbon, and nitrogen)	Porous polymer	NaPF6 compound (Sodium hexafluorophosphate)	Anode - aluminum Cathode - aluminum
Differences: Sodium vs. Lithium-ion	Bulkier; More expensive	Bulkier; Cheaper	More material required	Cheaper compound	Less mass; Cheaper

Source: Wood Mackenzie, Citi GPS

Sodium-ion batteries are safer than lithium-ion batteries during operation and transportation. Lithium-ion batteries have caused accidents relating to overcharging and overheating. The nature and chemical properties of sodium-ion technology give it superior safety features, both when batteries are fully discharged and fully charged. Sodium-ion batteries are easier to transport safely compared to lithium-ion batteries, which need to be discharged below a 30% state of charge before air transport. On the other hand, sodium-ion batteries can completely discharge to zero volts, eliminating the potential for thermal runway due to short circuiting.

The mining of lithium-ion battery metals is not completely "green," while sodium is more environmentally friendly to source. The development of lithium-ion batteries uses many raw materials such as lithium, nickel, cobalt, manganese, and graphite. Mining these materials comes with its own challenges, and the supply, especially of lithium, would take time to match the rate of demand growth. Also, the mining generates significant carbon emissions even though the materials are important components of the decarbonization agenda, causing concerns especially among ESG investors. Lithium mining through the brine process in South America alone consumes around 2.2 million liters of freshwater per ton of lithium produced. There are also concerns around lithium mining's impact on local flora and fauna. Sodium, by contrast, is abundant across geographies and can be extracted from seawater. The overall cost of extraction and purification is expected to be less than for lithium. The use of sodium in batteries would help less developed countries adopt EV technologies and achieve EV targets due to the mineral's greater abundance.

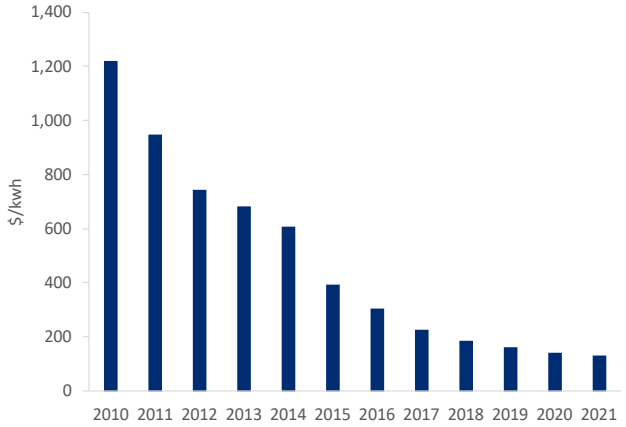
Figure 55. Comparison Between Lithium-Ion and Sodium-Ion Batteries

Parameter	Lithium-ion Battery	Sodium-ion Battery
Energy Density	~150-160 Wh/kg for lithium-iron-phosphate cathodes and ~200-220 Wh/kg for nickel-manganese-cobalt cathodes	~70-160 Wh/kg for sodium-ion cells with potential to expand to 200 Wh/kg
Manufacturing	Proven at scale and already used in EVs, energy storage systems, and portable electronics	Still in research and development phase
Raw Material Cost	Lithium hydroxide - $80,000/t	Sodium hydroxide - $800-$850/t
Cycle Life	Stable structure achieves many thousands of cycles	Sodium-ion cells achieve only hundreds of cycles
Safety	Prone to fire — can overheat and catch fire	No risk of thermal runaway
Temperature	Performance drops considerably at cooler temperatures	High capacity retention and performance even at -20 degrees Celsius

Source: Wood Mackenzie, Citi GPS

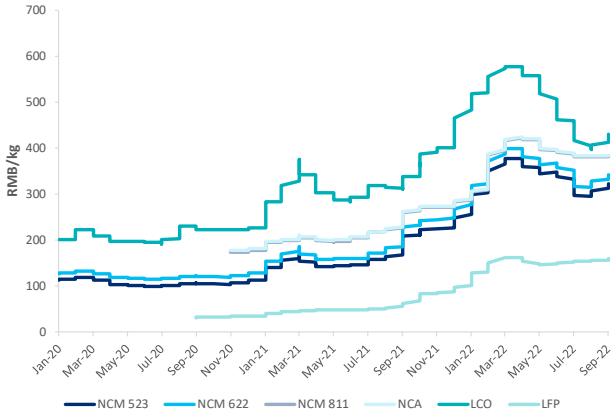
Sodium-ion cells are cheaper than lithium-ion cell chemistry types, and mass commercialization should drive down overall battery costs. A battery cell is the smallest unit of a battery and generally has four components, which include a cathode (positive electrode), anode (negative electrode), separator, and electrolyte. Sodium-ion cells are being touted as cheaper than lithium-ion battery cell chemistries, such as lithium iron phosphate (LFP) and lithium nickel manganese cobalt oxide (NMC). However, costs of certain cell components, such as the electrolyte and separator, could be higher as more material is needed to compensate for the lower energy density in sodium-ion batteries. This could result in comparatively higher sodium-ion battery costs in the initial phase of adoption. But cost reduction can be driven by mass commercialization and significant investment in gigafactories (factories that produce the battery cells). As shown in Figure 56, even in the case of lithium-ion batteries, battery pack costs have fallen around 90% since 2010 due to mass adoption and significant investment in the downstream supply chain. Sodium-ion batteries can also be produced using existing lithium-ion battery manufacturing setups, which could further reduce costs. Several companies across China and Europe are working on establishing pilot-plant production of sodium-ion cells and creating a working supply chain. We believe that over time, with large-scale investment, sodium-ion battery costs will come down, and with lower costs, commercial adoption of this battery technology should rise.

Figure 56. Lithium Battery Pack Costs ($/kWh) Have Fallen by Around 90% Since 2010, but Rising Raw Material Prices Pose a Problem



Source: BNEF, Citi GPS

Figure 57. Lithium-Ion Cathode Prices in China Remain at High Levels, Dragging Battery Prices Higher



Source: GGII, Asian Metal, Citi GPS

Sodium-ion cells have better performance characteristics than lithium-ion batteries across many parameters. These parameters include safety, performance in sub-zero temperatures, energy efficiency, and long-term manufacturing costs. The scientific community is now working on improving the batteries' energy density and cycle life. Energy density is the amount of energy stored per unit of volume and is also known as "volumetric energy density." Cycle life is the number of times a battery can be charged and discharged before it falls below a threshold capacity due to the degradation of cells. Some lithium-ion cells can reach energy densities of 300 watt-hours per kilogram (Wh/kg), compared to 70-160 Wh/kg for sodium-ion cells. Energy density is an important characteristic of batteries, but it is not so commercially critical that a less energy-dense chemistry can never be used. Major battery manufacturers are currently working on improving the energy density of sodium-ion batteries with launches targeted for low-range EVs. Low-range EVs, such as the Wuling Hongguang Mini EV, sell in large numbers in some emerging-market countries where customers prefer small cars over large sedans and SUVs. Targeting this market would also help bolster the adoption and penetration rates of EVs in many countries. There are many other applications where sodium-ion batteries could replace lithium-ion batteries before being rolled out to EVs. These include stationary energy storage and portable electronics, where somewhat lower energy density would be sufficient.

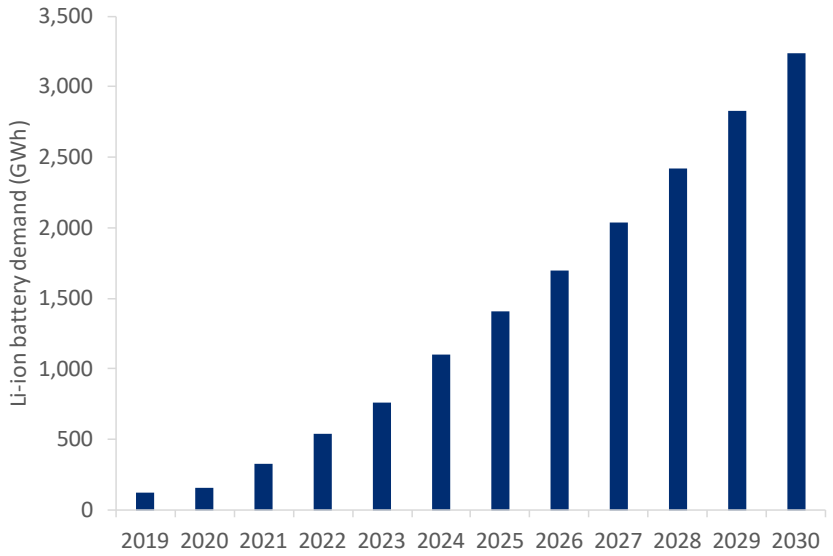
Sodium-ion batteries are likely to ease the supply chain pressure occurring in battery metals such as lithium. Battery raw materials play a key role not only in the performance of batteries, but also in their costs. Lithium-ion batteries, based on their cell chemistry, require lithium, nickel, cobalt, manganese, and other materials. Some of the metals used in the cathodes of lithium-ion batteries are now seeing multi-year deficits, increasing the price of these key raw materials, which in turn impacts battery costs and prices. According to Wood Mackenzie, battery materials in LFP and lithium-nickel-manganese-cobalt (NMC) cells account for 30% and 46% of battery pack prices, respectively. With sodium-ion battery cells, battery experts expect prices to be less sensitive to raw material price moves, as these cell chemistries would only be exposed to sodium, which is freely available. According to Wood Mackenzie, if raw material prices rise by 10%, sodium-ion material costs will increase by less than 1%, whereas raw material costs for LFP and NMC battery

chemistries could increase by 3% and 5%, respectively.[33] Given sodium's abundance, material costs of sodium-ion batteries are expected to be relatively stable.

We expect global lithium-ion battery demand from electric vehicles to reach around 3.2 terawatt-hours (TWh) by 2030. We see innovation coming to the battery sector — wider adoption and commercialization of sodium-ion batteries would lead to material cost savings for battery producers and ease supply pressures. However, sodium-ion batteries need technological advancement to raise their energy density for wider adoption among higher-range EVs. We expect the rapid adoption of EV technologies to drive demand for lithium-ion batteries to more than 3 TWh by 2030. We also expect that deficits of key materials will likely drive higher prices. These price increases could impact battery pack costs and lead to demand destruction.

The adoption of sodium-ion cells could replace lithium-ion battery chemistries such as LFP, which is used in a large proportion of electric vehicles in China. Once sodium-ion batteries become commercially viable, their share in the Chinese market could grow to 3%-5% by 2030. Chinese battery manufacturers are reportedly working on establishing an industrial supply chain by 2023-24. If successful, this would lead to faster adoption of sodium-ion batteries. Companies across Europe, India, and the U.S. are also working on establishing sodium-ion battery cell facilities to enable adoption and improve the batteries' energy density. We believe sodium-ion batteries will see a slow adoption rate from late 2025-26 onwards before achieving mass-scale adoption post-2030. Successful adoption would help auto original equipment manufacturers bring down the average price point of small EVs, which are usually popular in China and other emerging markets. This would help customers and countries to pursue their decarbonization objectives.

Figure 58. Increasing Adoption of EVs Likely to Drive Demand for Lithium-Ion Batteries to 3.2 TWh by 2030



Source: Wood Mackenzie, Benchmark Minerals, BNEF, Citi GPS

[33] Le Xu and Max Reid, "Will Sodium-Ion Battery Cells Be a Game-Changer for Electric Vehicle and Energy Storage Markets?" Wood Mackenzie, September 14, 2021.

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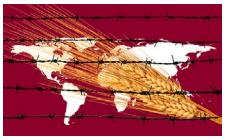

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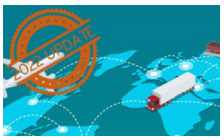

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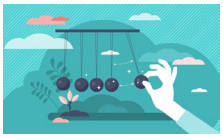

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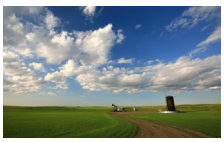

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Powering Up the Energy Transition
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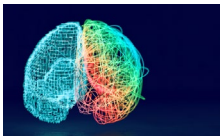

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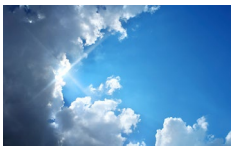

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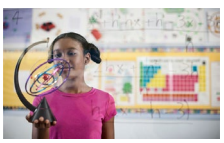

The Holistic Case for Investment in Girls

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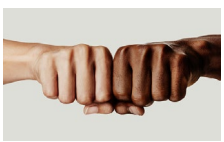

Closing the Racial Inequality Gaps

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IMPORTANT DISCLOSURES

NOW / NEXT

Key Insights regarding the future of Disruptive Innovation

INNOVATION

Rising demand for farmland has led to dangerous deforestation and negatively impacted biodiversity, while soil erosion and the use of pesticides and chemicals in farming has degraded the environment further. / Vertical farming uses 95% less water than conventional farm, as well as less land and fertilizer.

LABOR MARKET

Over the past two decades, the cost of attaining a tertiary education in both the U.S. and U.K. has risen significantly while the benefit of that education has declined. / Accrediting promises to create indirect disruption as employers use professional learnings, qualifications, and credentialing as a benefit to attract and retain the best talent in ever-tighter labor markets.

TECHNOLOGY

Historically, broadband service to home sand small- and medium-sized businesses was largely served by fixed wires and generally delivered by either a telecom incumbent or a cable firm. / The combination of spectrum availability, ongoing network densification, and technological advancements is providing a new and compelling opportunity for wireless firms to take share from the $115 billion fixed broadband market.