BIG IDEAS 2024

ARK INVEST

Annual Research Report

Risks Of Investing In Innovation

Please note: Companies that ARK believes are capitalizing on disruptive innovation and developing technologies to displace older technologies or create new markets may not in fact do so. ARK aims to educate investors and seeks to size the potential investment opportunity, noting that risks and uncertainties may impact our projections and research models. Investors should use the content presented for informational purposes only, and be aware of market risk, disruptive innovation risk, regulatory risk, and risks related to certain innovation areas.

Please read risk disclosure carefully.

RISK OF INVESTING IN INNOVATION

RAPID PACE OF CHANGE

EXPOSURE ACROSS SECTORS AND MARKET CAP

UNCERTAINTY AND UNKNOWNS

DISRUPTIVE INNOVATION

REGULATORY HURDLES

POLITICAL OR LEGAL PRESSURE

COMPETITIVE LANDSCAPE
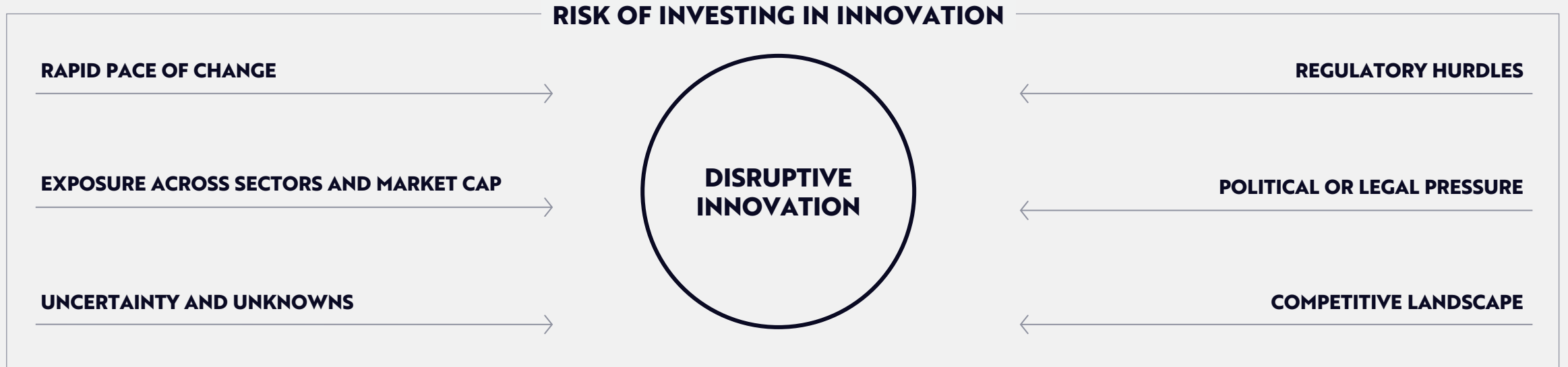
→ **Aim for a cross-sector understanding of technology and combine top-down and bottom-up research.**

→ **Aim to understand the regulatory, market, sector, and company risks. (See Disclosure Page)**

Sources: ARK Investment Management LLC, 2023.

Big Ideas 2024

Disrupting The Norm, Defining The Future

ARK Invest proudly presents "Big Ideas 2024: Disrupting the Norm, Defining the Future." A tradition since 2017, Big Ideas offers a comprehensive analysis of technological convergence and its potential to revolutionize industries and economies.

ARK seeks to deliver long-term capital appreciation by investing in the leaders, enablers, and beneficiaries of disruptive innovation. With a belief that innovation is key not only to growth but also to resilience, ARK emphasizes the necessity of a strategic allocation to innovation in every investor's portfolio. This approach aims to tap into the exponential growth opportunities often overlooked in broad-based indices, while simultaneously providing a hedge against the risks posed by incumbents facing disruption.

We hope you enjoy Big Ideas 2024.

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Research By: **Brett Winton**
Chief Futurist
ARK Venture Investment
Committee Member

BIG IDEAS 2024

Technological Convergence

CONVERGENCE

According to ARK's research, convergence among disruptive technologies will define this decade. Five major technology platforms—Artificial Intelligence, Public Blockchains, Multiomic Sequencing, Energy Storage, and Robotics—are coalescing and should transform global economic activity.

Technological convergence could create tectonic macroeconomic shifts more impactful than the first and second industrial revolutions. Globally, real economic growth could accelerate from 3% on average during the past 125 years to more than 7% during the next 7 years as robots reinvigorate manufacturing, robotaxis transform transportation, and artificial intelligence amplifies knowledge worker productivity.

Catalyzed by breakthroughs in artificial intelligence, the global equity market value associated with disruptive innovation could increase from 16% of the total* to more than 60% by 2030. As a result, the annualized equity return associated with disruptive innovation could exceed 40% during the next seven years, increasing its market capitalization from ~$19 trillion today to roughly $220 trillion by 2030.

CONVERGENCE

Five Innovation Platforms Are Converging And Defining This Technological Era

Public Blockchains

Upon large-scale adoption, all money and contracts likely will migrate onto Public Blockchains that enable and verify digital scarcity and proof of ownership. The financial ecosystem is likely to reconfigure to accommodate the rise of **Cryptocurrencies** and **Smart Contracts**. These technologies increase transparency, reduce the influence of capital and regulatory controls, and collapse contract execution costs. In such a world, **Digital Wallets** would become increasingly necessary as more assets become money-like, and corporations and consumers adapt to the new financial infrastructure. Corporate structures themselves may be called into question.

Multiomic Sequencing

The cost to gather, sequence, and understand digital biological data is falling precipitously. **Multiomic Technologies** provide research scientists, therapeutic organizations and health platforms with unprecedented access to DNA, RNA, protein, and digital health data. Cancer care should transform with pan-cancer blood tests. Multiomic data should feed into novel **Precision Therapies** using emerging gene editing techniques that target and cure rare diseases and chronic conditions. Multiomics should unlock entirely new **Programmable Biology** capabilities, including the design and synthesis of novel biological constructs with applications across industries, particularly agriculture and food production.

Artificial Intelligence

Computational systems and software that evolve with data can solve intractable problems, automate knowledge work, and accelerate technology's integration into every economic sector. The adoption of **Neural Networks** should prove more momentous than the introduction of the internet and potentially create 10s of trillion dollars of value. At scale these systems will require unprecedented computational resources, and AI-specific compute hardware should dominate the **Next Gen Cloud** datacenters that train and operate AI models. The potential for end-users is clear: a constellation of AI-driven **Intelligent Devices** that pervade people's lives, changing the way that they spend, work, and play. The adoption of artificial intelligence should transform every sector, impact every business, and catalyze every innovation platform.

Energy Storage

Declining costs of **Advanced Battery Technology** should cause an explosion in form factors, enabling **Autonomous Mobility** systems that collapse the cost of getting people and things from place to place. Electric drivetrain cost declines should unlock micro-mobility and aerial systems, including flying taxis, enabling business models that transform the landscape of cities. Autonomy should reduce the cost of taxi, delivery, and surveillance by an order of magnitude, enabling frictionless transport that could increase the velocity of e-commerce and make individual car ownership the exception rather than the rule. These innovations combined with large-scale stationary batteries should cause a transformation in energy, substituting electricity for liquid fuel and pushing generation infrastructure towards the edge of the network.

Robotics

Catalyzed by artificial intelligence, **Adaptive Robots** can operate alongside humans and navigate legacy infrastructure, changing the way products are made and sold. **3D Printing** should contribute to the digitization of manufacturing, increasing not only the performance and precision of end-use parts but also the resilience of supply chains. Meanwhile, the world's fastest robots, **Reusable Rockets**, should continue to reduce the cost of launching satellite constellations and enable uninterruptible connectivity. A nascent innovation platform, robotics could collapse the cost of distance with hypersonic travel, the cost of manufacturing complexity with 3D printers, and the cost of production with AI-guided robots.
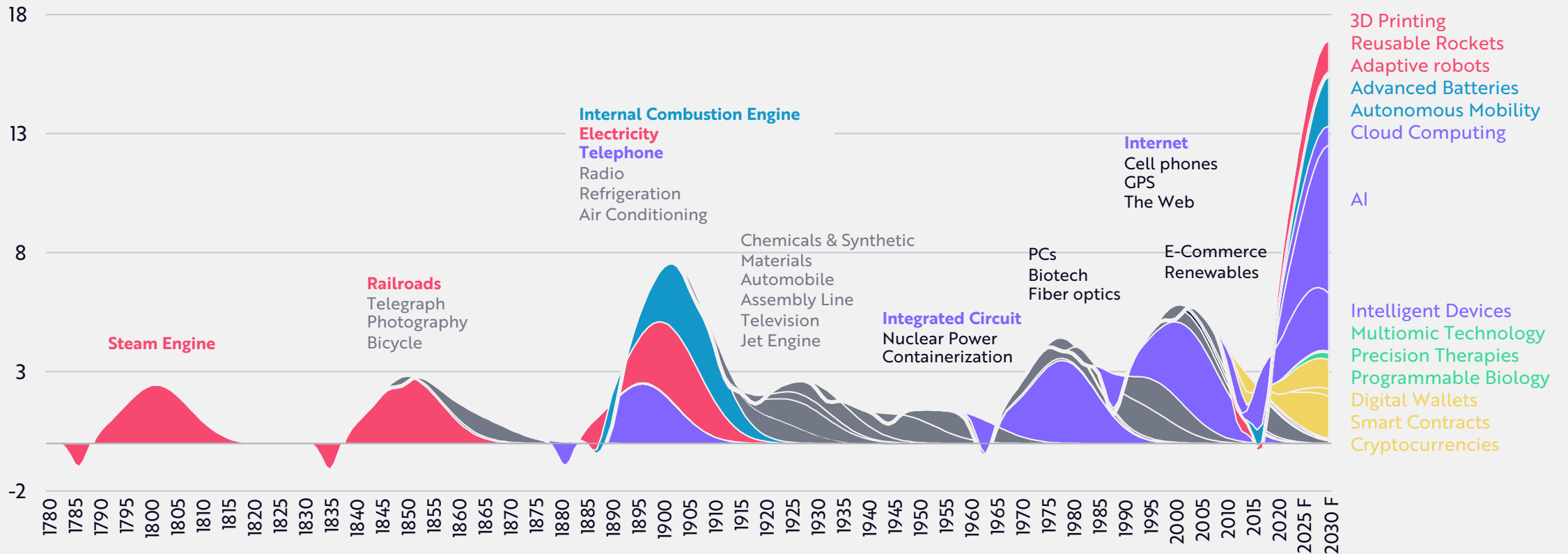
Converging Technologies Are Generating A Historic Technological Wave

Estimated Economic Impact of General Purpose Technologies

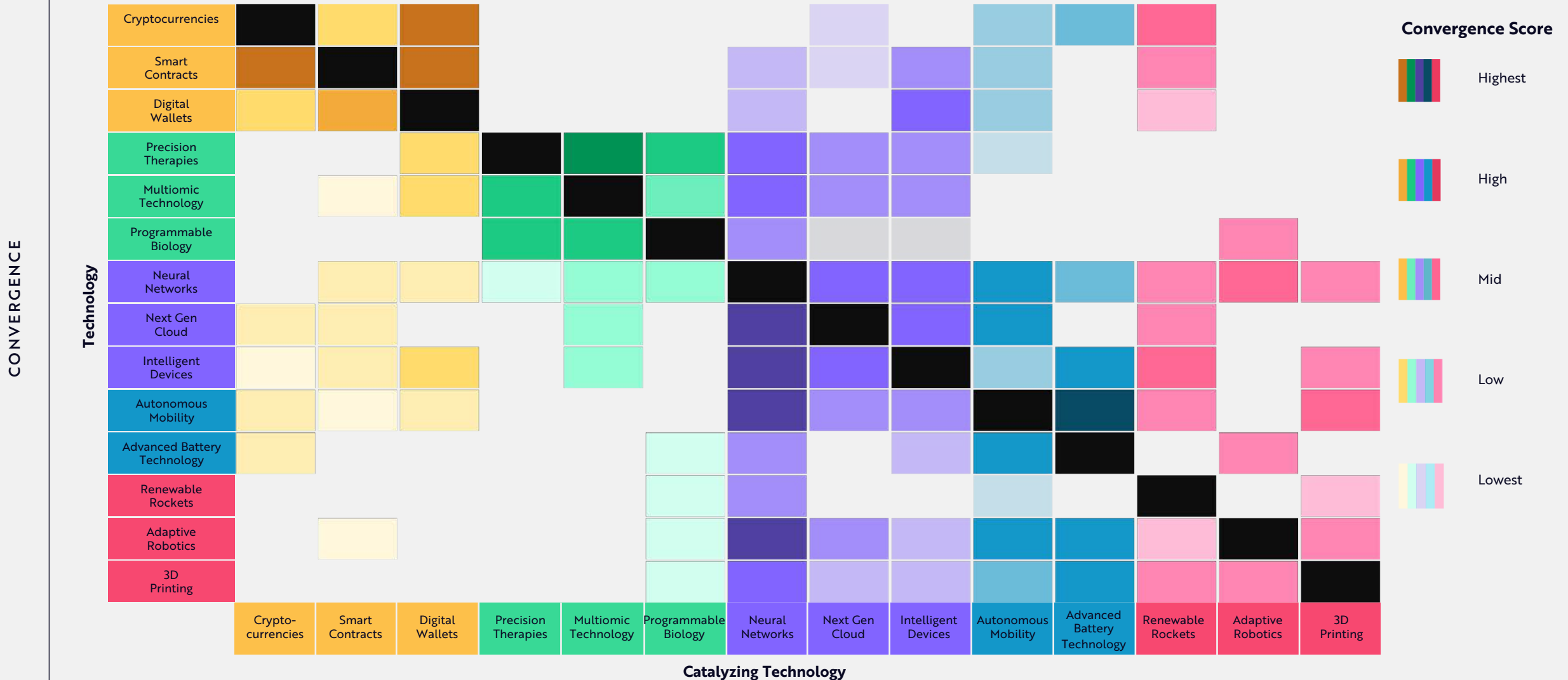### (Annual Percentage Point Additions to Real GDP Growth And Consumer Surplus)

CONVERGENCE

Internal Combustion Engine
Electricity
Telephone
Radio
Refrigeration
Air Conditioning

Internet
Cell phones
GPS
The Web

Railroads
Telegraph
Photography
Bicycle

Chemicals & Synthetic
Materials
Automobile
Assembly Line
Television
Jet Engine

PCs
Biotech
Fiber optics

E-Commerce
Renewables

Steam Engine

Integrated Circuit
Nuclear Power
Containerization

3D Printing
Reusable Rockets
Adaptive robots
Advanced Batteries
Autonomous Mobility
Cloud Computing

AI

Intelligent Devices
Multiomic Technology
Precision Therapies
Programmable Biology
Digital Wallets
Smart Contracts
Cryptocurrencies

AI Serves As The Central Technology Catalyst

The Technology Convergence matrix illustrates the relationships between and among technologies.

AI Is Accelerating Faster Than Forecasters Anticipated

CONVERGENCE

Expected Years Until Launch Of A General Artificial Intelligence System
(Log Scale)

Number of Years (y-axis): 100, 10, 1

- Pre GPT-3 average 80 years
- OpenAI announces GPT-3
- 50 years
- Google demonstrates advanced conversational agent, LLaMda2
- 34 years
- ChatGPT launches to the public
- GPT-4 launches
- 18 years
- 8 years
- If forecast is well-tuned
- If forecast error continues

x-axis: 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030

Individual Technology Advances Can Coalesce And Cascade Into Massive New Market Opportunities

CONVERGENCE

Neural Networks

Advanced AI enables robotaxis to rely on fewer, less expensive sensors.

+

Advanced Battery Technology

Battery electric drivetrains reduce robotaxi operating costs by 60%.

=

Autonomous Mobility

The combination of AI and battery electric drivetrains enables robotaxi systems to scale.

Robotaxi Manufacturing Costs (Per Vehicle, 2024)*

Thousands, $

Waymo
5 LIDARs, 29 cameras, 6 radars, 8 ultrasonic sensors

Tesla
9 Cameras

Robotaxi Operating Cost Per Mile By Drivetrain Type

$0.31 — **Internal combustion**
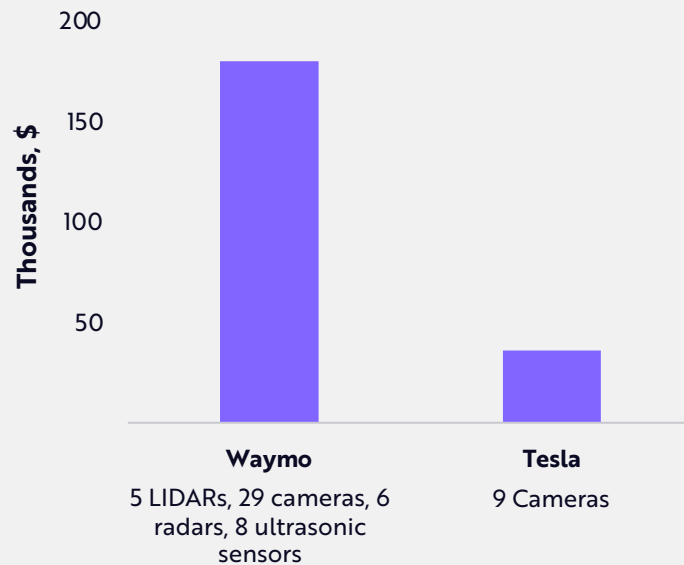
$0.12 — **Electric**

Adaptive Robotics

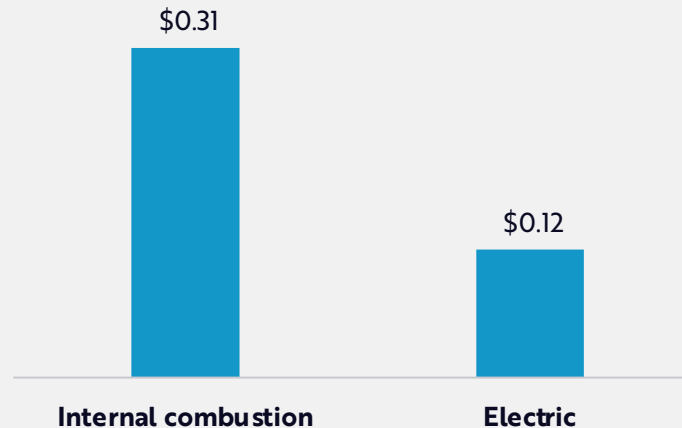In addition to better batteries and AI, general purpose robots will require better:
- Electric motors
- Power electronics
- Sensors
- Power-efficient compute

As robotaxis scale, the cost of each technology should decline according to its learning curve.

The Impact Of These Technologies On The Economy Should Prove Dramatic

CONVERGENCE

Economic Impact of Select Major Technologies
(Cumulative Increase In Real GDP Attributable to Technology After Introduction)
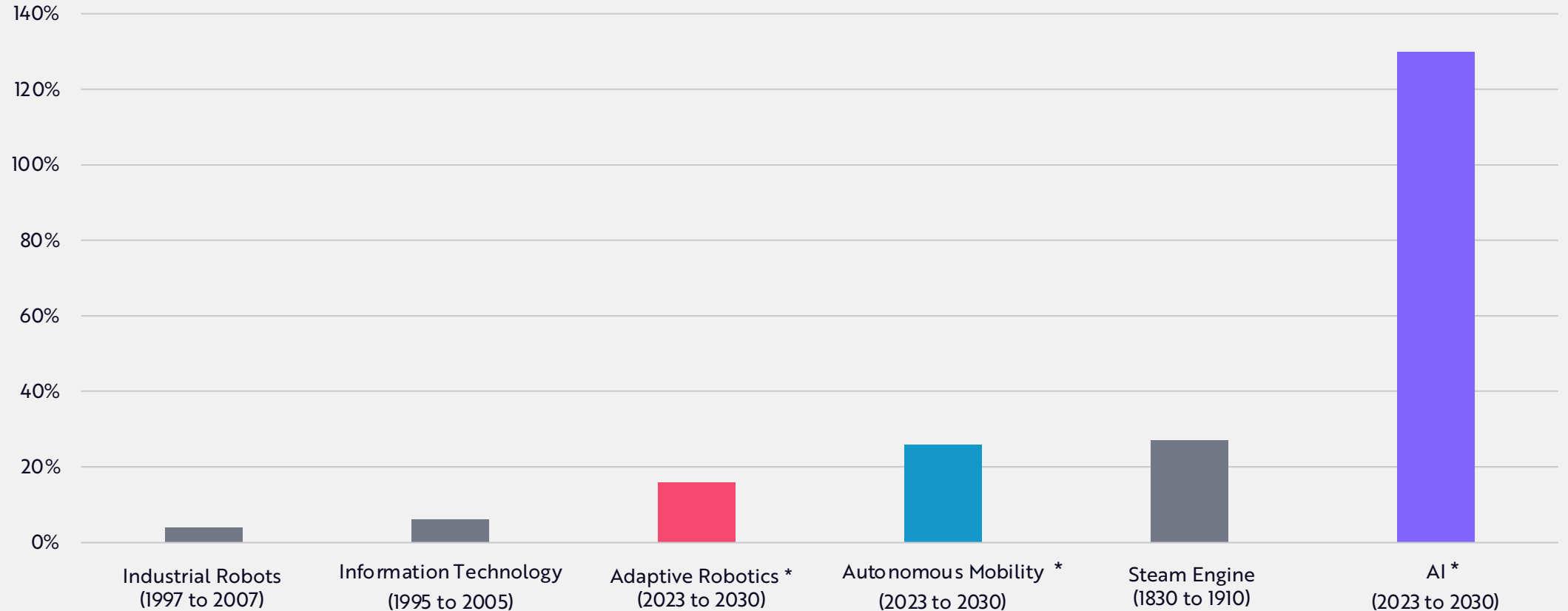
*Adaptive Robotics, Autonomous Mobility, and AI Impact are ARK Invest estimates. AI estimate includes consumer surpluses that may not be captured in traditional economic statistics. IT productivity impact likely also undercounts consumer surplus. Industrial Robot and IT impact measures impact on US, Europe, and Japanese economies. Steam Engine impact is measured against the UK economy. Sources: ARK Investment Management LLC, 2024, based on data from Crafts 2004, O'Mahony et al. 2009, and McKinsey Global Institute 2017. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Technological Innovation Could Be Disruptive Enough To Dominate Global Equity Market Capitalizations

CONVERGENCE

	2023 Equity Market Cap Estimate		2030 Equity Market Cap Forecast		Annual Growth Forecast
Non-innovation	$98 trillion	Non-innovation	$140 trillion		3%
Disruptive Innovation	$19 trillion	Disruptive Innovation	$220 trillion		42%
Total	$117 trillion	Total	$360 trillion		17%
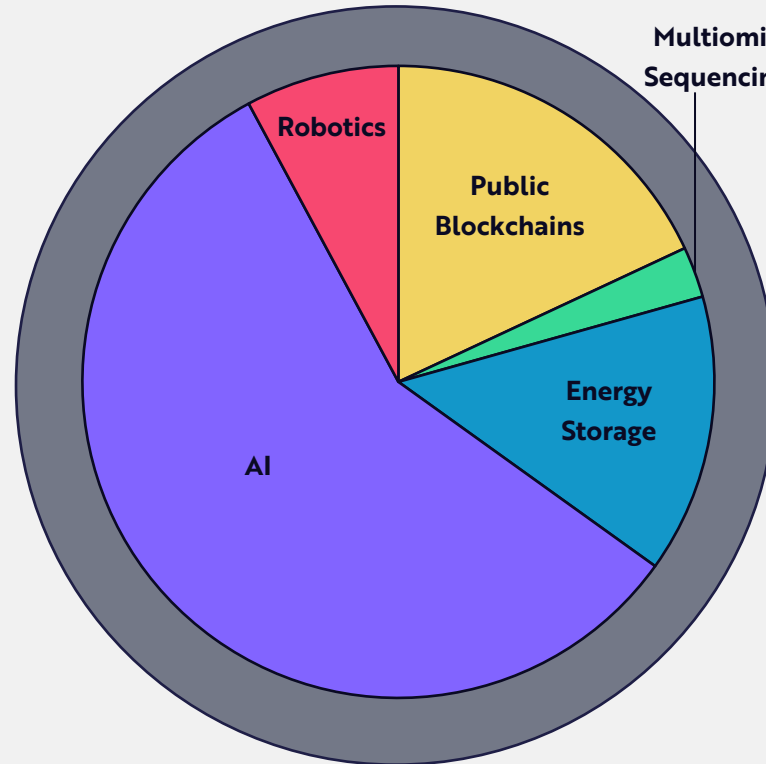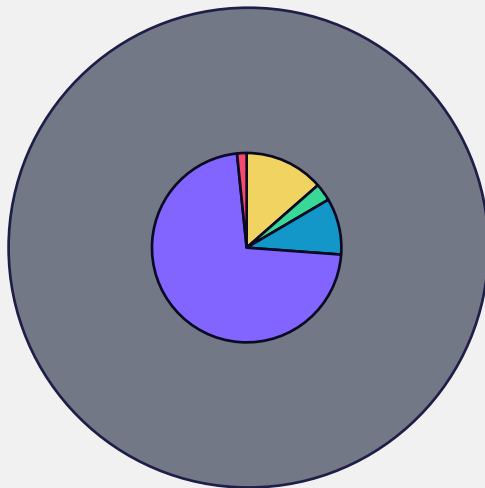
Artificial Intelligence
37%

Energy Storage
50%

Public Blockchains
48%

Robotics
78%

Multiomic Sequencing
39%

Expectations For Public Blockchains

Although the scenarios described in the table below are written in present tense, they are forecasted, possible outcomes based on ARK's views. These possible outcomes may not be realized in the future due to a number of uncertainties. The information provided should not be considered investment advice and should not form the basis of any investment decision.

Technology	2040 Possibilities	ARK's 2030 Expectation of Progress
Cryptocurrencies	Cryptocurrencies have displaced most permission-based, centrally controlled monetary systems, enabling financial ecosystems to reformulate around a digital asset that can eliminate counterparty risk while continuing to facilitate transaction flows. The reformulation began at the edges of the traditional financial system in geographies with broken money systems and in markets otherwise mis-served by traditional financial intermediaries. In developed markets, cryptocurrencies initially served as a store of value, providing little direct utility. Over time, the efficiencies of a truly neutral digital currency, primarily bitcoin, have prevailed over other financial architectures.	Global money supply has grown in tandem with GDP, and cryptocurrencies now account for ~10% of the total. Little of that value accrual is attributable to the direct displacement of money though there are instances in emerging markets. Much of the appreciation is a function of low single-digit percent allocations by institutional and high net worth individuals as well as corporate and nation-state treasuries. Cryptocurrencies continue to displace gold as a flight-to-safety asset, taking 40% share of the market. Utility use cases such as remittances and global settlements account for ~10% and~ 5% of volumes, respectively
Smart Contracts	Most contracts have migrated to open-source protocols that enable and verify digital scarcity and proof of ownership. Risk-sharing arrangements are more transparent, assets of all sorts are securitized, bought, and sold more easily, and counterparty risks have diminished substantially. The importance of traditional financial intermediaries has dwindled, even as more human activity becomes commercialized. Decentralized protocols, enabled by balance-sheet-light digital wallet platforms, facilitate most traditional financial functions. Consumer internet services rely on business models enabled by digital asset ownership. Every corporate entity and every consumer has adapted as centralized corporate structures themselves are called into question.	Global financial assets as percent of GDP have continued to increase, with less than 5% secured by smart contracting platforms—a dynamic consistent with the adoption curve of dialup internet. At 1%, the gross take from tokenized assets on decentralized protocols is less than a third of the fees that traditional financial institutions extract. Application protocols, which pay a larger share of fees to incentivize network participants, account for 75% of gross decentralized protocol revenues. The blended net take rate between application layer protocols and Level 1 protocols is roughly 60bps.
Digital Wallets	Digital wallets enable nearly every person with a connected device to transmit and receive money instantly, fundamentally transforming the through-flow of commercial and financial experiences. Digital wallets that facilitate wholesale pricing of financial services for individual users have disrupted retail banking relationships, fundamentally transforming consumer relationships with financial service providers. In addition to their financial functions, digital wallets are distribution platforms for a variety of digital services—from ride-hailing to e-commerce—and are secure repositories for digital health and other sensitive data. Traditional financial service institutions and their associated payment processing value chains have given way largely to internet-enabled digital wallets for most economic activity.	Roughly 90% of smartphone users rely on digital wallets to some degree. The majority uses digital wallets as the front-end for more than half of meaningful financial functions. Digital wallet platform providers continue to rely on traditional ecosystems to facilitate financial activities like lending but can extract lead generation fees of 5-20% for delivering customers to those institutions. They also can capture 3-10% commerce facilitation fees for e-commerce activity directed through their platforms.

CONVERGENCE

Expectations For Multiomic Sequencing

Although the scenarios described in the table below are written in present tense, they are forecasted, possible outcomes based on ARK's views. These possible outcomes may not be realized in the future due to a number of uncertainties. The information provided should not be considered investment advice and should not form the basis of any investment decision.

CONVERGENCE

Technology	2040 Possibilities	ARK's 2030 Expectation of Progress
Precision Therapies	Technology enables the manipulation of molecular biological systems, catalyzing a new generation of more efficacious and durable precision therapies. CRISPR-based gene-editing enables the manipulation of DNA directly with increasing specificity. RNA-acting therapeutic techniques restrict the area of DNA that can be transcribed into proteins. AI-advances enable the targeting of specific proteins that cause underlying disorders. These breakthroughs have shortened development timelines for and increased the efficacy of curative therapies that command higher prices than traditional therapies. Researchers are aiming to cure most rare diseases. Traditional health service spending declines, ceding economic terrain to molecular cures.	Precision therapies make up 25% of newly released drugs. By improving the quality of life, lowering ancillary medical costs, and often effectively curing diseases, they command average price premiums of 7x relative to traditional drugs. Combined with expected improvements in R&D efficiencies, these drugs add 15% or ~$300 billion to drug revenues in 2030.
Multiomic Technologies	Catalyzed by the precipitous fall in sequencing costs, researchers and clinicians routinely collect patients' epigenomic, transcriptomic, and proteomic data. With increasingly comprehensive digital health readouts from intelligent devices and emerging AI tools, they align this panoply of multiomic data to understand, predict, and treat disease. As a result, cancer care has transformed completely: multiomic technologies detect cancer at early stages, target treatment more precisely, and provide recurrence monitoring. Regular blood-based pan-cancer tests are a standard of care for patients in middle age. Multiomic technology has increased biotech R&D efficiency, as clinical trials target patient populations and measure outcomes more precisely and easily. Combined with AI, multiomic technology has transformed the relationship between patients and health systems. Digital health providers, diagnostic tool companies, and molecular testing companies are leading the charge. Legacy drug franchises and health service systems have lost their prominence. Wasteful healthcare spending declines as healthy lives extend.	At full penetration, R&D efficiency associated with drug development could double, thanks to AI-enhanced multiomic technology. By 2030, nearly all new drug development programs incorporate multiomics into preclinical R&D, and ~50% incorporate AI into clinical programs. Realized returns on R&D have improved by 10% with line-of-sight to a near doubling of R&D returns by 2035. Early detection multi-cancer blood tests have become standard of care as they have cut cancer mortality by 25% for some age cohorts. In developed markets, 30% of patients benefit from the new diagnostics regime.
Programmable Biology	AI tools, improved genomic synthesis techniques, and scalable biological manufacturing techniques enable novel, lower cost biological constructs with predictable performance, powering a renaissance in agriculture and materials science. Programmable biology enables breakthroughs in materials science and bio-based fuels that increase food production and reduce environmental externalities. Molecular biological primitives offer a substrate for new robust computation architectures.	Still restricted to early stage and development projects, gene synthesis generates $10 billion in annual revenue. Programmable biology platforms capture 10% of precision therapy revenue. Those platforms generate another $30 billion in revenue with gross margins at ~70%, EBITDA margins in the 35% range, and free cash flow margins at ~20%.

Expectations For Energy Storage

Although the scenarios described in the table below are written in present tense, they are forecasted, possible outcomes based on ARK's views. These possible outcomes may not be realized in the future due to a number of uncertainties. The information provided should not be considered investment advice and should not form the basis of any investment decision.

Technology	2040 Possibilities	ARK's 2030 Expectation of Progress
Autonomous Mobility	Robots move people and parcels from place to place and have changed the economics of physical movement entirely. The cost of taxi, delivery, and observation have fallen by an order of magnitude. Traveling by robotaxi is the norm and owning a personal vehicle the exception. Frictionless drone and robot delivery has catalyzed the velocity of ecommerce. The data generated by autonomous mobility systems provide pervasive, real-time insights into the state of the world. Consumers and businesses that harness autonomous mobility platforms are benefitting, while prior incumbents in the automotive, logistics, retail, and insurance sectors have been upended.	Autonomous robotaxis have transformed global transport, as point-to-point transportation is available in nearly every country at an average price of ~$.50 per mile. Given the compelling price-point and utility, robotaxis have traveled 13 trillion vehicle miles and are gaining traction. Autonomous robotaxi platforms charge platform fees or take-rates of 50%+, generate ~50% operating margins, and give asset owner-operators the opportunity to generate reasonable rates of return on capital. The number of autonomous vehicles facilitating this travel is ~100 million, and most of the incremental vehicle production is autonomous-capable.
Advanced Battery Systems	Declining battery costs have ignited a Cambrian explosion in mobility form factors, pushing electrical supply out to end-nodes on networks. Electric vehicles dominate transport as internal combustion dies. Micro-mobility and aerial systems that include flying taxis enable innovative business models that transform urban landscapes. All these innovations drive fundamental demand for electrical energy at the expense of liquid fuel. They also provide electrical energy more efficiently, reducing the vulnerability of grids, operational expenses, and the capital intensity of transmission and distribution. Oil demand is in decline, and traditional automotive manufacturers and suppliers have been displaced by a smaller number of vertically integrated technology providers.	As ridership shifts to electric autonomous platforms, the number of autonomous capable EVs sold annually is ~74 million, accounting for most of the automotive market. At an average selling price of ~$20,000, EV manufacturers generate $1.4 trillion in annual revenue, ~20% gross margins, and ~10% EBIT margins. With manufacturing consolidation, margins increase. Batteries account for ~20% of the value of EVs. Much like that of EVs, battery manufacturing is capital-intensive and low-margin. Supplying the EV OEMs, battery manufacturers generate revenue of $300 billion per year. Stationary energy storage requires a volume of batteries roughly equivalent to that consumed by EVs, generating another $300 billion in revenue.

CONVERGENCE

CONVERGENCE

Expectations For Artificial Intelligence

Although the scenarios described in the table below are written in present tense, they are forecasted, possible outcomes based on ARK's views. These possible outcomes may not be realized in the future due to a number of uncertainties. The information provided should not be considered investment advice and should not form the basis of any investment decision.

Technology	2040 Possibilities	ARK's 2030 Expectation of Progress
Neural Networks	Fed by massive amounts of data, computational systems and software are solving previously unsolvable problems, automating knowledge work, and accelerating the integration of technology into all economic processes. As costs have plummeted, custom software is improving with every AI model enhancement and connecting the world. Learning systems are blazingly fast, their impact as momentous as the introduction of the microprocessor, transforming every sector and region.	The cost of training AI models has fallen more than 40,000-fold which, when combined with aggressive investments in AI hardware, has catapulted aggregate AI capability roughly 600,000-fold since 2023. Adopted by 50% of knowledge workers, AI software systems have improved their productivity by 9x on average. Consistent with other software products, enterprises pay 10% of the productivity increase to access the software.
Next Gen Cloud	Cloud tools train the AI models that dominate software stacks and the software connections that stitch together the AI-run world. The infrastructure-as-a-service providers, chip manufacturers, and tool-manufacturers that facilitate the training of neural networks have enjoyed a multi-decade demand cycle. Software development has been democratized, and the companies providing API hooks that stitch together interoperable software layers experience unprecedented demand.	AI hardware spend of $1.3 trillion supports $13 trillion in AI software sales and accommodates traditional software gross margins of 75%. Three types of customers support the demand for AI hardware--infrastructure-as-a-service providers, software companies, and AI foundation model providers—which should generate 20% cashflow margins, consistent with those of chip manufacturers.
Intelligent Devices	AI powers a new class of intelligent devices in the home and on the go. Fixed internet-and AI-powered infrastructure exists in homes and other social environments, transforming distribution for all media providers. End-users interface with the world in completely new ways, and data on their consumption preferences spawn new business models and services. Commerce and wagering permeate entertainment experiences, enabling and catalyzing new advertising formats and content monetization. The show is the store. Linear TV is obsolete, as digital curation and direct consumer preference drive visual content. Linear content is ceding ground to interactive experiences, sometimes subtly. AI-mediated glasses and headsets thread through the fabric of everyday life.	Consumer spending on intelligent device hardware continues its uptrend to ~$60 per internet user per year. Time spent connected grows dramatically to half of waking leisure hours, or 20 trillion globally. Digital experiences continue to monetize at a discount to in-person experiences and yield $0.25 per hour spent online in revenue to platform providers. Between device spend and digital entertainment experiences, $5.4 trillion in revenue accrues to intelligent devices, entertainment, and social platforms. Advertising and commerce comprise 80% of that revenue.

Expectations For Robotics

Although the scenarios described in the table below are written in present tense, they are forecasted, possible outcomes based on ARK's views. These possible outcomes may not be realized in the future due to a number of uncertainties. The information provided should not be considered investment advice and should not form the basis of any investment decision.

CONVERGENCE

Technology	2040 Possibilities	ARK's 2030 Expectation of Progress
Reusable Rockets	Reusable rockets are inexpensive and have spawned new business models. Low-earth orbit constellations connect every smartphone user on earth to a censor-resistant data feed. Hypersonic point-to-point travel is becoming a reality, disrupting long-haul flight, transforming military asset delivery, and shrinking global supply chains. Extra-planetary human exploration has begun ramping.	Led by SpaceX's Starship launch volumes, a 40,000 strong satellite network is in orbit, facilitating direct-to-satellite communications for nearly all smartphones and delivering broadband-type speeds to ships, RVs, airplanes, and rural residents in developed and developing countries. Given the relative ease with which customers can be on-boarded—a power outlet, an antenna, and a clear path to the sky—most customers are engaged in an addressable market totaling $130 billion annually.
Adaptive Robotics	Adaptive robots powered by artificial intelligence are transforming the economy. The cost of humanoid robots that are backward-compatible with existing infrastructure has dropped below that of human manufacturing labor for many applications. Previously intractable household tasks are submitting to automation at price points that create compelling end-markets. Fleets of robots grow more performant with every AI software upgrade. A virtuous circle of fleet data generation and AI model training drives performance forward. Manufacturing productivity growth accelerates as a wider array of physical goods submit to technologically-driven cost declines. Robots continue to penetrate the service sector as well. The economy has entered a period of undeniable and unprecedented explosive growth.	Adaptive robots have penetrated manufacturing processes enough to increase productivity by 15%, and annual unit sales of humanoid robots have grown to 10% of the number of humans in the manufacturing workforce. Less expensive robots in human form-factors have begun to populate households, particularly in developed countries. While still limited in capability, these robots address a third of household chores, their sticker prices justified by the time that household members save. Robot manufacturers enjoy margins at the higher end of capital equipment suppliers, thanks to software.
3D Printing	3D printing has removed design barriers and reduced cost, weight, and time to production, dramatically transforming traditional manufacturing methods. Healthcare tools created with 3D printing are personalized and custom-made, resulting in better experiences for both patients and doctors. Lighter 3D-printed aerospace parts reduce global emissions and give flight to new aircraft both for earth and outer space. Replacement parts across industries are printed on demand at a fraction of previous costs, ultimately short-circuiting supply-chain shortfalls. 3D printing enables artificial intelligence to design parts once impossible to manufacture.	3D printing continues to dominate the prototyping market and has penetrated substantial parts of the intermediate tooling market, enabling low-cost design iterations across injection molding and metal casting applications. Most important to industry growth, 3D printing has begun to see meaningful uptake into end-use applications across aerospace and automotive, markets that collectively sell more than $4 trillion in equipment per year. Across all industries, nearly $900 billion in end-use parts could adopt 3D printing, though that penetration remains in the teens.

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Jozef Soja
Research Associate

Artificial Intelligence

Scaling Global Intelligence
And Redefining Work

With superhuman performance on a wide range of tests, AI models like GPT-4 should catalyze an unprecedented boom in productivity. Jolted by ChatGPT's "iPhone" like moment, enterprises are scrambling to harness the potential of artificial intelligence (AI).

AI promises more than efficiency gains, thanks to rapidly falling costs and open-source models. If knowledge worker productivity were to quadruple by 2030, as we believe is likely, growth in real GDP could accelerate and break records during the next five to ten years.

# ChatGPT Delighted Consumers And Amazed Enterprises

Building on years of progress since Google invented transformer architecture in 2017, ChatGPT catalyzed the public's understanding of generative AI. No longer a tool just for developers, ChatGPT's simple chat interface enabled anyone speaking any language to harness the power of large language models (LLMs). In 2023, enterprises scrambled to understand and deploy generative AI.

ARTIFICIAL INTELLIGENCE

ChatGPT Users Hit 100 Million Users In Two Months
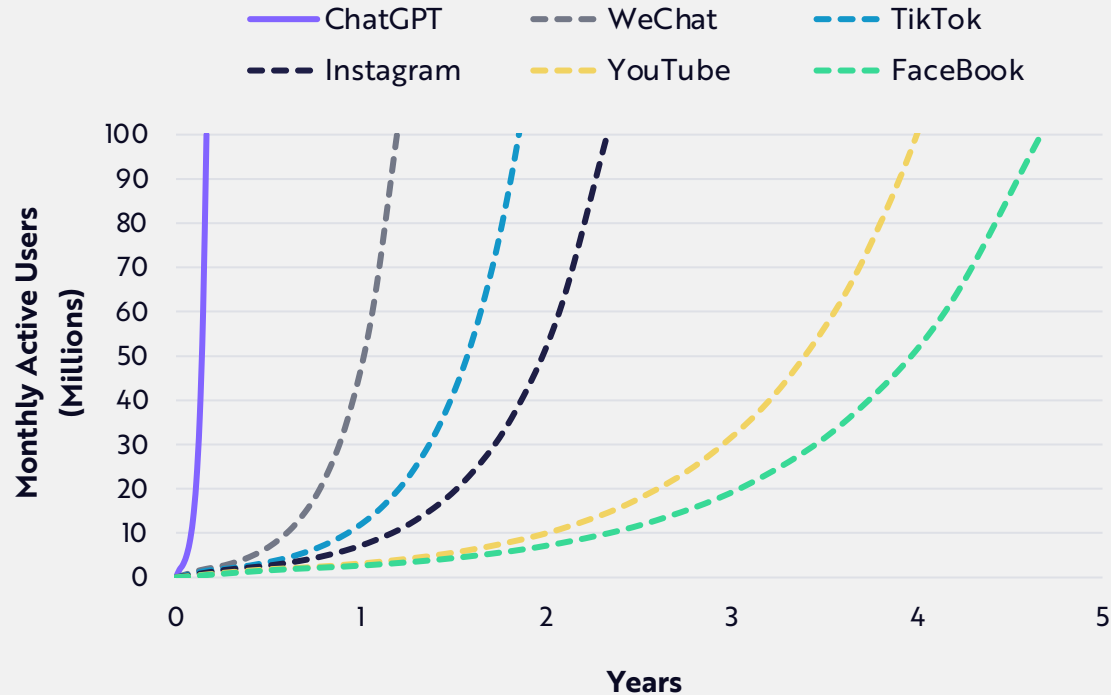
*values between 0 and 100 million users are estimates
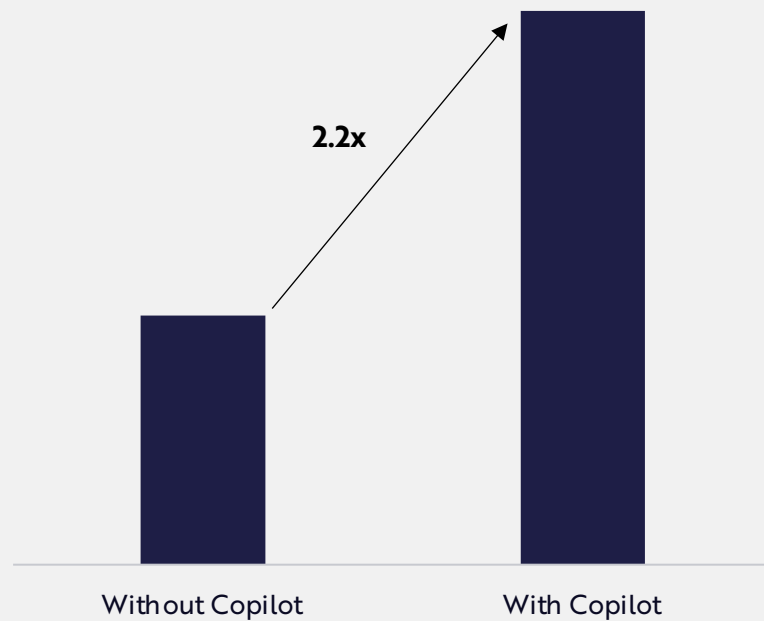
The Number of AI Mentions Tripled On Earnings Calls
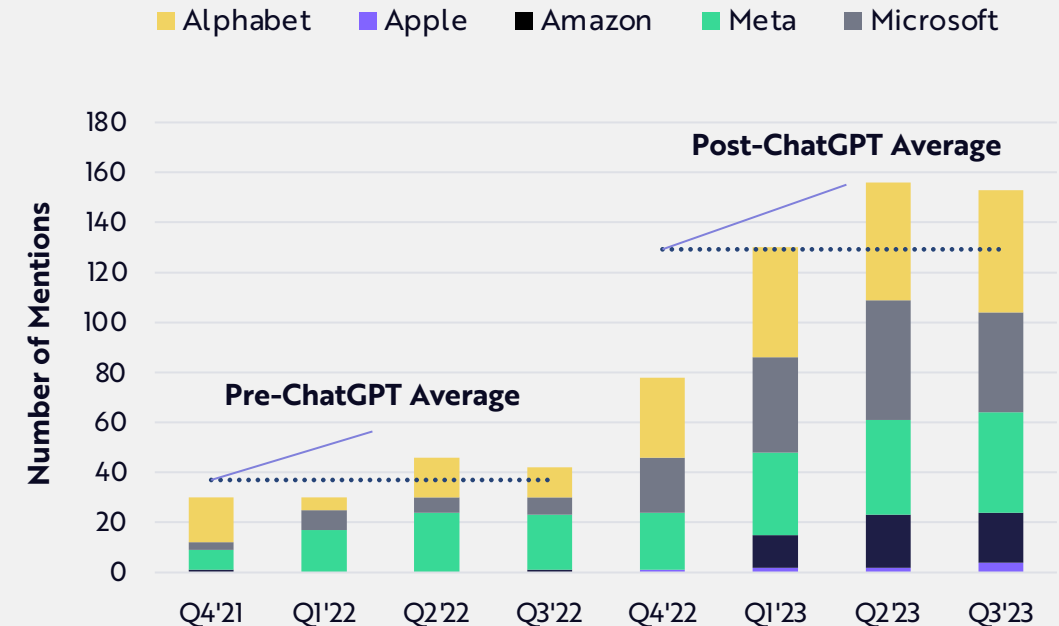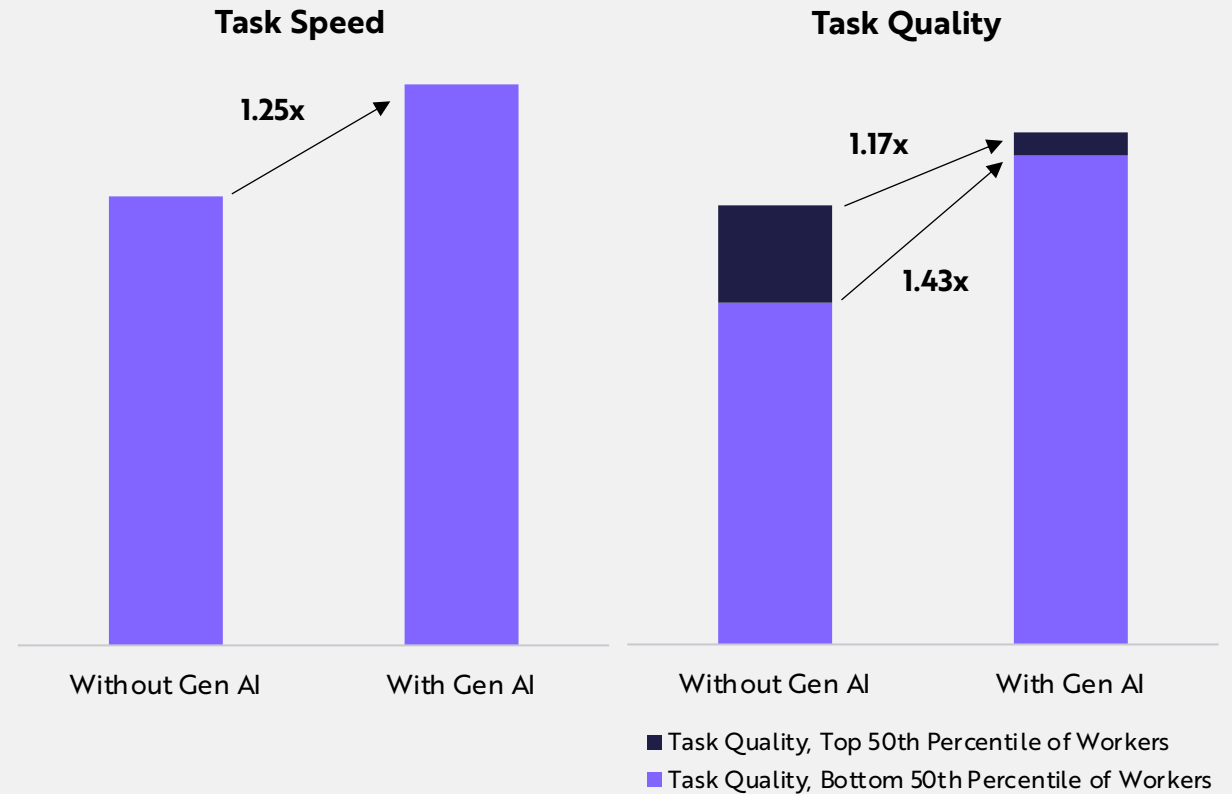
ARTIFICIAL INTELLIGENCE

AI Already Has Boosted Productivity Significantly

Coding assistants like GitHub Copilot and Replit AI are early success stories that have boosted the productivity and job satisfaction of software developers. AI-powered assistants are increasing the performance of knowledge workers and, interestingly, benefiting underperforming workers relatively more than high performers.

Productivity of Developers On Coding Tasks Using Github Copilot in 2023

2.2x

Without Copilot   With Copilot

Productivity of Consultants Using Gen AI In 2023

Task Speed

1.25x

Without Gen AI   With Gen AI

Task Quality

1.17x

1.43x

Without Gen AI   With Gen AI

■ Task Quality, Top 50th Percentile of Workers
■ Task Quality, Bottom 50th Percentile of Workers

Sources: ARK Investment Management LLC, 2024. The data used to analyze productivity were collected from several different studies with varying numbers of participants and definitions of task quality. The sources used are Dell'Acqua et al. 2023 and GitHub 2022. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Foundation Models Are Improving Across Domains

With larger training datasets and more parameters, GPT-4 outperforms GPT-3.5 significantly. Increasingly, foundation models are becoming "multimodal"—supporting text, images, audio, and video—and are not only more dynamic and user friendly, but also more performant.

ARTIFICIAL INTELLIGENCE

GPT-3.5, GPT-4, and Claude 2 Results on Professional and Academic Exams

Legend: ■ GPT-3.5 ■ GPT-4 ■ Claude 2 ■ GPT-4 Vision
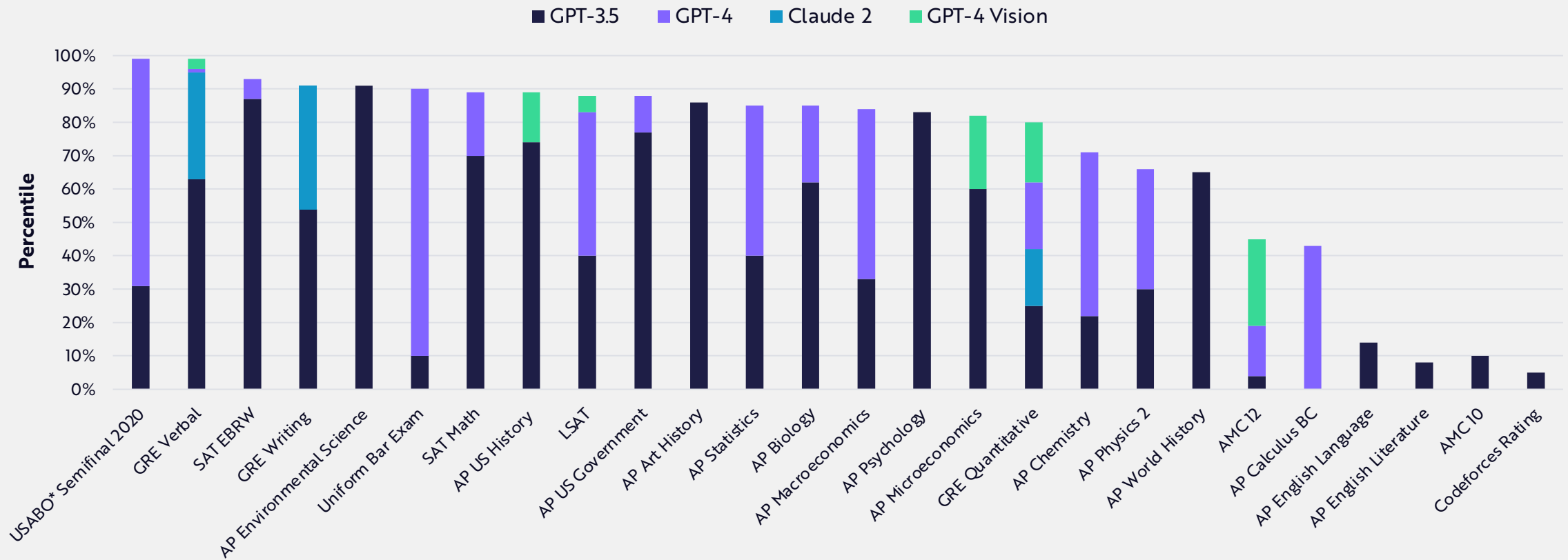
*USA Biology Olympiad, a prestigious national competition testing high school students in biology. Sources: ARK Investment Management LLC, 2024, based on data from OpenAI and Anthropic as of Jan. 9, 2024. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Text-To-Image Models Are Reinventing Graphic Design

Eight years after researchers at the University of Toronto introduced the first modern text-to-image model, the output from image models now rivals that of professional graphic designers. A human designer can create an image—like a herd of elephants walking across a green grass field—in several hours for several hundred dollars. Text-to-image models can produce the same graphic in seconds for pennies. Professional apps like Adobe Photoshop and consumer apps like Lensa and ChatGPT are integrating image models into their products and services.

ARTIFICIAL INTELLIGENCE

🔍 A herd of elephants walking across a green grass field

February 2016
alignDRAW

February 2022
Midjourney v1

November 2022
Midjourney v4
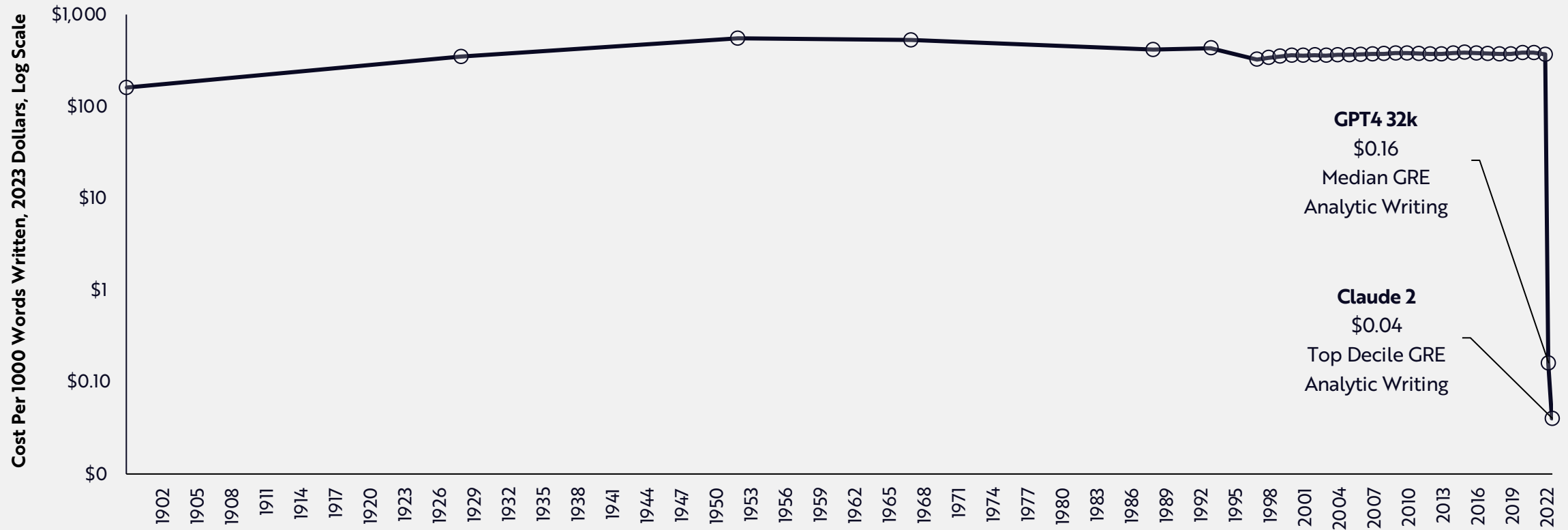
December 2023
Midjourney v6

The Cost Of Authoring The Written Word Has Collapsed

Over the past century, the cost of authoring written content has been relatively constant in real terms. During the past two years, as the writing quality of LLMs has improved, the cost has collapsed.

ARTIFICIAL INTELLIGENCE

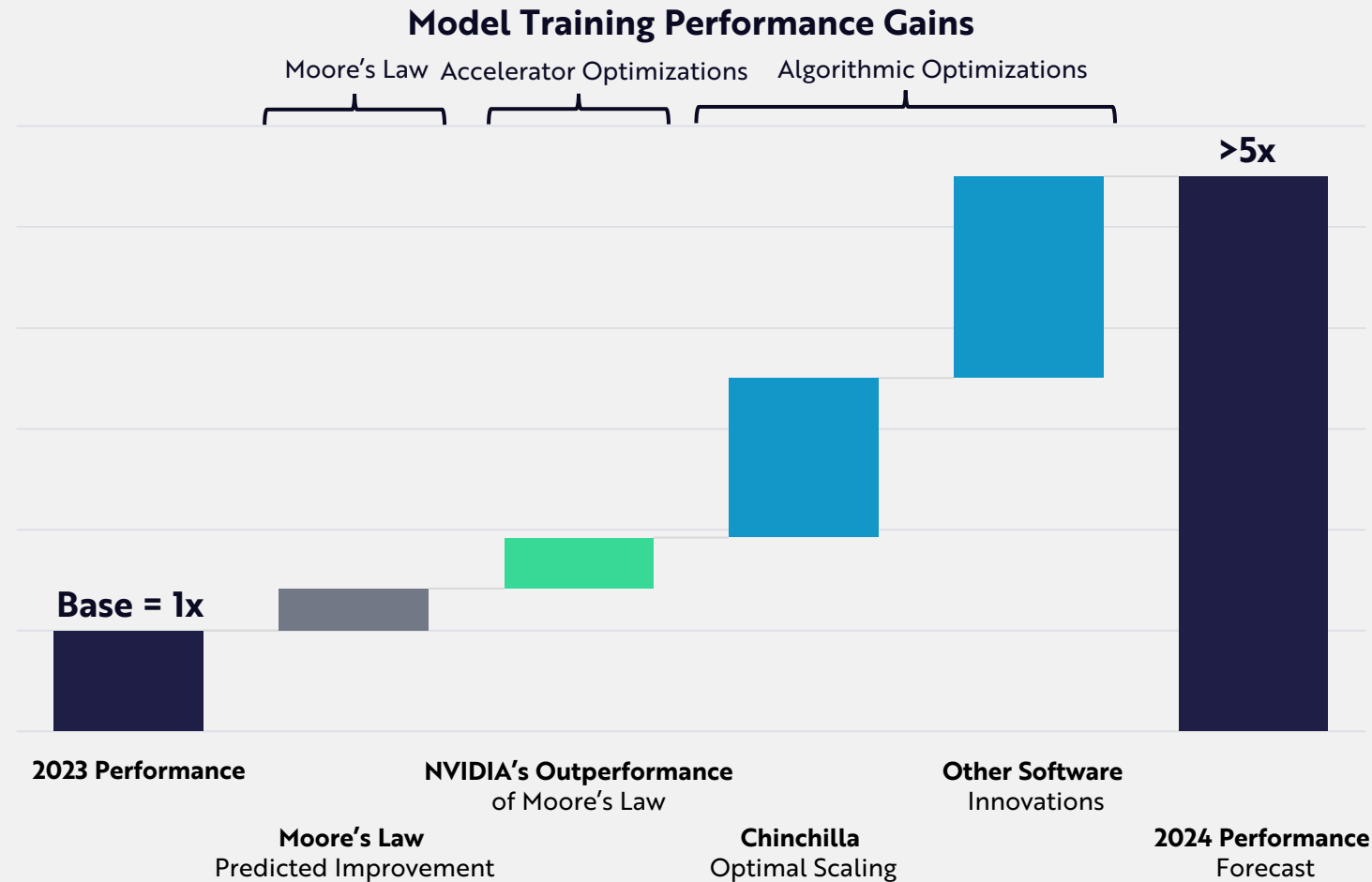**The Cost of Authoring Written Content**

GPT4 32k
$0.16
Median GRE
Analytic Writing

Claude 2
$0.04
Top Decile GRE
Analytic Writing

Post 1997 assumes constant words per employed writer over time

AI Training Performance Is Improving Rapidly

AI researchers are innovating across training and inference, hardware, and model designs to increase performance and lower costs.

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Model Training Performance Gains

Moore's Law · Accelerator Optimizations · Algorithmic Optimizations

>5x

Base = 1x

2023 Performance

NVIDIA's Outperformance of Moore's Law

Other Software Innovations

Moore's Law Predicted Improvement

Chinchilla Optimal Scaling

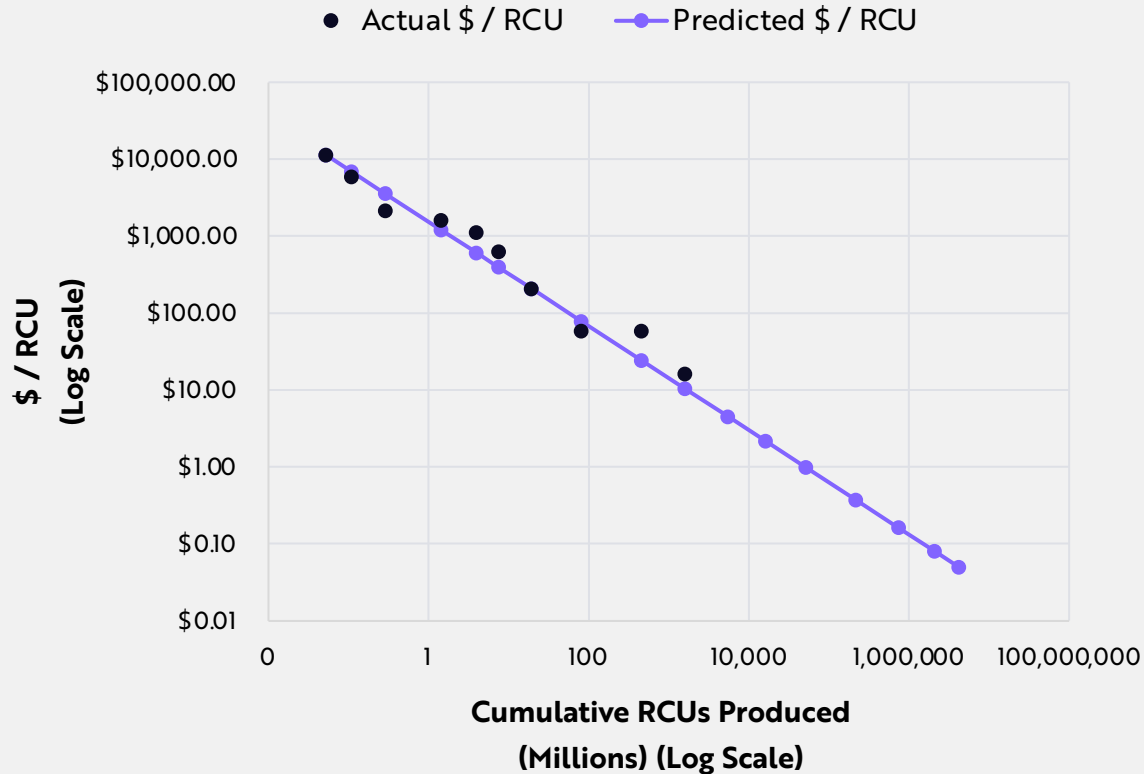**2024 Performance** Forecast

Other Algorithmic Innovations

- Llama2 suggests superior writing ability of LLMs is fundamentally driven by reinforcement learning from human feedback (RLHF)

- Optimized prompts can outperform human prompts by over 50%

- Speculative Decoding speeds up inference 2-3x on certain models

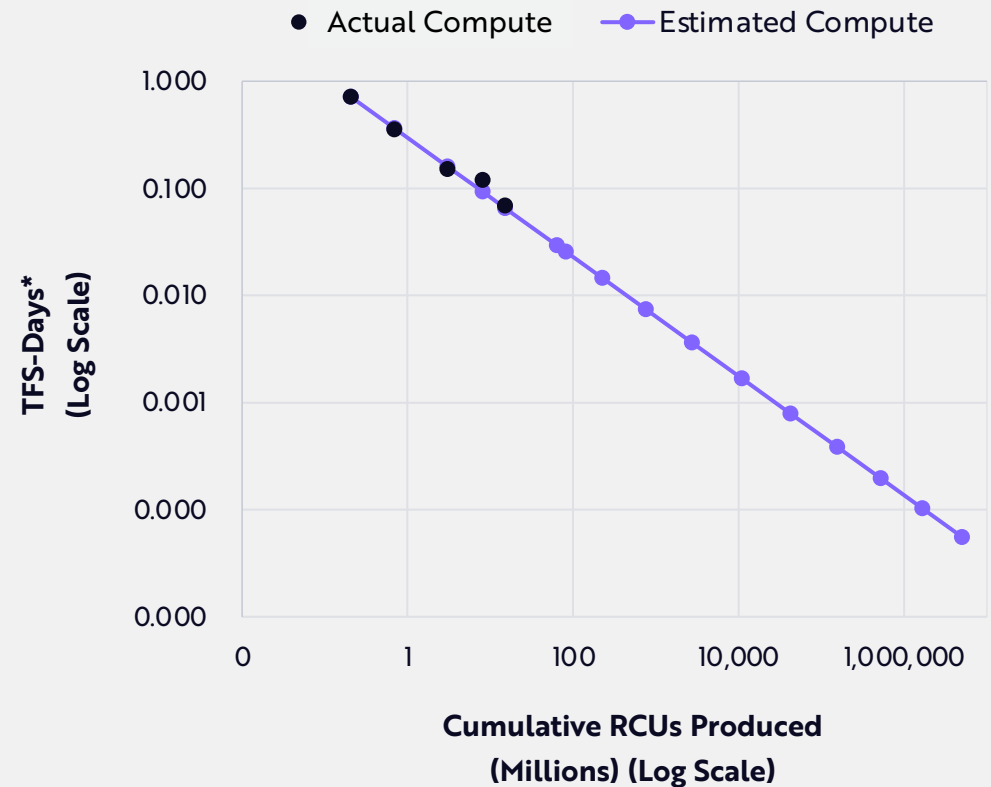- Flash Attention 2 results in a 2.8x training speedup in GPT models

Training Costs Should Continue To Fall 75% Per Year

According to Wright's Law, improvements in accelerated compute hardware should reduce AI-relative compute unit (RCU) production costs by **53%** per year, while algorithmic model enhancements could lower training costs further by **47%** per year. In other words, the convergence of hardware and software could drive AI training costs down by 75% at an annual rate through 2030.

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AI Training Hardware Cost

● Actual $ / RCU ●— Predicted $ / RCU

$ / RCU (Log Scale)

Cumulative RCUs Produced (Millions) (Log Scale)

AI Software Training Cost Using Neural Networks

● Actual Compute ●— Estimated Compute

TFS-Days* (Log Scale)

Cumulative RCUs Produced (Millions) (Log Scale)

As Production Use Cases Emerge, AI Focus Is Shifting To Inference Costs

After focusing initially on LLM training cost optimization, researchers now are prioritizing inference costs. Based on enterprise scale use cases, inference costs seem to be falling at an annual rate of ~86%, even faster than training costs. Today, the inference costs associated with GPT-4 Turbo are lower than those for GPT-3 a year ago.

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**GPT-3 and GPT-4 API Inference Costs
Per 1,000 Tokens**

**GPT-4-32k:
Context Window:**
32k Tokens
Speed:
12 Tokens/Sec

86% Annualized Cost Decline

92% Annualized Cost Decline

**GPT-4 Turbo:
Context Window:**
128k Tokens, ↑4x
Speed:
44 Tokens/Sec, ↑4x

Date of Price Change

ARTIFICIAL INTELLIGENCE

The Open-Source Community Is Competing With Private Models

Challenging closed-source models from OpenAI and Google, the open-source community and its corporate champion, Meta, are democratizing access to generative AI. On balance, the performance of open-source models is improving faster than that of closed-source models, helped recently by models from China.

Open Source vs Private Models
5-Shot MMLU Performance
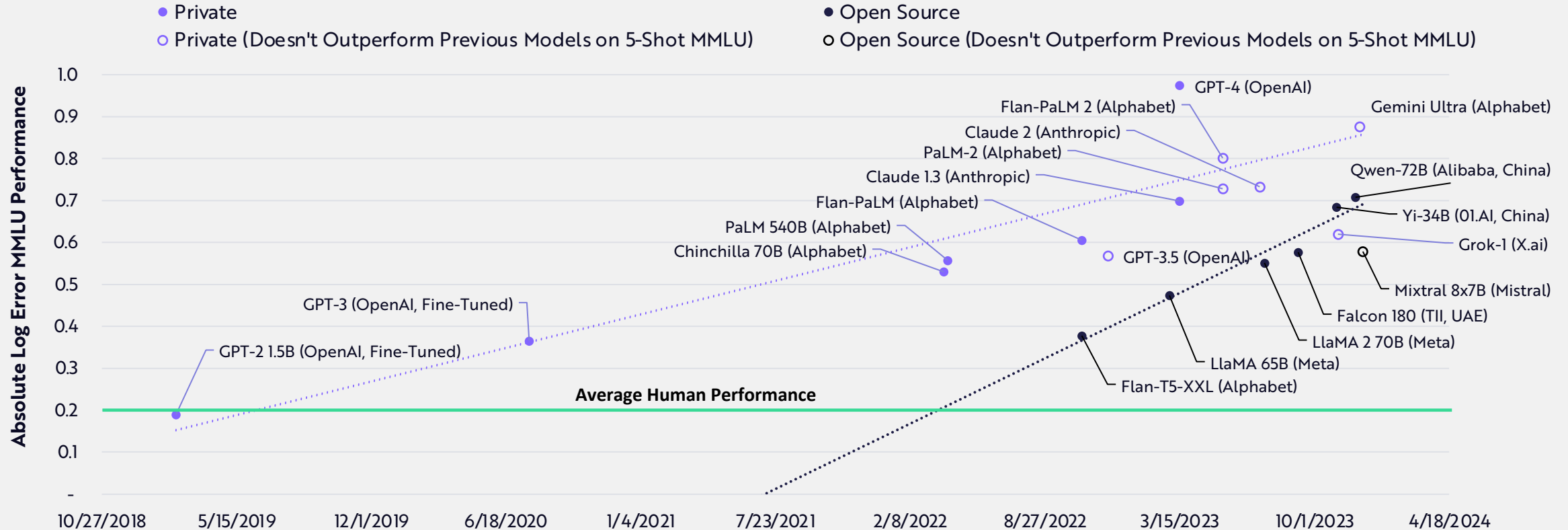
Note: The chart's trendlines are fit to the most performant open- or closed-source models on 5-Shot MMLU (Massive Multitask Language Understanding) at the time of their release. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of data sources as of Jan. 9, 2024, which are available upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

ARTIFICIAL INTELLIGENCE

Language Model Performance Advances Require Nuanced Techniques

GPT-4 performs significantly better than the average human on standardized education tests, from the SAT to the Advanced Sommelier exam. Yet, it lags human-level capability in commonsense reasoning, as measured by WinnoGrande. Stanford's framework—Holistic Evaluation of Language Models (HELM)—is one of the most comprehensive, continuously updated evaluation methodologies, having tested over 80 models against a combination of 73 scenarios and 65 metrics.

Select GPT-4 Benchmark Results

Legend: ■ Human Avg. ■ GPT-4

Y-axis: Score (0–100)

Categories: USABO* Semifinal 2020, Uniform Bar Exam, SAT, Advanced Sommelier, WinoGrande (commonsense)
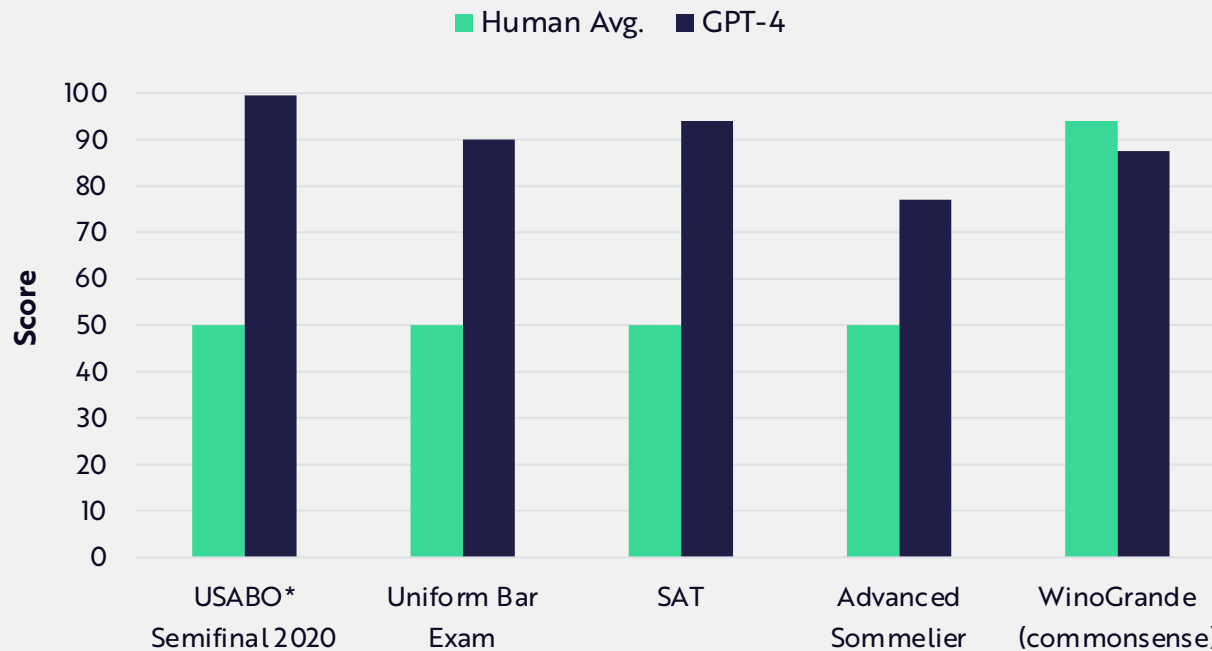
HELM Evaluation Metrics
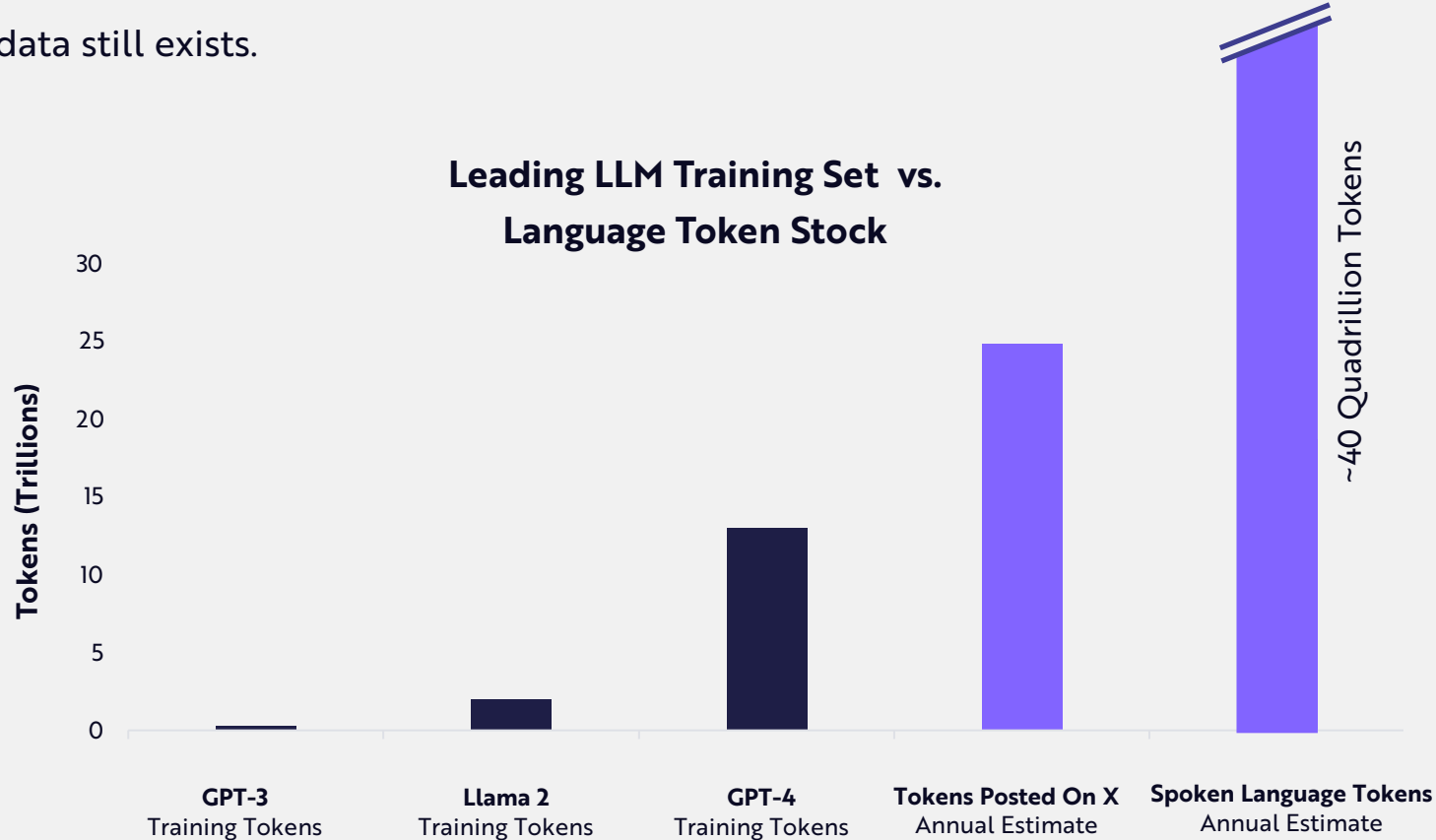
Metric	Description
Accuracy	Comparison with ground truth data
Calibration	Probability distribution assessment
Robustness	Stress testing with perturbed inputs
Fairness	Performance across diverse groups
Bias	Analysis of decision patterns for skew
Toxicity	Detection rate of harmful content
Efficiency	Resource usage during task execution

Will LLMs Run Out Of Data, Limiting Their Performance?

Computing power and high-quality training data appear to be the primary contributors to model performance. As models grow and require more training data, will a lack of fresh data cause model performance to plateau? Epoch AI estimates that high-quality language/data sources like books and scientific papers could be exhausted by 2024, though a larger set of untapped vision data still exists.

ARTIFICIAL INTELLIGENCE

**Leading LLM Training Set vs.
Language Token Stock**

Tokens (Trillions)

~40 Quadrillion Tokens

|	
GPT-3 Training Tokens	
Llama 2 Training Tokens	
GPT-4 Training Tokens	
Tokens Posted On X Annual Estimate	
Spoken Language Tokens Annual Estimate	

Untapped Data Sources

- 30 quadrillion words spoken annually

- Speech-to-text tools that capture the estimated 80+ trillion words spoken daily.

- Synthetic data that augments primary data.

- Autonomous taxis, trucks, drones, and other robots that generate large volumes of physical world data.

Customized AI Offerings Should Enjoy More Pricing Power

As open-source alternatives emerge and costs decline, software vendors tailoring AI to end-use applications should be able to monetize them more readily. Conversely, simple generative AI applications are likely to commoditize rapidly.

ARTIFICIAL INTELLIGENCE

Take-Rate Of Notable Enterprise Software Solutions
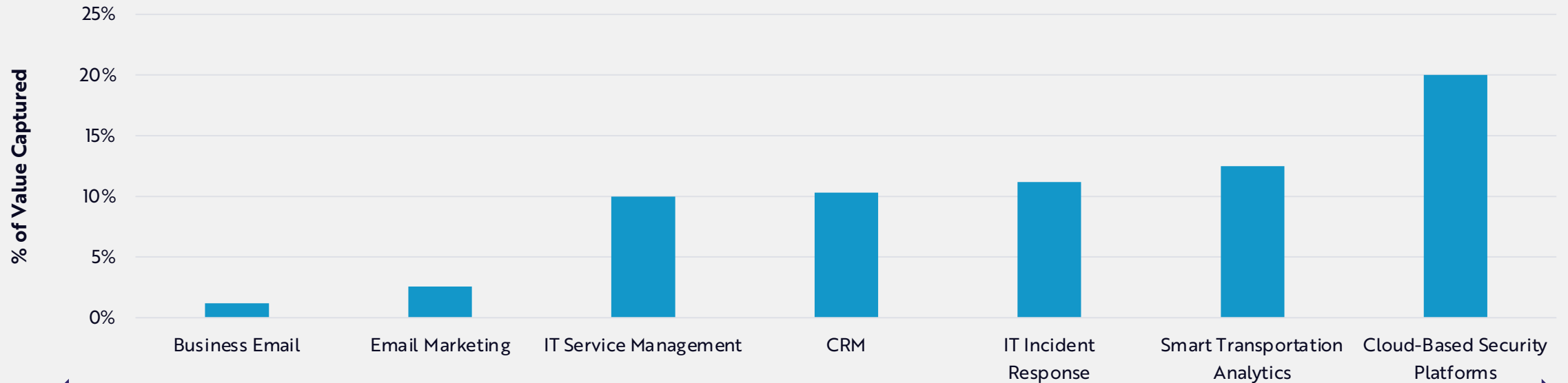
Low Value Capture

High Value Capture

- Horizontal, Commoditized Tools
- < 5% Value Captured
- Example: AI Meeting Summaries

- Verticalized, Highly Differentiated Tools
- 20%+ Value Captured
- Example: Autonomous Ride-hail

ARTIFICIAL INTELLIGENCE

Accelerating The Growth Of Knowledge Worker Productivity Represents A Potential Multi-Trillion Dollar Opportunity

Artificial intelligence has the potential to automate most tasks in knowledge-based professions by 2030, dramatically increasing the average worker's productivity. Software solutions that automate and accelerate knowledge work tasks should be prime beneficiaries.

AI Total Addressable Market (TAM) Forecast In 2030

Software Vendor Value Capture % Of Productivity Gain

Productivity Uplift (Multiple)	1%	10%	20%
2.5	$0.7T	$7T	$14T
4.5	$1.3T	$13T	$26T
6.5	$1.9T	$19T	$37T
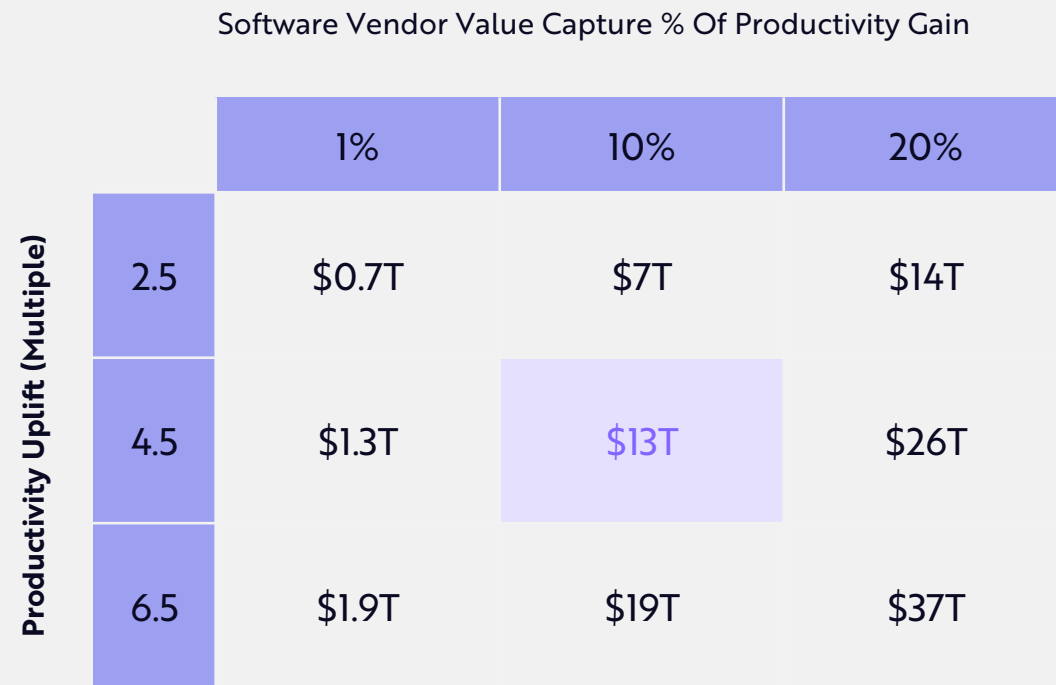
Impact of AI on Software Growth
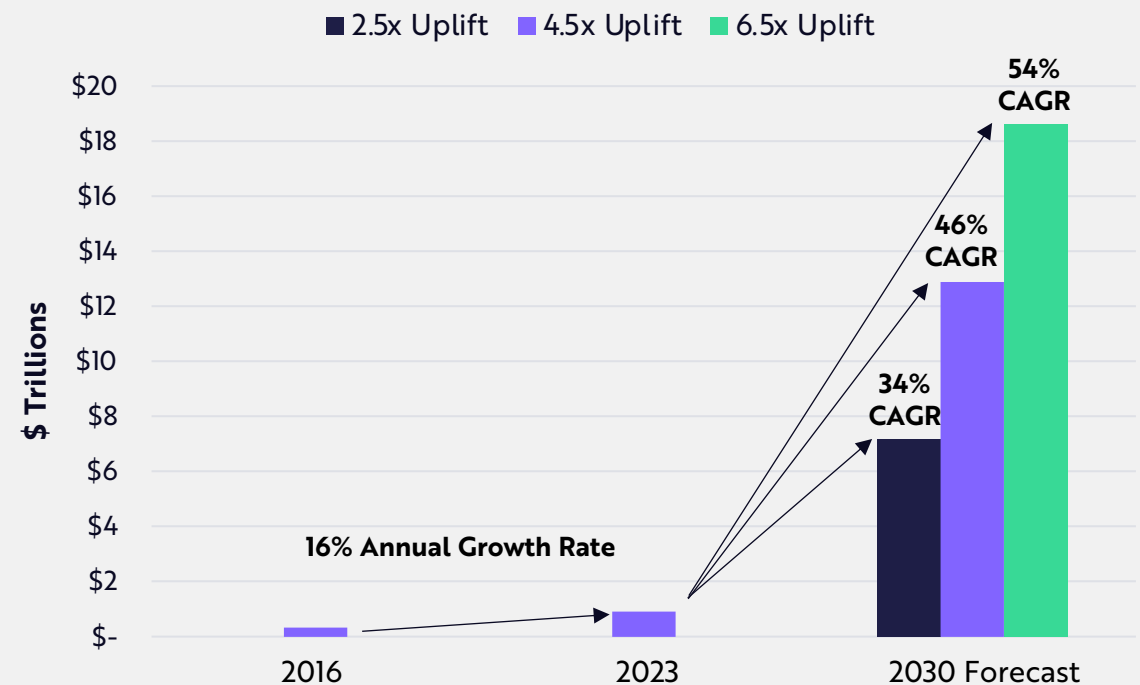
■ 2.5x Uplift   ■ 4.5x Uplift   ■ 6.5x Uplift

16% Annual Growth Rate

34% CAGR

46% CAGR

54% CAGR

2016   2023   2030 Forecast

$ Trillions

Research By: **Yassine Elmandjra**   **David Puell**
Director of Digital Assets   Research Associate

Bitcoin Allocation

Growing The Role Of Bitcoin In Investment Portfolios

Important Information

Bitcoin is a relatively new asset class, and the market for bitcoin is subject to rapid changes and uncertainty. Bitcoin is largely unregulated and bitcoin investments may be more susceptible to fraud and manipulation than more regulated investments. Bitcoin is subject to unique and substantial risks, including significant price volatility and lack of liquidity, and theft.

Bitcoin is subject to rapid price swings, including as a result of actions and statements by influencers and the media, changes in the supply of and demand for bitcoin, and other factors. There is no assurance that bitcoin will maintain its value over the long term.

The information provided on the following slides is based on ARK's research and is not intended to be investment advice. ARK researches the utility of bitcoin as an investment in order to determine its potential future value as presented on the following slides. This material does not constitute, either explicitly or implicitly, any provision of services or products by ARK, and investors should determine for themselves whether a particular investment management service is suitable for their investment needs. ARK strongly encourages any investor considering an investment in bitcoin or any other digital asset to consult with a financial professional before investing. All statements made regarding bitcoin are strictly beliefs and points of view held by ARK and are not recommendations by ARK to buy, sell or hold bitcoin. Historical results are not indications of future results.

Important Terms and Concepts

The research presented on the following slides contains some terms and concepts that may not be familiar to some readers, so below we provide explanations to help provide a basis for evaluating the research.

- **Sharpe Ratio** is a well-known and well-reputed measure of **risk-adjusted return** on an investment or portfolio, which indicates how well an investment performs in comparison to the rate of return on a risk-free investment such as U.S. government treasury bonds or bills. Sharpe ratio is calculated by first calculating the expected return on an investment portfolio or individual investment and then subtracting the risk-free rate of return. Normally, a higher Sharpe Ratio indicates good investment performance, given the risk, while a Sharpe Ratio less than 1 is considered less than good. Sharpe ratio is used in our research to determine, hypothetically, at what allocation percentage bitcoin would maximize the risk-adjusted return of an overall portfolio consisting of other commonly used asset classes.

- **Efficient Frontier** is the set of optimal portfolios that offer the highest expected return for a defined level of risk or the lowest risk for a given level of expected return. In other words, it graphically represents portfolios that maximize returns for the risk assumed. Portfolios that lie below the efficient frontier are considered sub-optimal because they do not provide enough return for the level of risk, and portfolios that cluster to the right of the efficient frontier are also considered sub-optimal because they have a higher level of risk for the defined rate of return. The Efficient Frontier chart is used in this section to illustrate that the simulated portfolio we constructed with an allocation to bitcoin lies along the efficient frontier as compared to the portfolios consisting of single asset classes which would be considered sub-optimal.

- **Compound Annual Growth Rate ("CAGR")** is the average annual amount an investment grows over a period of years assuming profits are reinvested during the period. In other words, it breaks an investment's total return over a number of years into a single average rate. CAGR is typically used to compare assets or portfolios over a longer time period by using an average as opposed to analyzing each year individually as returns from year to year may be uneven. We use CAGR in our research to determine the expected return of a portfolio or asset class over a period of years, typically 5 years.

- **Standard Deviation** is a measure of risk, or volatility, in a portfolio by indicating how much the investment will deviate from its expected return. An investment with higher volatility means a higher standard deviation, and therefore more risk. We use standard deviation to determine the amount of return that would be commensurate with certain levels of risk.

Digital Assets Like Bitcoin Are A New Asset Class

According to ARK's research, bitcoin has emerged as an independent asset class worthy of a strategic allocation in institutional portfolios.

BITCOIN ALLOCATION

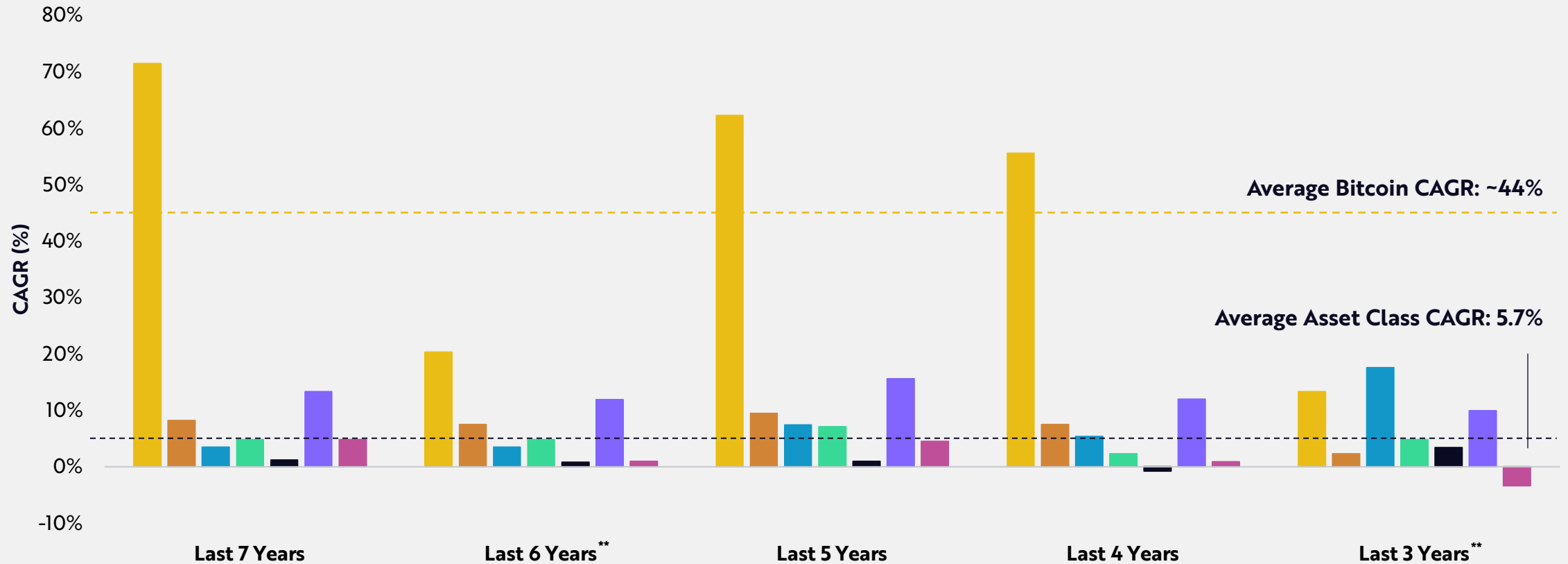|	Bitcoin	Commodities (Including Gold)	Real Estate	Bonds	Equities (Including Emerging Markets)
History	Created during the Global Financial Crisis in 2009 by an individual or group under the pseudonym Satoshi Nakamoto	Origins trace back thousands of years to commodities like gold being used as a store of value	Earliest known private property rights took shape in ancient Greece and Rome	Earliest known bond was issued by the city of Venice in the 12th century, but the concept of debt/lending can be traced back to ancient Mesopotamia	Origins trace back to the 1600s with the establishment of the Amsterdam Stock Exchange
Investability	Highly liquid and accessible to anyone with access to the internet. Traded on crypto exchanges and through spot ETFs	Fairly liquid and accessible through physical coins and ETFs through banks and brokers.	Illiquid, purchased directly or through REITs	Highly liquid. Traded on bond markets, accessible through brokers	Highly liquid. Traded on stock exchanges, accessible through brokers
Basis Of Value	Tied to demand for a decentralized, independent monetary system powered by open-source software	Tied to supply and demand, influenced by global economic conditions	Tied to interest rates, property markets, and local economic factors	Tied to interest rate policies and credit risk	Tied to expectations of future cash flow
Correlation Of Returns	Low correlation with traditional asset classes	Typically inversely correlated with asset classes, especially during economic uncertainty	Typically low to moderate correlation with stocks and bonds	Inversely correlated recently, but not always throughout economic history, with equities	Correlated with the health of global economy and market sentiment
Governance	Decentralized and community-driven, leveraging open-source software for decision making	Governed by mining regulation	Governed by local and national property laws	Governed by issuance terms set by government or corporations	Governed by company management and regulated by government agencies
Use Cases	Scarce digital store of value, its currency native to the internet	Industrial activity, wealth preservation, and hedging	Personal residence, rental income	Fixed income investment, with regular interest payments and return of principal at maturity	Company ownership, often with voting rights and dividends

Bitcoin Has Outperformed Every Major Asset Over Longer Time Horizons

During the last seven years, bitcoin's annualized return has averaged ~44%, while that of other major assets has averaged 5.7%.

BITCOIN ALLOCATION

Annualized Returns Across Major Asset Classes*

Legend: Bitcoin · Gold · Commodities · Real Estate · Bonds · Equities · Emerging Markets

CAGR (%)

Average Bitcoin CAGR: ~44%

Average Asset Class CAGR: 5.7%

Last 7 Years   Last 6 Years**   Last 5 Years   Last 4 Years   Last 3 Years**

*Asset classes are represented by the following instruments: SPDR S&P 500 ETF Trust (SPY, equities), Vanguard Total Bond Market Index Fund Investor Shares (VBMFX, bonds), Vanguard Real Estate Market Index Fund Investor Shares (VGSIX, real estate), SPDR Gold Trust (GLD, gold), iShares S&P GSCI Commodity-Indexed Trust ETF (GSG, commodities), and Vanguard Emerging Markets Stock Index Fund Investor Shares (VEIEX, emerging markets). The performance used to represent each asset class reflects the net asset value (NAV) performance of each ETF/fund for the time periods shown. **"Last 6 Years" includes 2018, 2021, and 2022; "Last 3 Years" includes 2021 and 2022, all years of market downturn or relatively low returns for bitcoin. Sources: ARK Investment Management LLC, 2024, based on data and calculation from PortfolioVisualizer.com, with bitcoin price data from Glassnode, as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Generally, Bitcoin Investors With A Long-Term Time Horizon Have Benefited Over Time

"Time, Not Timing"*

Bitcoin's volatility can obfuscate its long-term returns. While significant appreciation or depreciation can occur over the short term, a long-term investment horizon has been key to investing in bitcoin.

Instead of "when," the better question is "for how long?"

Historically, investors who bought and held bitcoin for at least 5 years have profited, no matter when they made their purchases.

Bitcoin Realized Returns
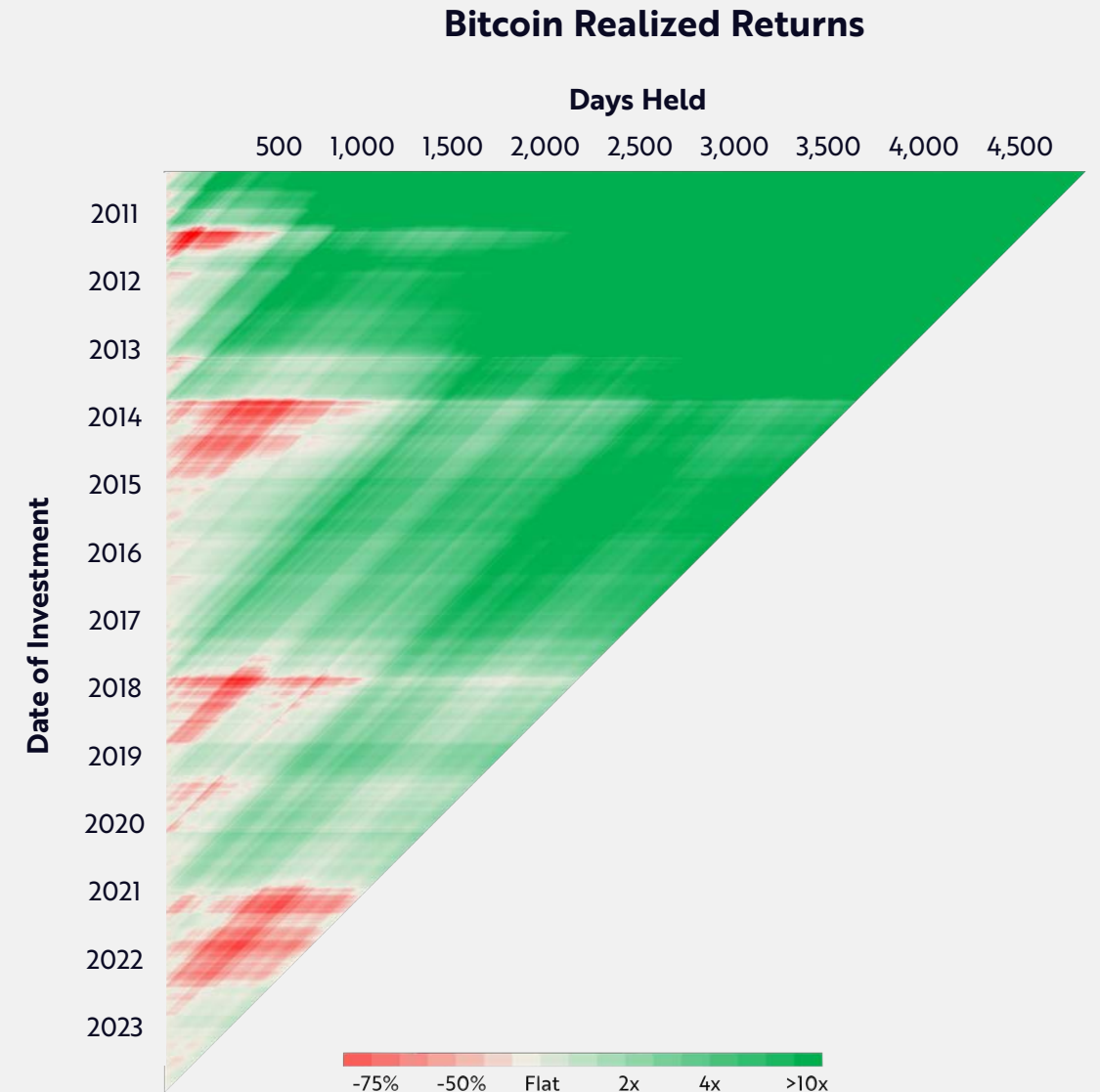
*Adage first put forth in this configuration by Mizuho Financial Group. Sources: ARK Investment Management LLC, 2024, based on data from Glassnode as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Bitcoin's Correlation To Traditional Assets Is Low

Historically, bitcoin's price movements have not correlated highly to those of other asset classes. During the past five years, the correlation of bitcoin's returns relative to traditional asset classes has averaged only 0.27.

Asset Class Correlation Matrix[1,2]

(12-Month As Of December 2023)

High correlation: coefficient value lies between ± 0.66 and ±1
Moderate correlation: coefficient value lies between ± 0..4 and ± 0.66
Low correlation: coefficient value lies below ± 0.4

	Bitcoin	Gold	Commodities	Real Estate	Bonds	Equities	Emerging Markets
Bitcoin		0.2	0.1	0.4	0.26	0.41	0.23
Gold	0.2		-0.03	0.28	0.46	0.26	0.34
Commodities	0.1	-0.03		0.42	-0.12	0.43	0.5
Real Estate	0.4	0.28	0.42		0.57	0.86	0.68
Bonds	0.26	0.46	-0.12	0.57		0.48	0.46
Equities	0.41	0.26	0.43	0.86	0.48		0.73
Emerging Markets	0.23	0.34	0.5	0.68	0.46	0.73	
AVERAGE	0.27	0.25	0.21	0.53	0.35	0.53	0.49

[1] A correlation of 1 connotes that assets perfectly move in tandem; 0 means their movement is completely independent from each other; –1 suggests that they move in perfectly opposite directions. [2] Asset classes are represented by the following instruments: SPDR S&P 500 ETF Trust (SPY, equities), Vanguard Total Bond Market Index Fund Investor Shares (VBMFX, bonds), Vanguard Real Estate Market Index Fund Investor Shares (VGSIX, real estate), SPDR Gold Trust (GLD, gold), iShares S&P GSCI Commodity-Indexed Trust ETF (GSG, commodities), and Vanguard Emerging Markets Stock Index Fund Investor Shares (VEIEX, emerging markets). The performance used to represent each asset class reflects the net asset value (NAV) performance of each ETF/fund for the time periods shown. Sources: ARK Investment Management LLC, 2024, based on data and calculation from PortfolioVisualizer.com, with bitcoin price data from Glassnode, as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.
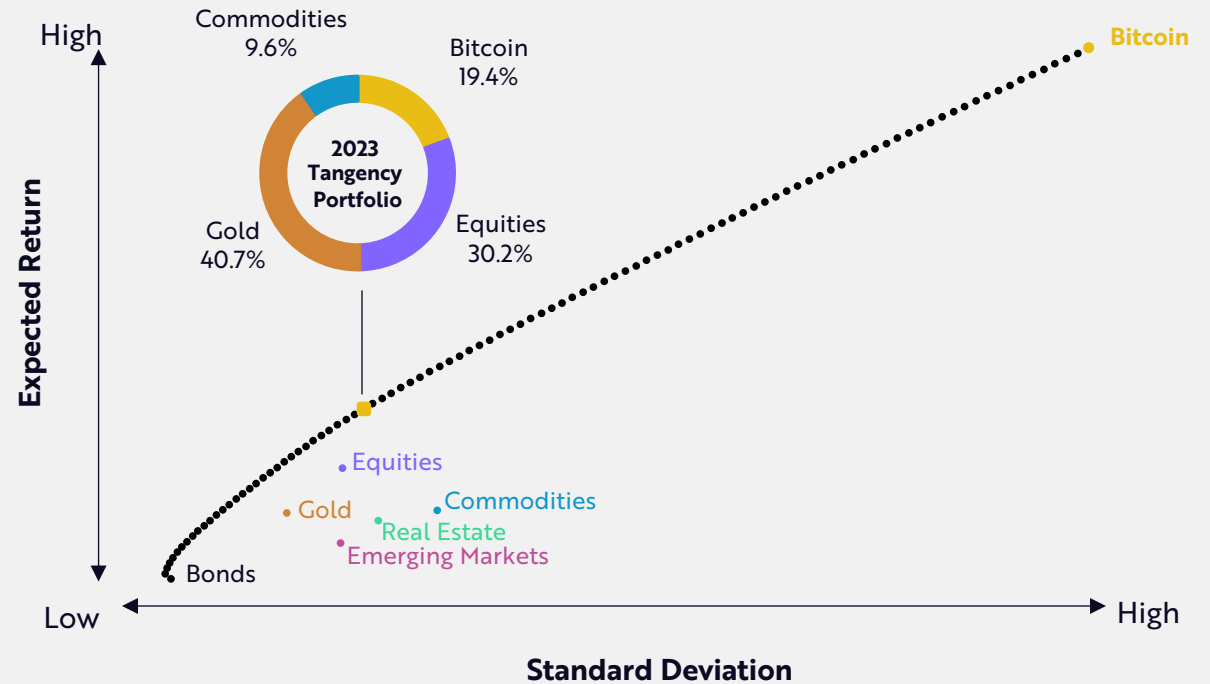
BITCOIN ALLOCATION

Bitcoin Could Play An Important Role In Maximizing Risk-Adjusted Returns

Focused on the volatility and return profiles of traditional asset classes, ARK's research suggests that a portfolio seeking to maximize risk-adjusted returns[1] would have allocated 19.4% to bitcoin in 2023.

BITCOIN ALLOCATION

Simulated Optimal Portfolio Allocation Targets By Year[2,3]
(Rolling 5-Year As Of End Of Every Year[6])

	Bitcoin	Gold	Commodities	Bonds	Equities
2015	0.5%	0%	0%	82.5%	16.9%
2016	0.9%	0%	0%	62.1%	36.9%
2017	0.9%	0%	0%	58.7%	40.3%
2018	2.4%	0%	0%	77.3%	20.2%
2019	3.9%	1.4%	0%	70.4%	24.2%
2020	4.3%	4.1%	0%	75.6%	15.8%
2021	4.7%	7.3%	0%	65.3%	22.6%
2022	6.2%	52.8%	9.1%	0%	31.8%
2023	19.4%	40.7%	9.6%	0%	30.3%

2023 Simulated Portfolio Optimization[3,4,5]
Based On Monthly Asset Class Returns (No Limit, Rolling 5-Year[6])

2023 Tangency Portfolio

Commodities 9.6%
Bitcoin 19.4%
Equities 30.2%
Gold 40.7%

Expected Return — High / Low
Standard Deviation — High

Bitcoin
Equities
Commodities
Gold
Real Estate
Emerging Markets
Bonds

[1] Measurement of returns of an asset against its risk (in this case, volatility). [2] Real Estate and Emerging Markets are calculated out of these tangency portfolios given their low participation in maximizing risk-adjusted returns relative to the other asset classes included in this table. [3] Asset classes are represented by the following instruments: SPDR S&P 500 ETF Trust (SPY, equities), Vanguard Total Bond Market Index Fund Investor Shares (VBMFX, bonds), Vanguard Real Estate Market Index Fund Investor Shares (VGSIX, real estate), SPDR Gold Trust (GLD, gold), iShares S&P GSCI Commodity-Indexed Trust ETF (GSG, commodities), and Vanguard Emerging Markets Stock Index Fund Investor Shares (VEIEX, emerging markets). The performance used to represent each asset class reflects the net asset value (NAV) performance of each ETF/fund for the time periods shown. [4] This simulation, also known as "efficient frontier", is a set of theoretical investment portfolios expected to provide the highest returns at multiple levels of risk. [5] The dots under the efficient frontier in the chart represent portfolios comprised of a single asset class. [6] 5 years were used since, in our view, they represent a sample of a long-term time horizon. Sources: ARK Investment Management LLC, 2024, based on data and calculation from PortfolioVisualizer.com, with bitcoin price data from Glassnode, as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.
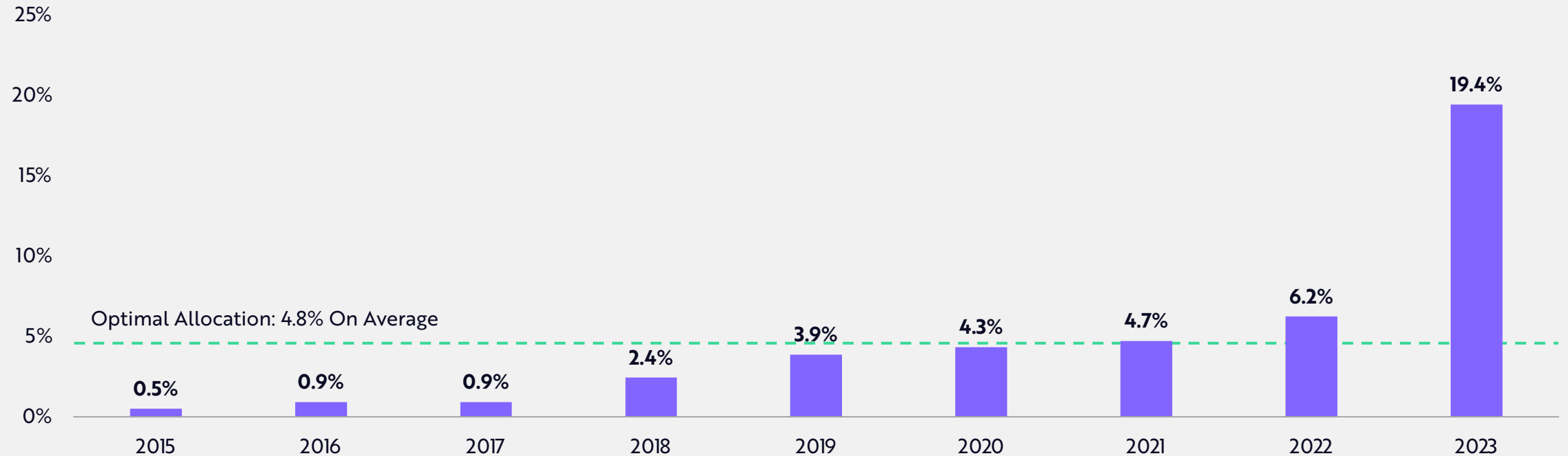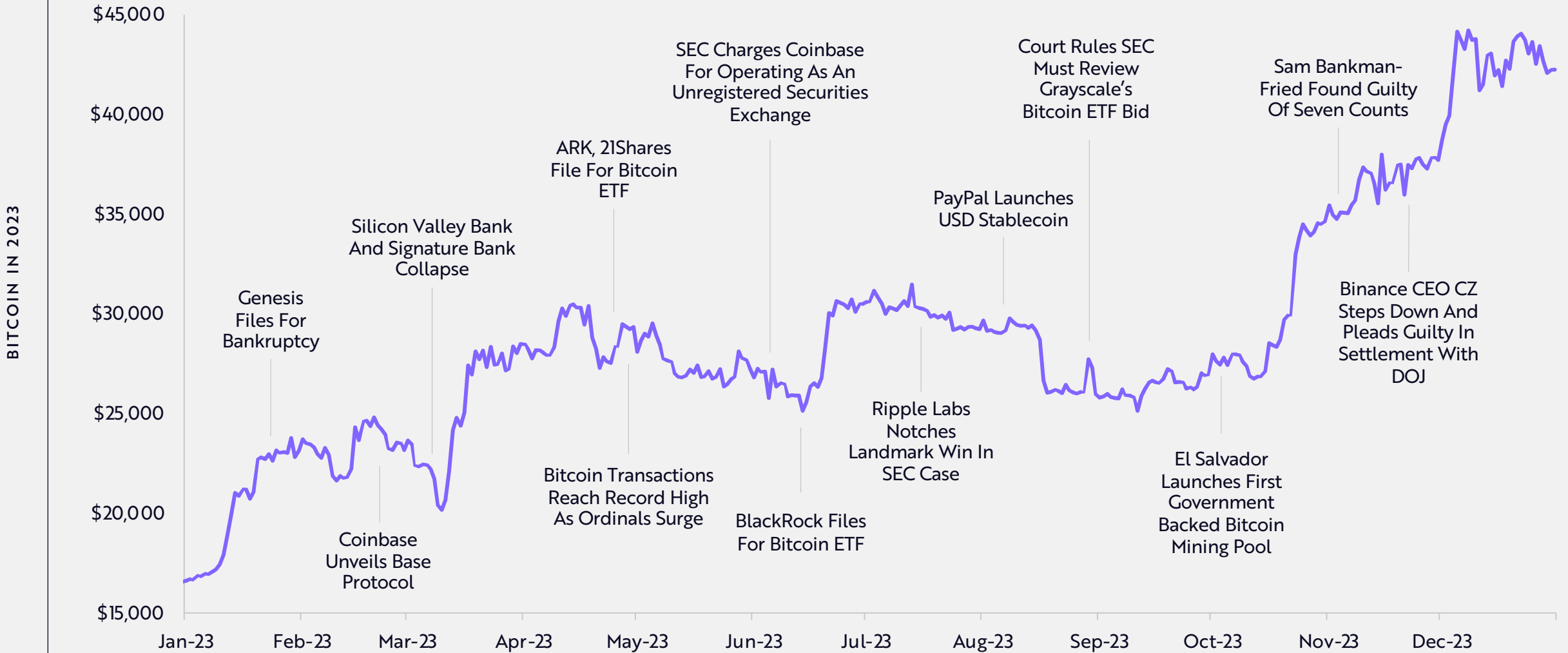
On A 5-Year Rolling Basis, An Allocation To Bitcoin Would Have Maximized Risk-Adjusted Returns During The Past 9 Years

According to our analysis, in 2015, the optimal allocation to maximize risk-adjusted returns[1]—on a 5-year time horizon[3]—would have been 0.5%. Since then, on the same basis, the average allocation to bitcoin would have been 4.8%, and in 2023 alone, 19.4%.

Allocation Into Bitcoin By Year To Maximize Risk-adjusted Returns[2]
(Maximization By Sharpe Ratio, Rolling 5-Year Time Horizon[3,4])

BITCOIN ALLOCATION

Optimal Allocation: 4.8% On Average

Year	Allocation
2015	0.5%
2016	0.9%
2017	0.9%
2018	2.4%
2019	3.9%
2020	4.3%
2021	4.7%
2022	6.2%
2023	19.4%

[1] Risk-adjusted returns given by the Sharpe ratio, which divides expected returns minus the risk-free rate by the standard deviation of the asset. [2] For asset class representation in this calculation, please refer to the previous slide. [3] 5 years were used since, in our view, they represent a sample of a long-term time horizon.. Sources: ARK Investment Management LLC, 2024, based on data and calculation from PortfolioVisualizer.com, with bitcoin price data from Glassnode, as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

What Would Be The Impact Of An Optimal Allocation Into Bitcoin?

Allocations from the $250 trillion global investable asset base into bitcoin would have a significant impact on the price.

BITCOIN ALLOCATION

Hypothetical Impact of Institutional Investment On The Price Of Bitcoin[1,2]

Bar chart titled "Price Potential (USD)" with y-axis ranging from $0 to $2,500,000.

- **1% Allocation**: ~$120,000
- **4.8% Average Allocation** (Average Maximum Sharpe Ratio 2015-2023, Rolling 5-Year Time Horizon): ~$550,000
- **19.4% Allocation** (Maximum Sharpe Ratio 2023, Rolling 5-Year Time Horizon): ~$2,300,000
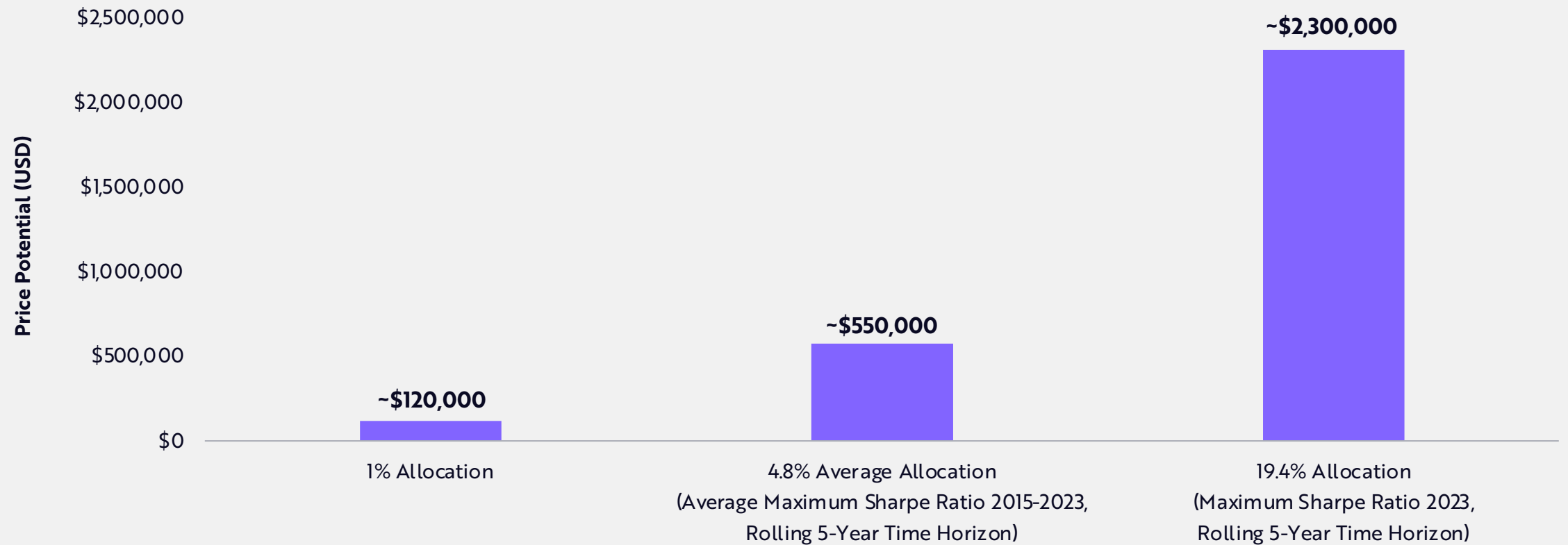
[1] This chart was calculated by dividing each percentage allocation of the estimated global investable asset base of $250 trillion USD (Chung 2021) by the fully diluted expected bitcoin supply of 21 million. When dividing the investable asset base by the bitcoin supply of 19.5 million as of 12/31/2023, the price potential increases to ~$127k (1% allocation), ~$615k (4.8% allocation), and ~$2.5 million (19.4% allocation). [2] Asset classes are represented by the following instruments: SPDR S&P 500 ETF Trust (SPY, equities) and Vanguard Total Bond Market Index Fund Investor Shares (VBMFX, bonds). The performance used to represent each asset class reflects the net asset value (NAV) performance of each ETF/fund for the time periods shown. Sources: ARK Investment Management LLC, 2024, based on data and calculation from PortfolioVisualizer.com, with bitcoin price data from Glassnode, as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Research By: **Yassine Elmandjra**   **David Puell**
Director of Digital Assets   Research Associate

Bitcoin In 2023

Demonstrating Resilience And Recovery After Challenges In 2022

In 2023, Bitcoin's Price Surged 155%, Increasing Its Market Cap To $827 Billion

Bitcoin Price, 2023

BITCOIN IN 2023

Genesis Files For Bankruptcy

Silicon Valley Bank And Signature Bank Collapse

Coinbase Unveils Base Protocol

ARK, 21Shares File For Bitcoin ETF

Bitcoin Transactions Reach Record High As Ordinals Surge

SEC Charges Coinbase For Operating As An Unregistered Securities Exchange

BlackRock Files For Bitcoin ETF

Ripple Labs Notches Landmark Win In SEC Case

PayPal Launches USD Stablecoin

Court Rules SEC Must Review Grayscale's Bitcoin ETF Bid

El Salvador Launches First Government Backed Bitcoin Mining Pool

Sam Bankman-Fried Found Guilty Of Seven Counts

Binance CEO CZ Steps Down And Pleads Guilty In Settlement With DOJ

Bitcoin's Price Crossed Above Its On-Chain Market Mean For The First Time In ~4 Years

An original ARK metric, the on-chain market mean has been a reliable demarcation point between risk-on and risk-off bitcoin markets. Historically, when the price of bitcoin crosses above the market mean, it typically indicates the early stages of a bull market.

BITCOIN IN 2023

Bitcoin's Break Above Its True Market Mean Signals The Onset Of A Bull Market
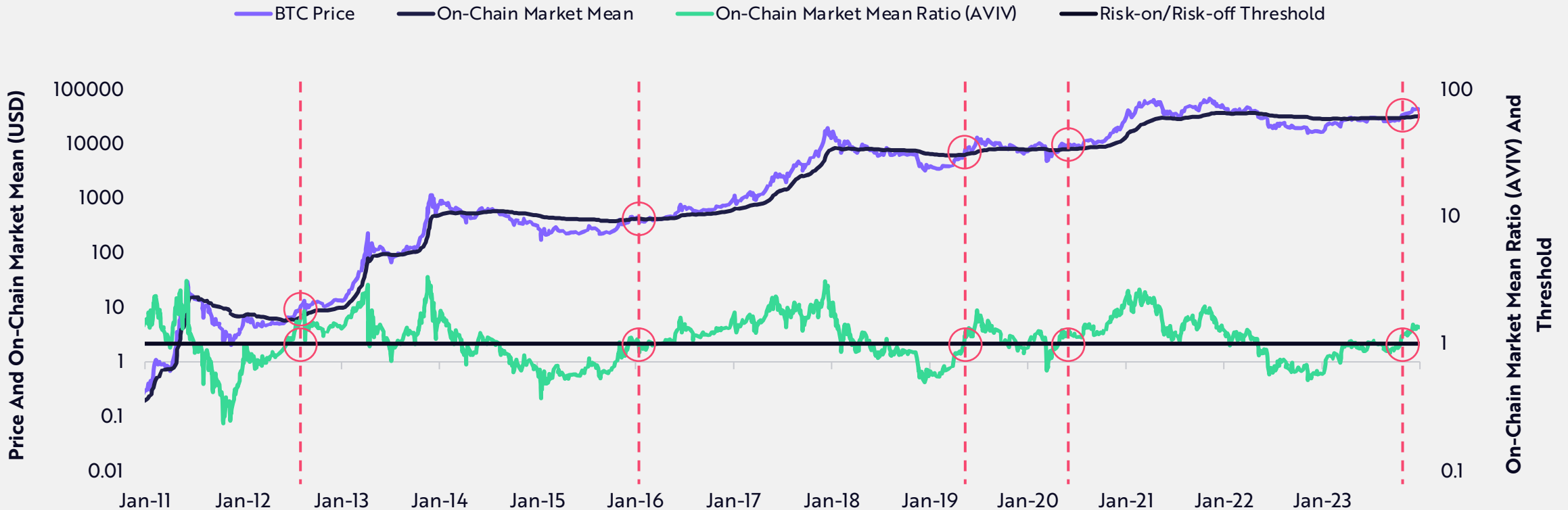
— BTC Price   — On-Chain Market Mean   — On-Chain Market Mean Ratio (AVIV)   — Risk-on/Risk-off Threshold

2023 Provided Important Answers To The Crises In 2022

BITCOIN IN 2023

Entity	2022 Crisis	2023 Resolution
Luna, UST	Algorithmic stablecoin UST collapsed, causing a significant sell-off in its sister cryptocurrency, LUNA, erasing over 60 billion USD in market value.*	Founder Do Kwon was arrested and faces eight indictments in Manhattan's U.S. District Court, while his startup, Terraform Labs, faces SEC civil charges for orchestrating a multi-billion-dollar securities fraud.
Three Arrows Capital	LUNA's collapse led high profile hedge fund Three Arrows Capital (3AC) into a liquidity crisis, forcing it into bankruptcy.	The Monetary Authority of Singapore banned 3AC's co-founders from capital markets activity for nine years, and a court in the British Virgin Islands froze their assets.
Celsius Network	Crypto lending platform Celsius froze withdrawals and then filed for bankruptcy.	A bankruptcy court approved a restructuring plan for Celsius that will return assets to customers and establish a new company focused on mining and staking. CEO Alex Mashinsky faces criminal charges for allegedly misleading customers.
FTX	After Coindesk exposed the fraudulent financial entanglement between trading firm Alameda and FTX, FTX suffered a bank run and collapsed.	The Southern District of New York convicted Sam Bankman-Fried on seven counts of fraud related to the collapse of FTX. A bankruptcy court granted the FTX estate approval to sell its assets.
BlockFi	BlockFi's exposure to FTX forced it into bankruptcy.	BlockFi received court approval to liquidate, with partial in-kind repayment to creditors.
Genesis	With significant loans to 3AC, crypto lender Genesis declared bankruptcy.	Crypto lender Genesis reached a settlement with parent company DCG, involving $620 million in repayments. The SEC is suing Genesis for selling unregistered securities.

Bitcoin Was A Safe Haven During The Regional Banking Collapse

In early 2023, during the historic collapse of US regional banks, bitcoin's price appreciated more than 40%, highlighting its role as a hedge against counterparty risk.

BITCOIN IN 2023

As Regional Banks Collapsed, Bitcoin's Price Appreciated ~40%
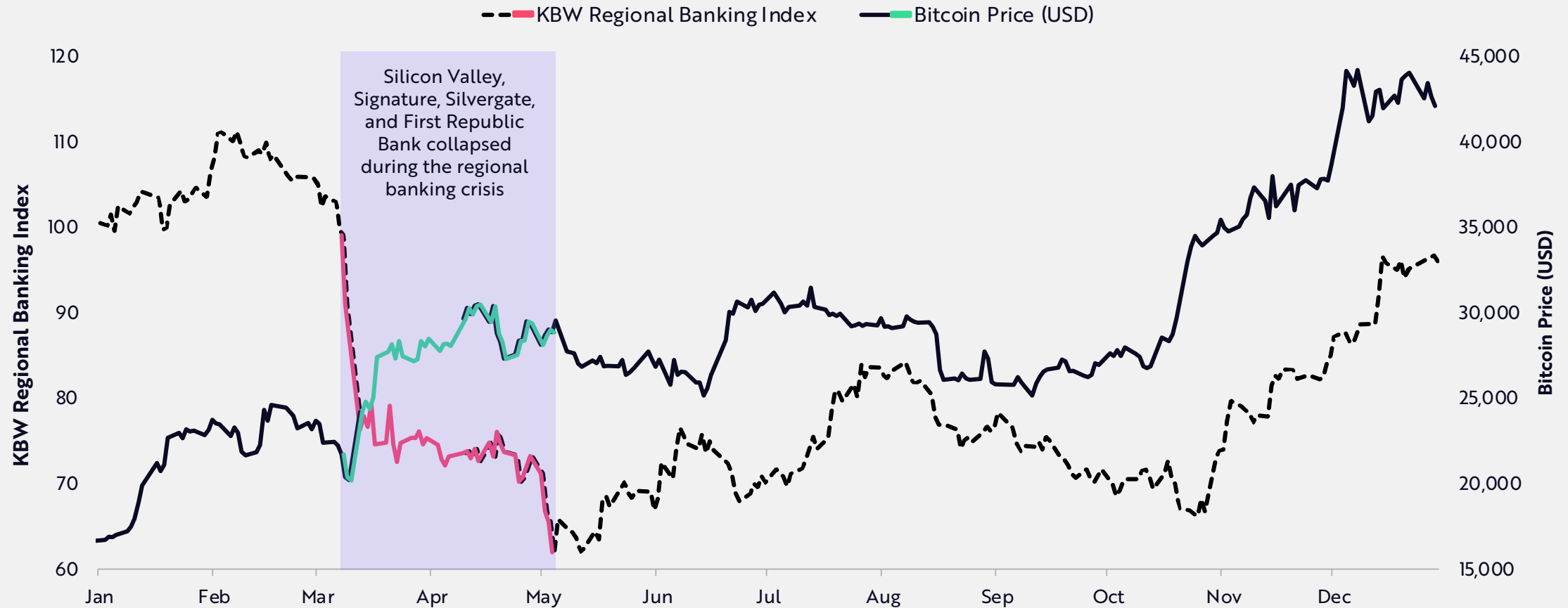
— KBW Regional Banking Index   — Bitcoin Price (USD)

Silicon Valley, Signature, Silvergate, and First Republic Bank collapsed during the regional banking crisis

KBW Regional Banking Index

Bitcoin Price (USD)

The Surge In Inscriptions Signaled A Role For The Bitcoin Network Beyond Transaction Settlement

Launched in January 2023, Bitcoin Inscriptions introduced a unique numbering system for each satoshi, the smallest unit of bitcoin, based on its position in the blockchain. Each satoshi is identifiable and immutable, allowing users to inscribe their data, images, or text.

Unlike other blockchains that require smart contracts for NFTs[1], Bitcoin Inscriptions are on the base layer of the Bitcoin blockchain.

Ordinals[2] have sparked debate about the impact of Inscriptions on transaction sizes and block space. In our view, Ordinals are a product of the free market and represent healthy innovation on Bitcoin.

Bitcoin Inscriptions[3]

■ Audio, Image, Video, Other   ■ Text/BRC-20

Cumulative Inscriptions (Millions)
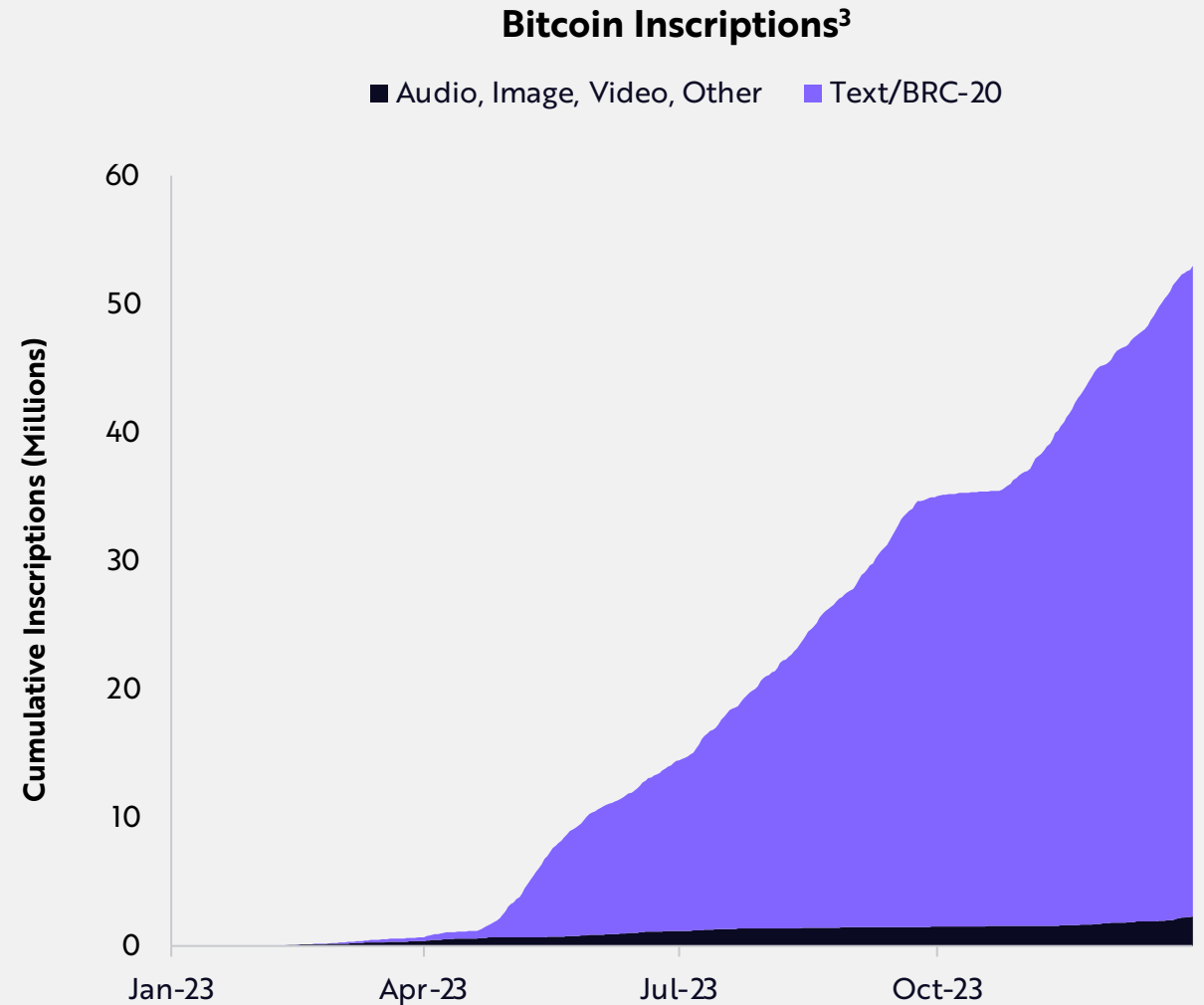
[1] Short for Non-Fungible Token, it is tokenized metadata via unique identification codes recorded on a blockchain. [2] Refers to the creation of non-fungible tokens (NFTs) in the Bitcoin network by making Inscriptions, where metadata such as images or videos are attached to individual satoshis (the smallest unit of account). [3] BRC-20: A token standard that enables the minting and transaction of fungible tokens via the Ordinals protocol on the Bitcoin network. Sources: ARK Investment Management LLC, 2024, based on data from Glassnode as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Bitcoin's Fundamentals Didn't Skip A Beat During The Crisis in 2022 And Continued Apace In 2023

Bitcoin Network Stats	2022	2023
Price	$16,553	$42,225
Market Cost Basis[1] ($ Billions)[1]	$380.7	$427.7
Hash Rate[2] (EH/s[3], 14-Day Average)	254.3	523.2
Supply Of BTC Last Moved >1 Year Ago (%)	66.5%	70.2%
BTC Addresses With Non-Zero Balance[3] (Millions)	43.3	51.7
Long-Term Holder Supply [4] (BTC, Millions)	14.1	14.8
Transaction Count[5] (Non-Inscriptions Related, Thousands)	256.2	367.5

Bitcoin's Hash Rate[2], A Proxy for Network Security, Hit An All-Time High In 2023
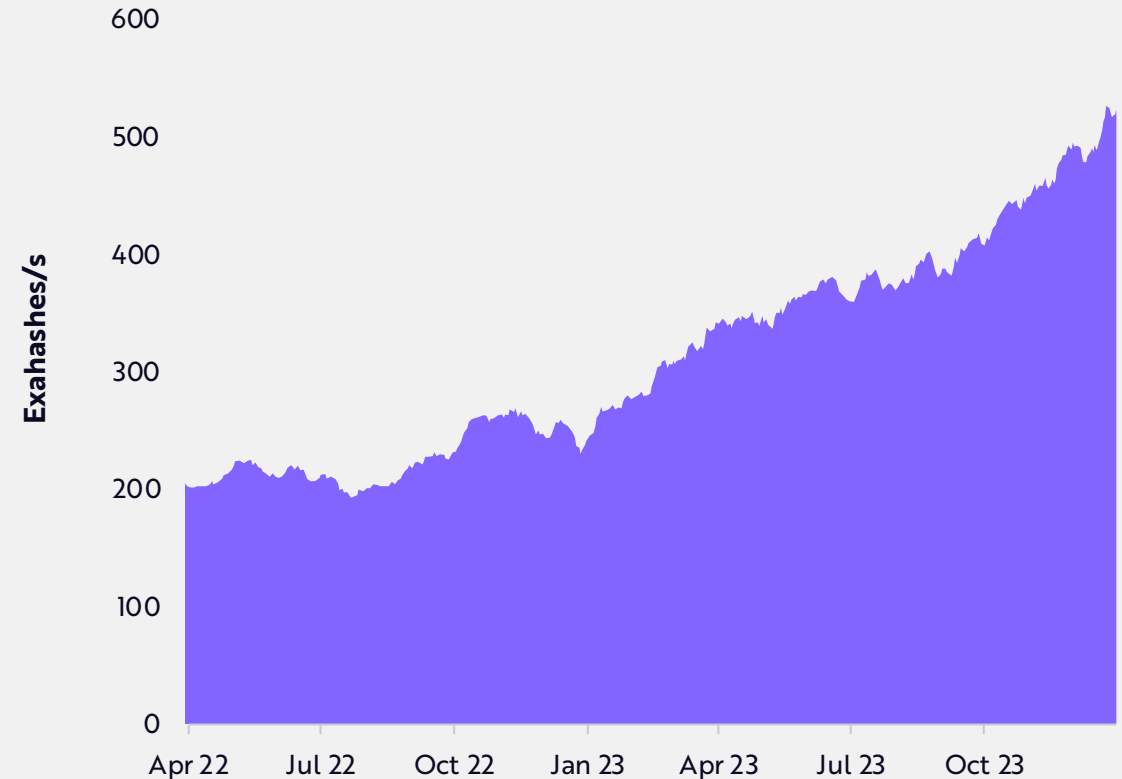
[1] The on-chain volume-weighted average price of the market, calculated by aggregating the value of all bitcoins in circulation at the time when they last moved. Also known as realized price or realized cap. [2] The estimated computational power mining within and providing security to the Bitcoin network. [3] Number of addresses in the Bitcoin network with a balance larger that zero. [4] Bitcoin supply last moved 155 days ago or more, the threshold at which the possibility of a bitcoin remaining unmoved increases drastically. [5] Number of transactions between two addresses of the Bitcoin network. Sources: ARK Investment Management LLC, 2024, based on data from Glassnode as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

CME* Surpassed Binance As The World's Largest Bitcoin Futures Exchange

As the demand for more regulated and secure infrastructure increased following the contagion in 2022, bitcoin's market dynamics shifted more to the US.

BITCOIN IN 2023

Bitcoin Futures Open Interest Hit a Record $4.5 Billion on the CME

■ CME ■ Binance ■ FTX

After outpacing the CME, FTX's market share of open interest collapsed in late 2022.

CME's open interest surpassed Binance's for the first time.
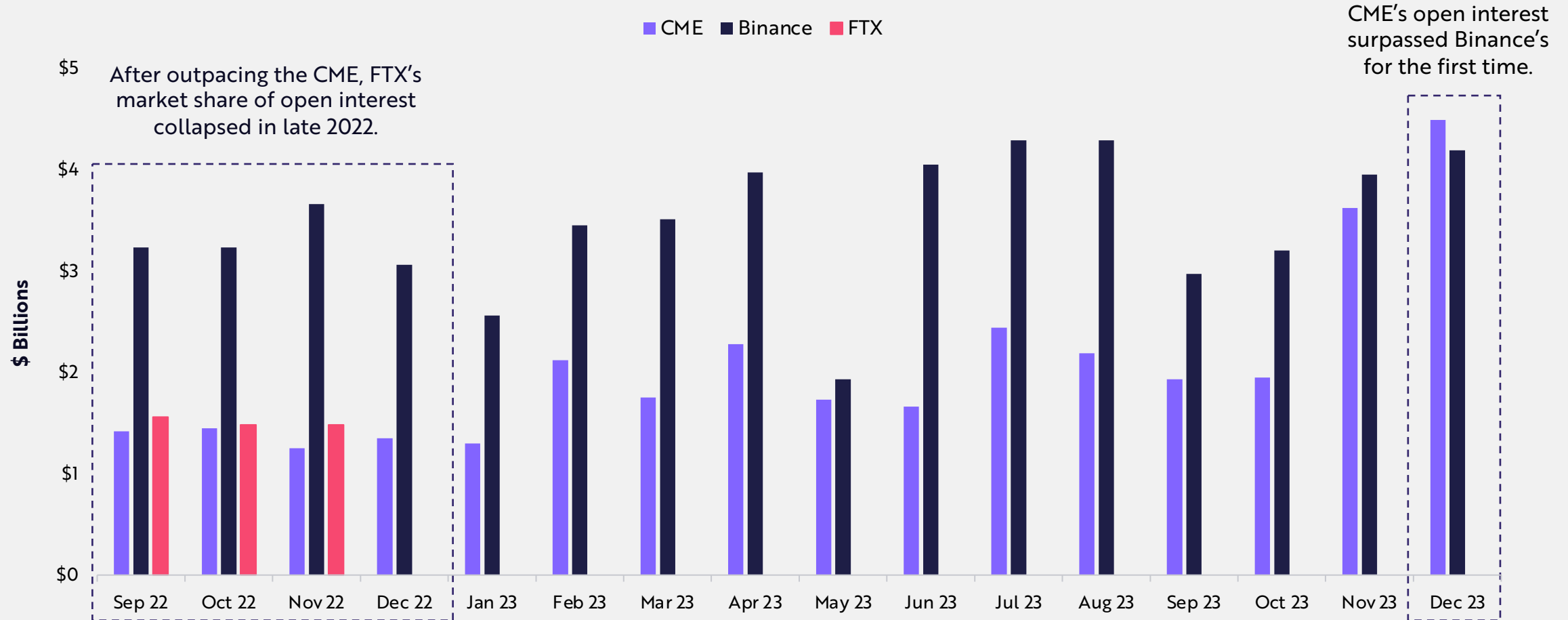
*Short for Chicago Mercantile Exchange. Sources: ARK Investment Management LLC, 2024, based on data from Glassnode as of December 31, 2023. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security or cryptocurrency. Past performance is not indicative of future results.

Bitcoin Is Evolving Into A Reliable Risk-Off Asset

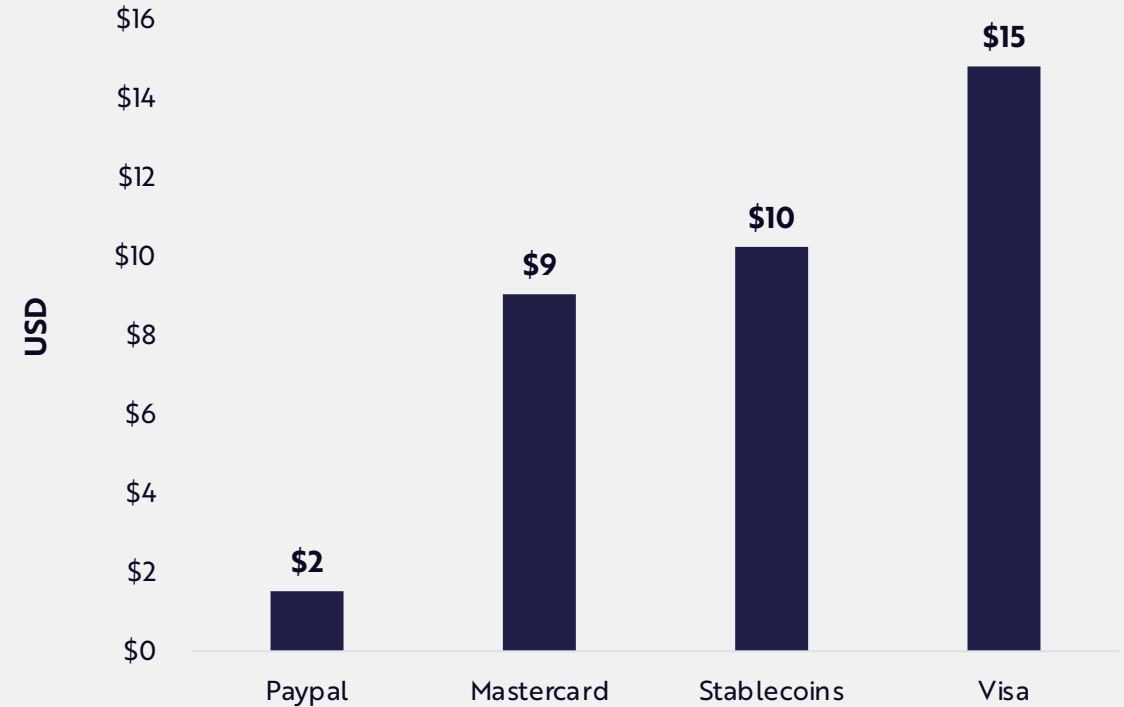With increasing macroeconomic uncertainty and less trust in traditional "flights to safety," bitcoin has become a viable alternative.

BITCOIN IN 2023

Evaluating Bitcoin As A Risk-Off Asset

Safety & Capital Preservation	Diversification	Long-Term Investment Horizon	Liquidity & Accessibility	Inflation Hedge
Bitcoin operates on a decentralized network, independent of any single entity, government, or central bank. Its distributed, open-source nature protects it against arbitrary asset seizure and counterparty risk.	Bitcoin's historically low correlation with traditional asset classes is increasing its role as a source of diversification. Adding a non-correlated asset to portfolios potentially increases returns per unit of risk and provides a buffer against market downturns.	Despite its short-term volatility, bitcoin has delivered significant long-term price appreciation. By design, scarcity increases the probability of capital preservation.	Global investors can access and trade bitcoin 24/7, which is increasingly important in times of risk-off uncertainty.	Bitcoin's supply will be capped at 21 million coins. As with gold, scarcity characterizes bitcoin's role as a safe-haven asset.

Major Catalysts Await Bitcoin In 2024

Bitcoin Spot ETF Launch

On January 11, 2024, the launch of spot bitcoin ETFs set the stage for Bitcoin's growth, by offering investors a more direct, regulated, and liquid way to gain exposure. Bitcoin spot ETFs are traded on major stock exchanges, allowing investors to buy and sell shares through their existing brokerage accounts, and should reduce the learning curve and operational complexities associated with direct investments in bitcoin.

Bitcoin Halving

The Bitcoin halving occurs approximately every 4 years, cutting the reward for mining new bitcoin blocks in half. Historically, each halving event has coincided with the beginnings of a bull market. Expected in April 2024, this halving will reduce bitcoin's inflation rate from ~1.8% to ~0.9%.

Bitcoin's Circulating Supply

Legend:
— BTC Supply (units)
— BTC Supply Cap
- - - Expected Bitcoin Issuance

Y-axis: Units Of Bitcoin (Million) — 0, 10, 20
X-axis: 2009, 2015, 2021, 2027
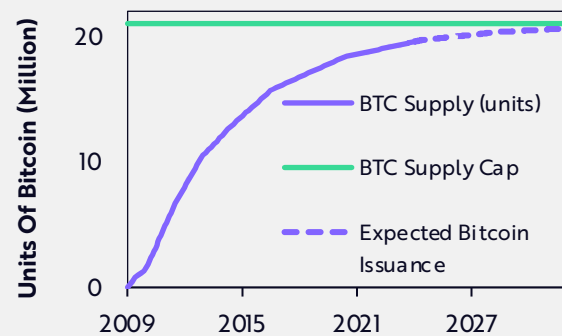
Institutional Acceptance

Thanks to its continued resilience and performance, the shift in perception of bitcoin—from a speculative instrument to a strategic investment in a diversified portfolio—should characterize its evolution in 2024. Exemplifying this evolution, Larry Fink, CEO of BlackRock, has shifted his stance from bitcoin skepticism to its potential as a "flight to quality."

Regulatory Developments

The bankruptcies of FTX and Celsius have advanced the push for more transparent and open global crypto regulation, including the potential passage of a US bill establishing a regulatory framework for cryptocurrencies, and the implementation of Europe's Markets in Crypto-Assets (MiCA) regulation, which mandates licensing for crypto wallet providers and exchanges in the EU.

Research By: **Frank Downing**
Director of Research,
Next Generation Internet

BIG IDEAS 2024

Smart Contracts

Powering The Internet-Native Financial System

Deployed on public blockchains, smart contracts offer a global, automated, and auditable alternative to rent-seeking intermediaries and legacy financial infrastructure.

In the aftermath of the "crypto crisis" in 2022, several digital asset solutions gained traction, including stablecoins, tokenized treasury funds, and scaling technologies.

According to ARK's research, as the value of on-chain financial assets increases, the market value associated with decentralized applications could scale 32% at an annual rate, from $775 billion in 2023 to $5.2 trillion in 2030.

Smart Contracts Are The Foundation Of The Internet Financial System

In their infancy, smart contracts are powering a novel financial system that is native to the internet. Ignited by Ethereum, the largest smart contract blockchain, multiple networks are supporting on-chain activity and vying for market share.

SMART CONTRACTS

Smart Contract Network	Market Value 2023e		Price Performance 2023
Ethereum	$	274 billion	+90%
BNB Chain	$	49 billion	+28%
Solana	$	44 billion	+924%
Avalanche	$	14 billion	+254%
Tron	$	9 billion	+120%
Polygon PoS	$	9 billion	+28%

Transaction Fees
Top 6 Smart Contract Networks, 2023

Ethereum ■ Tron ■ BNB Chain ■ Avalanche ■ Solana ■ Polygon PoS
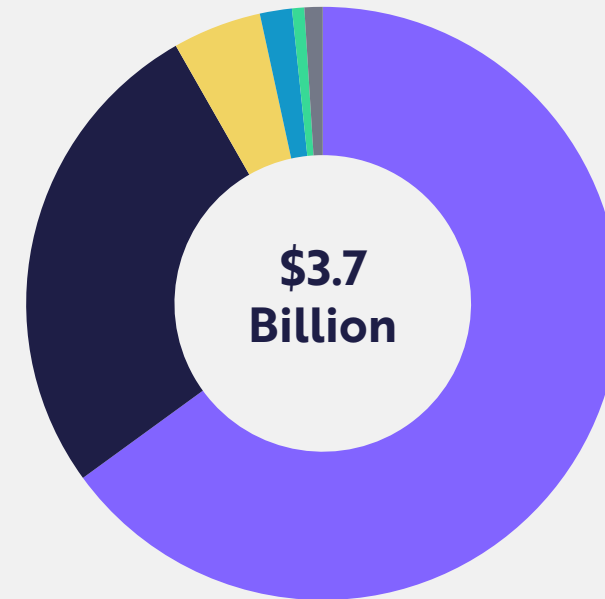
$3.7 Billion

Stablecoins Highlight The Value Proposition Of Smart Contracts

Given hyperinflation in emerging markets and an increase in global instability, the demand for stablecoins offering digital access to the US dollar is soaring. During the past three years, the number of daily active stablecoin addresses globally has increased at an annual rate of 93%, from 171 thousand to 1.2 million. In 2023, stablecoin transfer volumes surpassed those of Mastercard.

Stablecoin Daily Active Addresses

- Tron
- Avalanche C-Chain
- ETH L2s
- BNB Chain
- Polygon PoS
- Ethereum
- Solana
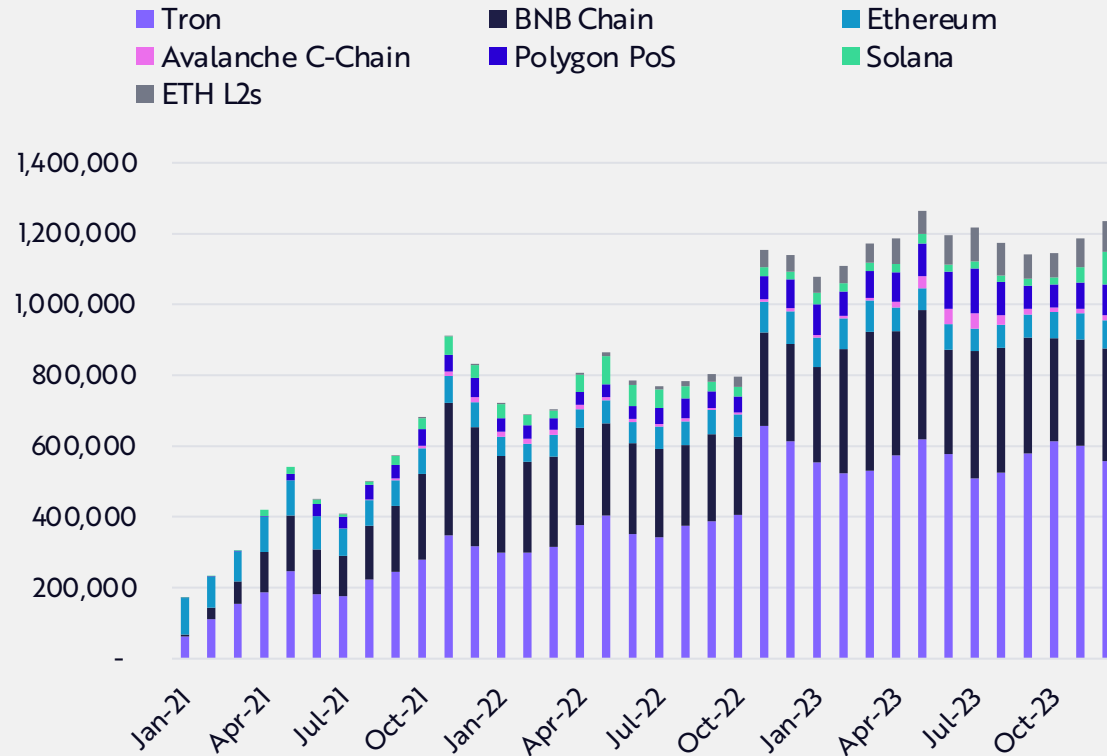
Total Transfer Volume, 2023 (Trillions)

	USD
Paypal	$2
Mastercard	$9
Stablecoins	$10
Visa	$15

NOTE: Stablecoin Daily Active Addresses are averaged for each month displayed in chart. Transfer volume estimates are used where Q4 2023 data is not yet available at time of publication. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which are available upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
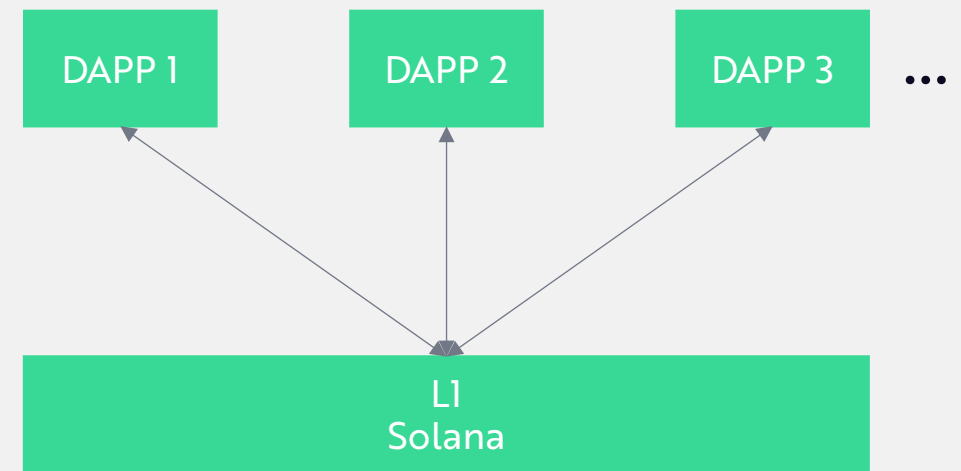
Traditional Financial Assets Are Moving On-Chain

Tokenization allows treasurers to track, trade, and collateralize funds more easily on public blockchains than in traditional financial markets. In 2023, tokenized treasury funds jumped more than 7-fold to $850 million. Early funds launched on the Stellar blockchain, but Ethereum became the largest market for tokenized treasuries in 2023.
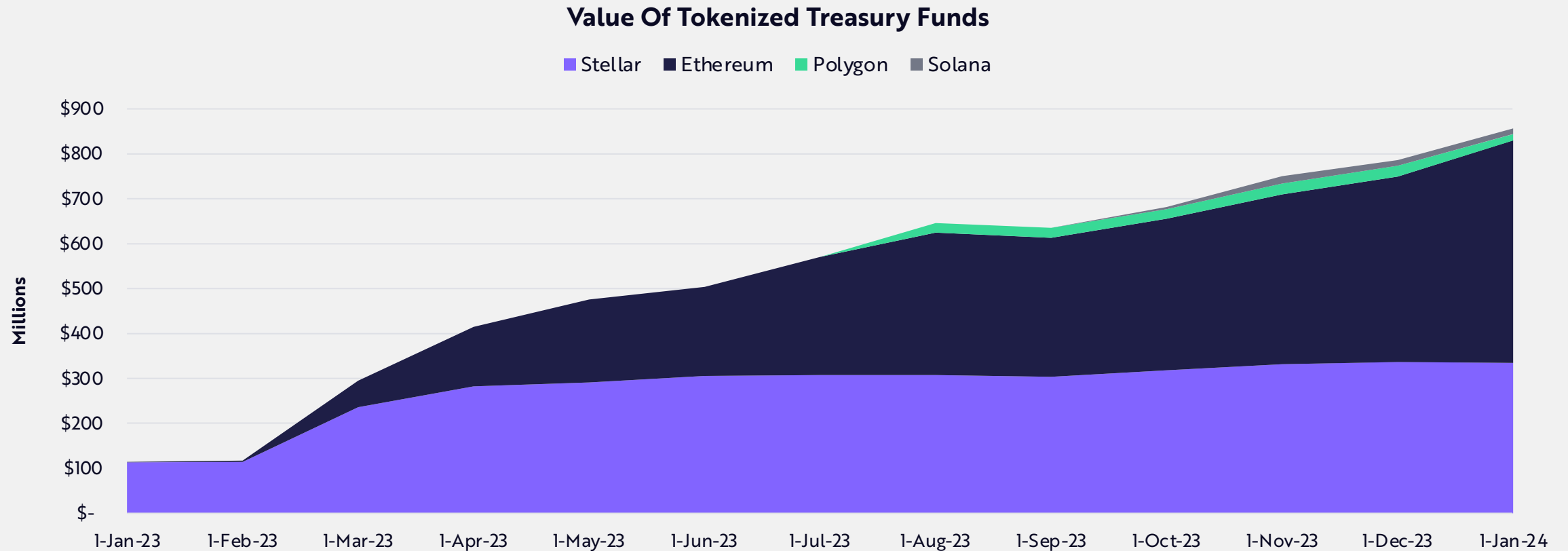
SMART CONTRACTS

Value Of Tokenized Treasury Funds

■ Stellar   ■ Ethereum   ■ Polygon   ■ Solana

Developers Refined Protocols During The Bear Market

In the face of crises and their aftermath in 2022, core developers advanced technical roadmaps and hardened protocols to support the next bull market. Ethereum moved successfully to Proof-of-Stake (PoS)* consensus, and Solana hit a new record for continuous uptime.

SMART CONTRACTS

Staked Ether

Number Of Ether (Millions)

Withdrawals Enabled

PoS Merge

Solana Network Uptime

Number Of Days

Block propogation bug

Transaction spam

Transaction spam

Failed validator upgrade

Deduplication error

Node misconfiguration

Software bug

Launch
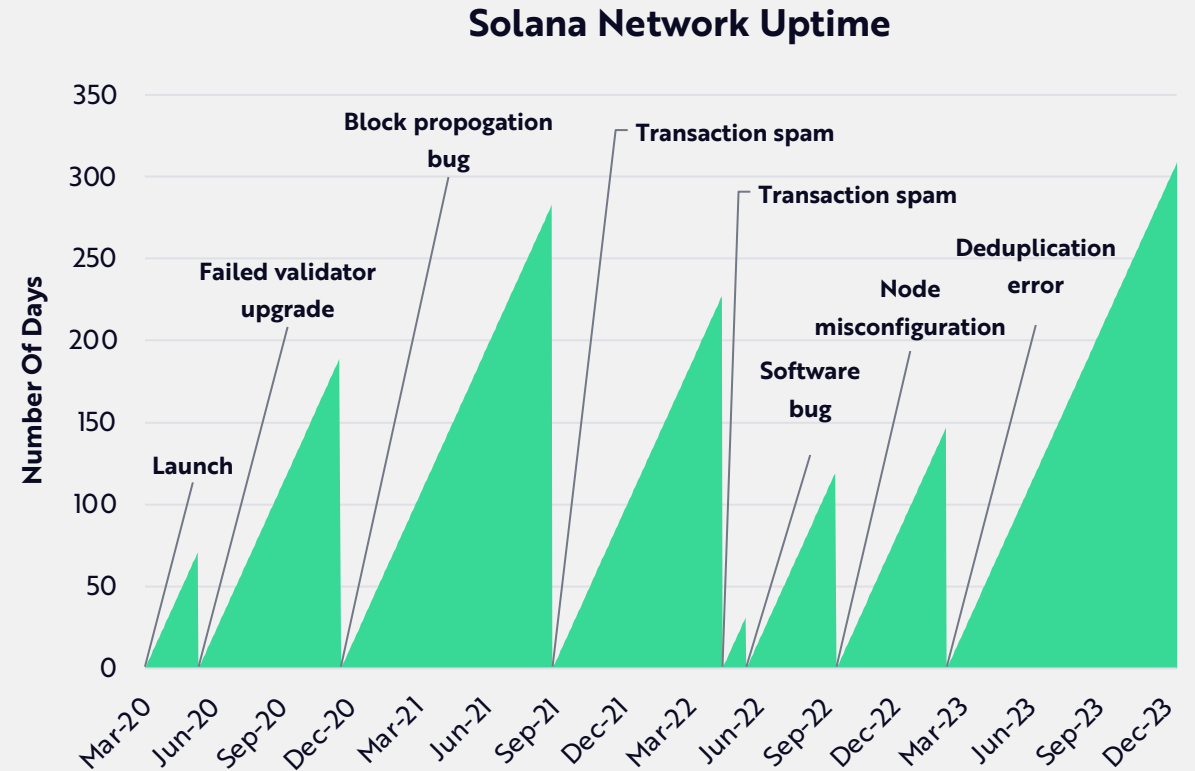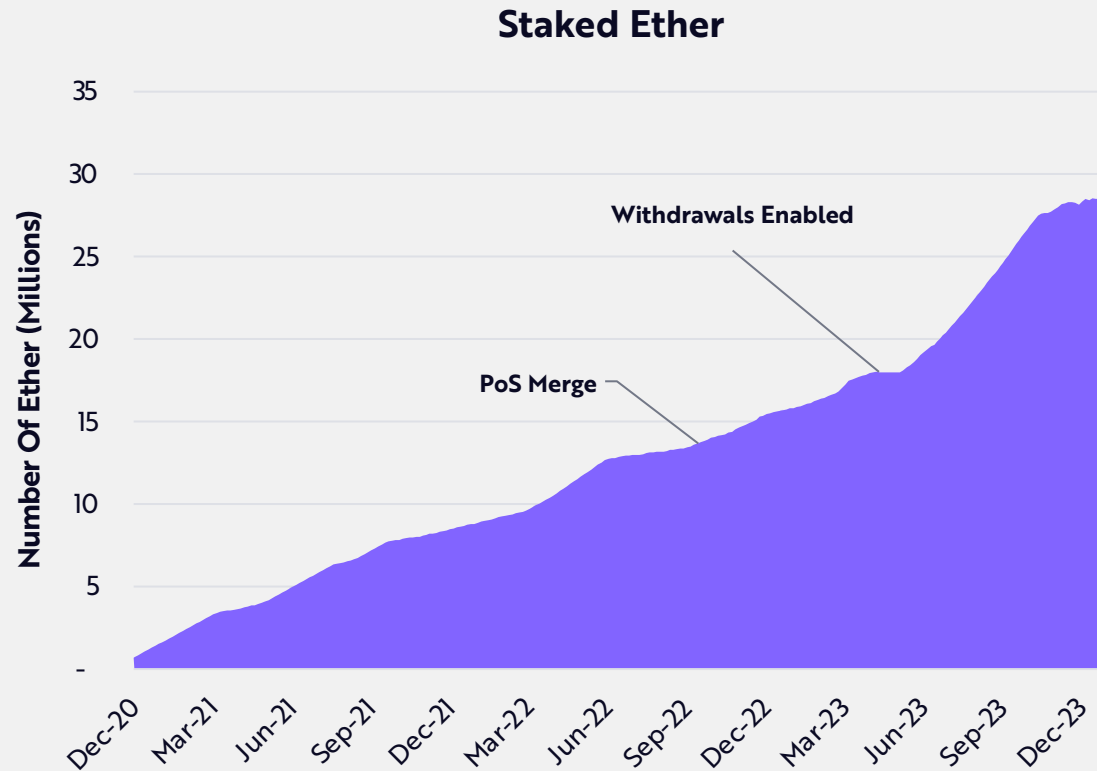
*Proof-of-Stake is a method of securing public blockchains, in which network participants who wish to validate transactions on the network pledge or "stake" their assets at risk of loss if they fail to operate within the network's rules. Chart data end 12/31/23. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which are available upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Layer 2 Networks Have Scaled Transactions In The Ethereum Ecosystem

Since early 2021, more than 20 Layer 2 (L2)* networks have launched, enabling Ethereum to scale average daily transactions at lower fees by 4x. Despite their early success, most L2 networks are controlled centrally. The proliferation of L2s has complicated user and developer experiences.

SMART CONTRACTS

Average Daily Transactions

■ Ethereum Mainnet   ■ Layer 2 Neworks
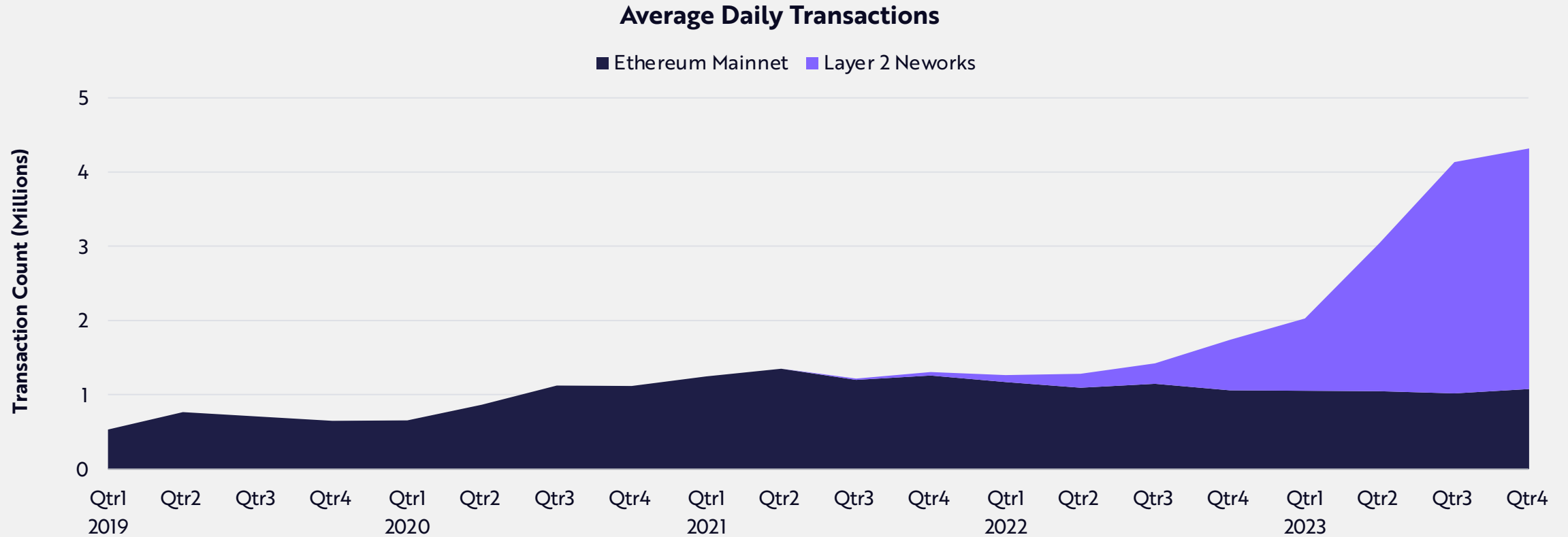
*L2 networks aggregate transactions and settle the resulting state changes to a base-layer smart contract network like Ethereum, typically at higher throughput and lower cost compared to the base network. L2 transaction count is based on data available on Artemis Dashboard: Arbitrum, Base, Linea, Optimism, Polygon zkEVM, Scroll, StarkNet, zkSync Era, Zora Network. Chart data end 12/31/23. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which are available upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Lower Costs Are Boosting On-Chain Engagement

As transaction costs have declined, on-chain engagement—as measured by the ratio of daily active addresses (DAUs) to monthly active addresses (MAUs)—has increased.

SMART CONTRACTS

Engagement Relative To Transaction Fees
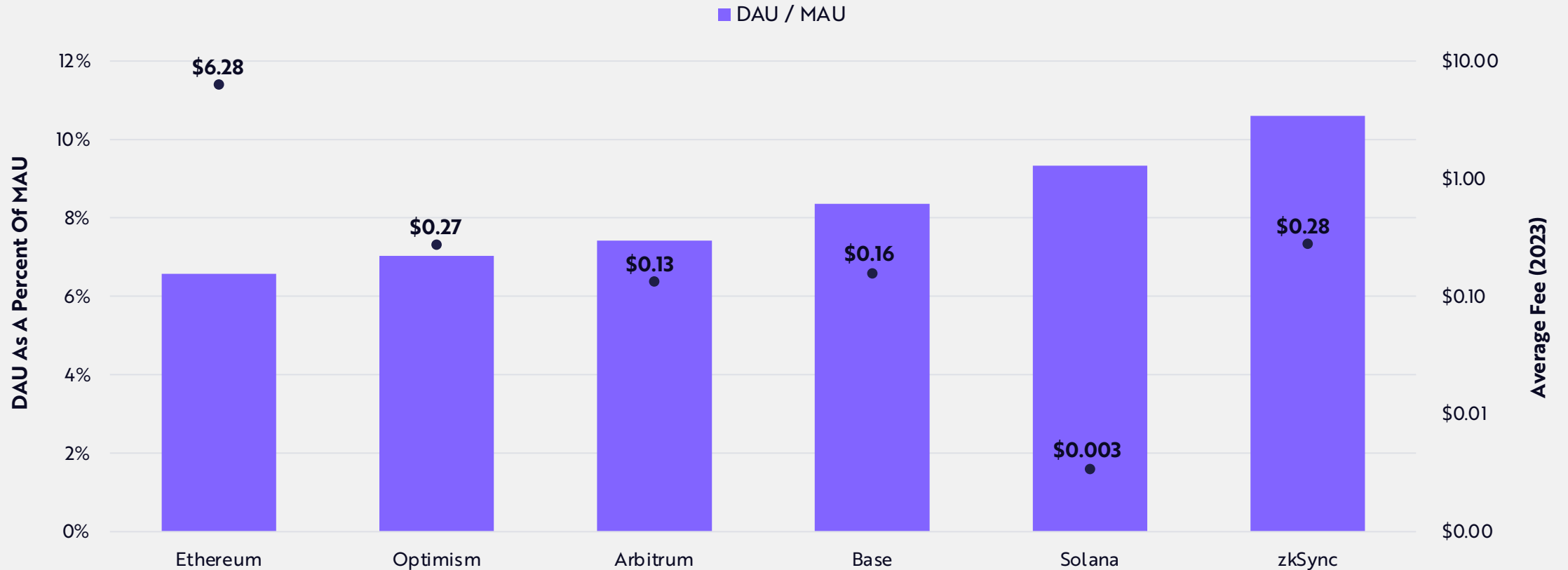
■ DAU / MAU

Note: DAU / MAU traditionally refers to a measure of unique users. For this analysis, we are using a measure of unique addresses as an approximation for users. They are correlated but not equivalent. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which are available upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Monolithic Chains Like Solana Offer An Alternative To Vertical Scaling

Smart contract network designs offer tradeoffs. By prioritizing base-layer decentralization, the Ethereum ecosystem became more complex as it scaled. By prioritizing scalability in a single layer, Solana maintained a simple architecture for users and app developers and has gained traction.

SMART CONTRACTS

Vertical Scaling

| | DAPP 1 | | DAPP 2 | | DAPP 3 | ... |

| L2 Arbitrum | L2 Optimism | L2 Base | ... |

| L1 Ethereum |
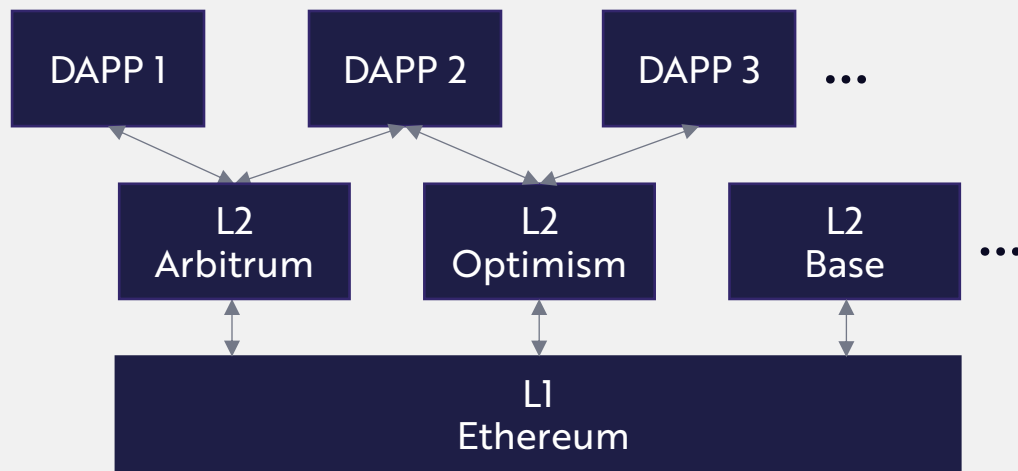
+ Minimizes L1 validation cost	- Requires asset bridging between L1 and L2, fragmenting liquidity
+ Supports multiple approaches for scaling, encouraging flexibility & innovation	- Increases complexity for developers and users
+ Leverages the network effect and liquidity advantages of Ethereum mainnet	- Introduces additional reliability and security considerations across L2s

Horizontal Scaling

| DAPP 1 | DAPP 2 | DAPP 3 | ... |

| L1 Solana |

+ Simplifies the environment for developers and users	- Raises L1 validation costs
+ Maximizes composability and interoperability	- Potentially requires L2s to maximally scale
+ Lowers fees and increases throughput for base layer transactions	- Requires apps depend L1 execution environment

Smart Contracts Could Collapse The Cost Of Financial Services

The value of financial assets globally ballooned from $140 trillion in 2000 to $510 trillion in 2020, thanks to a combination of global economic growth, increased financialization, and expanding equity multiples. The operating cost of the global financial system increased in tandem with the value of financial assets. At $20 trillion in total annual revenue, the aggregate financial services industry's take rate has been 3.3% relative to the value of all financial assets. Smart contracts could lower this drag on the economy materially.

Value Of Global Financial Assets

Global Financial Services Revenue
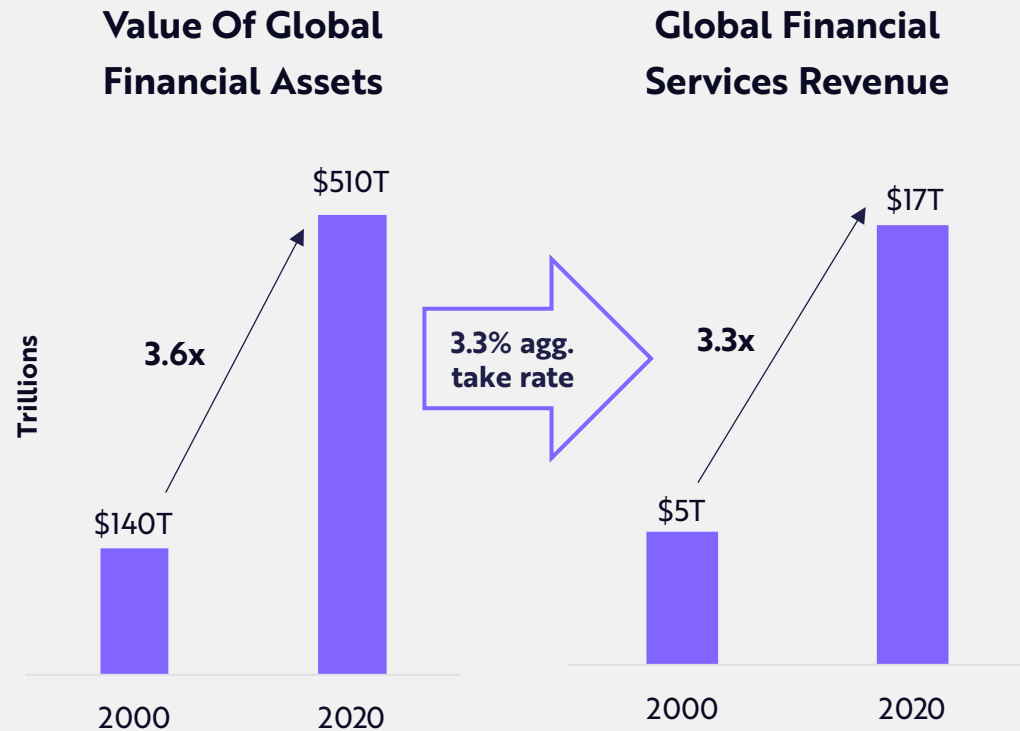
Economic Impact of Financial Regulatory Compliance

Value Of Global Financial Assets (Trillions)
- 2000: $140T
- 2020: $510T
- 3.6x

3.3% agg. take rate

Global Financial Services Revenue
- 2000: $5T
- 2020: $17T
- 3.3x

Activity	Cost To Current System	Cost Lowering Solution
Know Your Customer Verification	$1,500-$3,000+ per individual verification	Unified digital identity verifiable across institutions
Nasdaq Listing Fee	$270k per listing + $52-$180k annually	Direct DEX listing with global distribution
Global Anti-Money Laundering Compliance	$274 billion cost to the global financial system annually	Auditable provenance of funds on global ledger

SMART CONTRACTS

Smart Contract Networks Could Generate Fees Of $450 Billion In 2030

Smart contracts could facilitate the origination, ownership, and management of on-chain assets for a fraction of traditional financial costs. If financial assets were to migrate to blockchain infrastructure at a rate similar to the adoption of the internet, and the take rates associated with decentralized financial services were a third those of traditional financial services, smart contracts could generate annual fees of more than $450 billion and create more than $5 trillion in market value, increasing at compound annual rates of 78% and 32%, respectively, through 2030.
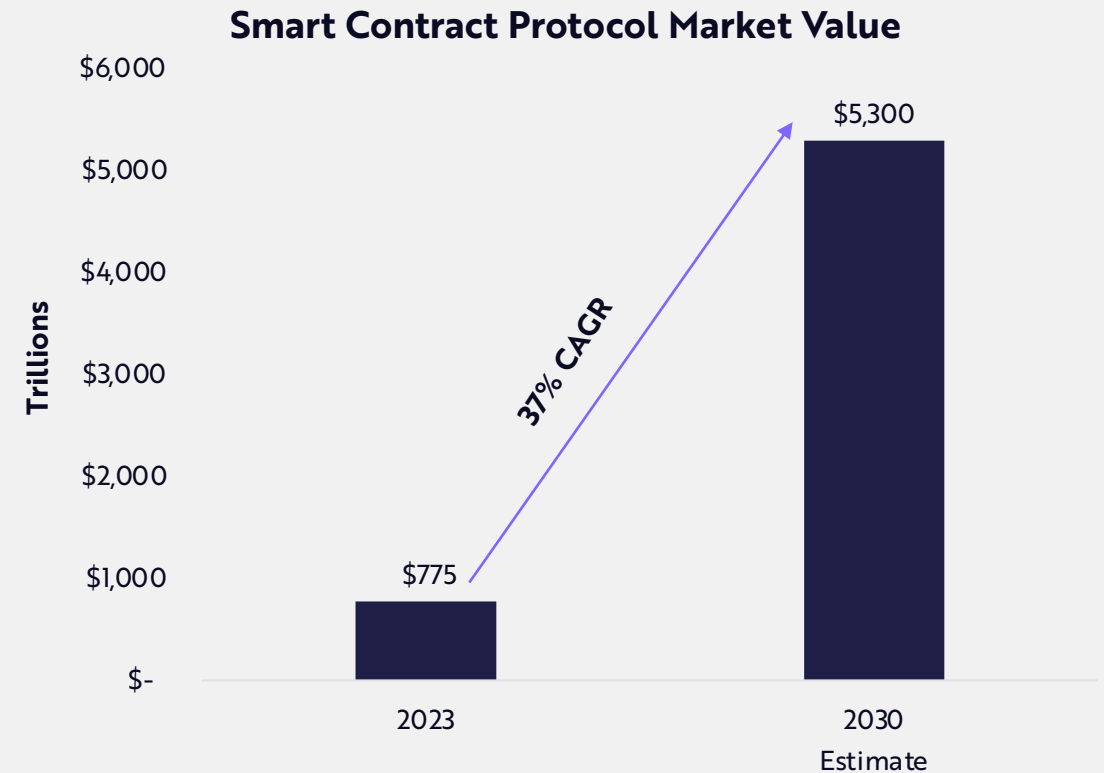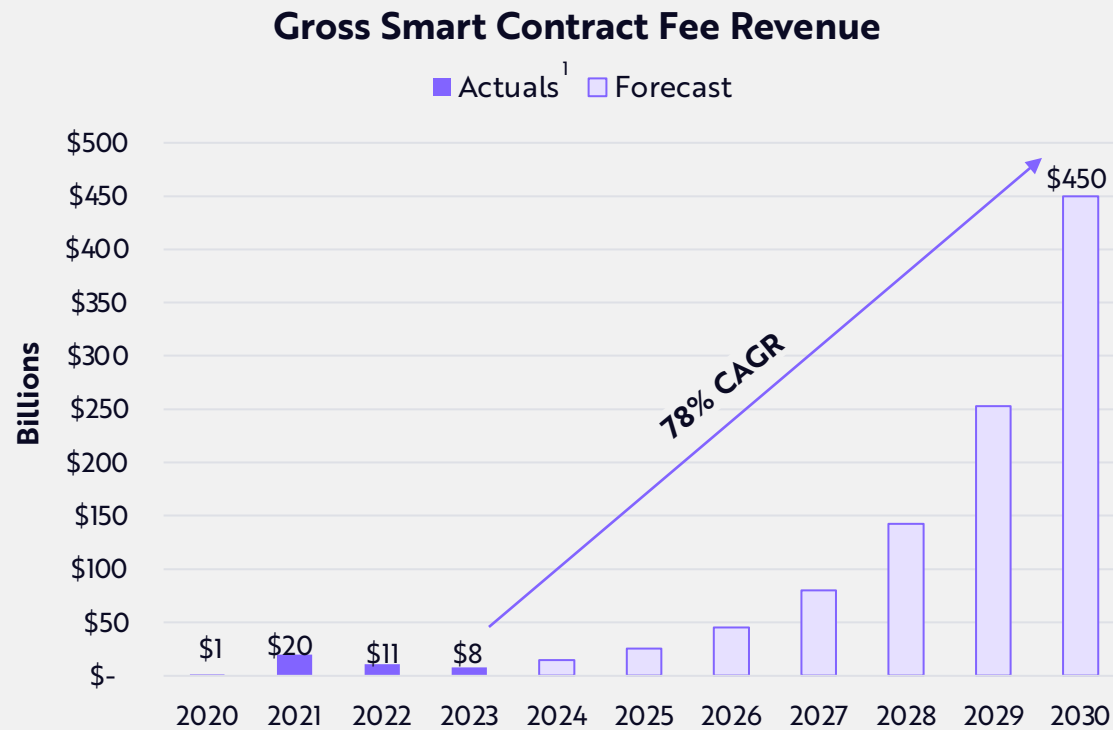
Gross Smart Contract Fee Revenue

■ Actuals[1] □ Forecast

78% CAGR

Smart Contract Protocol Market Value

37% CAGR

Research By: **Nicholas Grous**   **Andrew Kim**
Associate Portfolio Manager   Analyst

Digital Consumers

Transitioning Toward Digital Leisure

According to ARK's research, spending on digital leisure should take share from physical options and grow 19% at an annual rate during the next seven years, from $7 trillion in 2023 to $23 trillion in 2030. Several trends are accelerating the shift to digital leisure:

- **Connected TV (CTV) Advertising** should grow 17% at a compound annual rate, from $25 billion in 2023 to $73 billion in 2030.
- **Social Commerce** should grow 32% at an annual rate, from $730 billion today to over $5 trillion in 2030.
- **Sports Betting** should remain turbocharged by the legalization of online/mobile betting.
- **AI-assisted Video Game Creation** is the new wave in gaming, building on user-generated platforms like Roblox, which has hosted more than ~470 million experiences globally—52x the combined number of PC, consoles, and mobile games.
- **AI-enabled Hardware** could redefine personal wearable computing, especially if virtual reality (VR) continues to face challenges.

Artificial Intelligence Could Lower The Average Workweek And Stimulate Digital Consumption

During the 80 years between the Second Industrial Revolution through the end of World War II, labor hours per worker decreased 0.5% at an annual rate globally. Generative AI could lower labor hours per worker by 1.3% on average, from 5.0 hours per day in 2022 to 4.5 hours in 2030.*

As a result, consumers might devote more time to online entertainment, potentially increasing the share of total waking hours spent online from 40% in 2023 to 49% in 2030.

Global Labor Hours Per Worker Per Day*
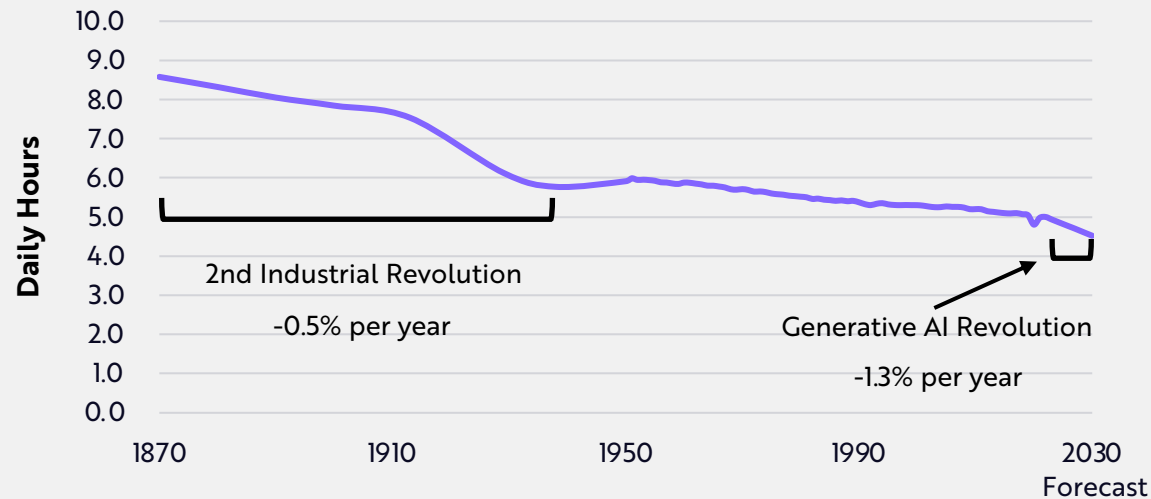
Global Online And Offline Time**
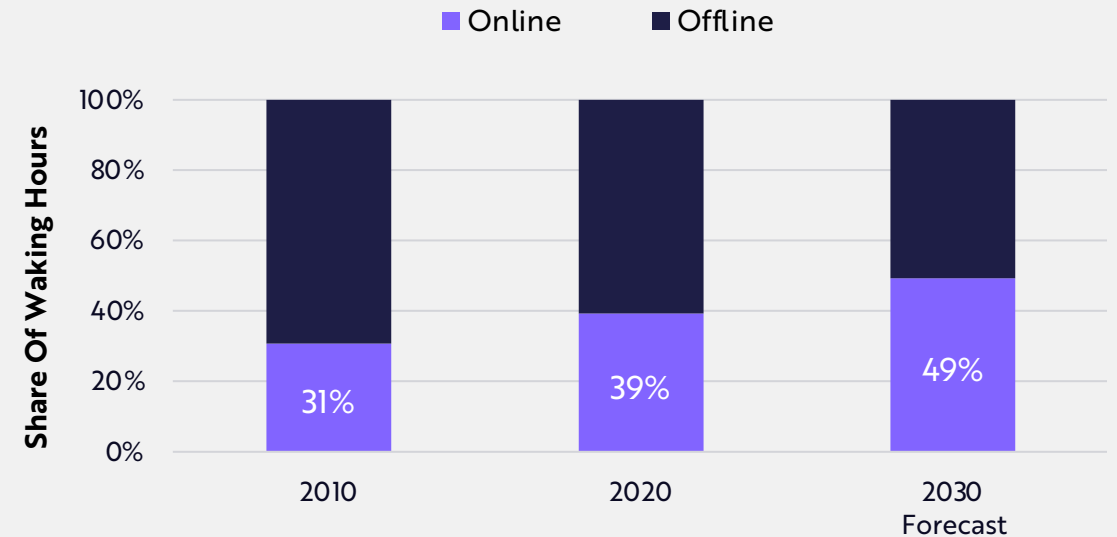
*To calculate global daily working hours, we divide total annual hours of labor per worker by the total days of the year. **The chart illustrating daily allocation of online vs. offline time captures total daily waking hours, including those allocated 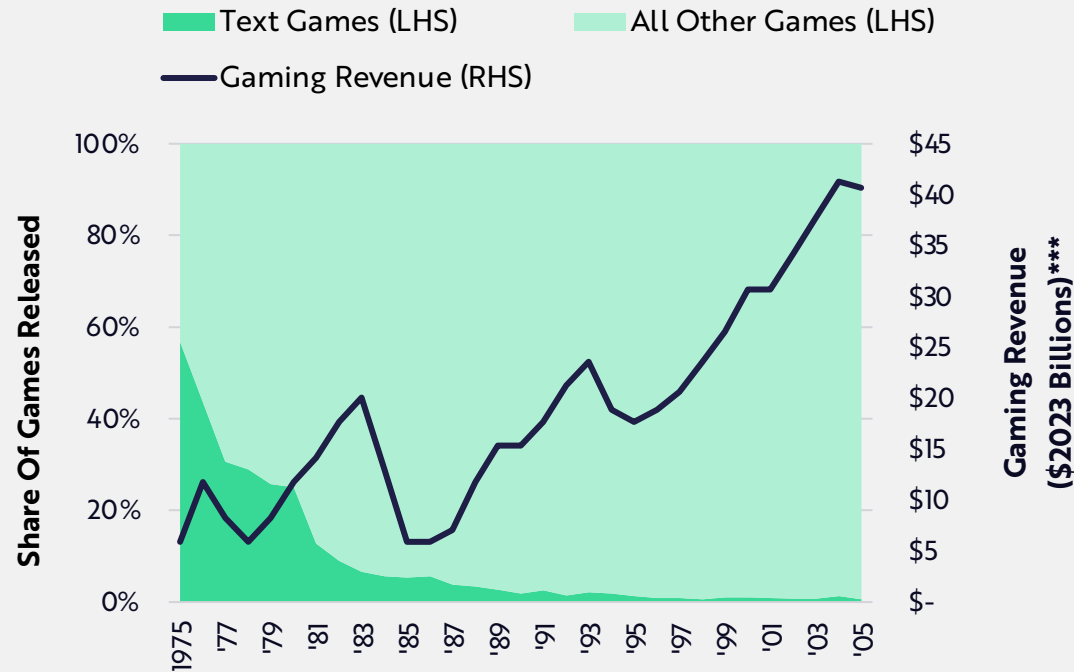to labor or education. The chart captures hours generated by internet users only. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
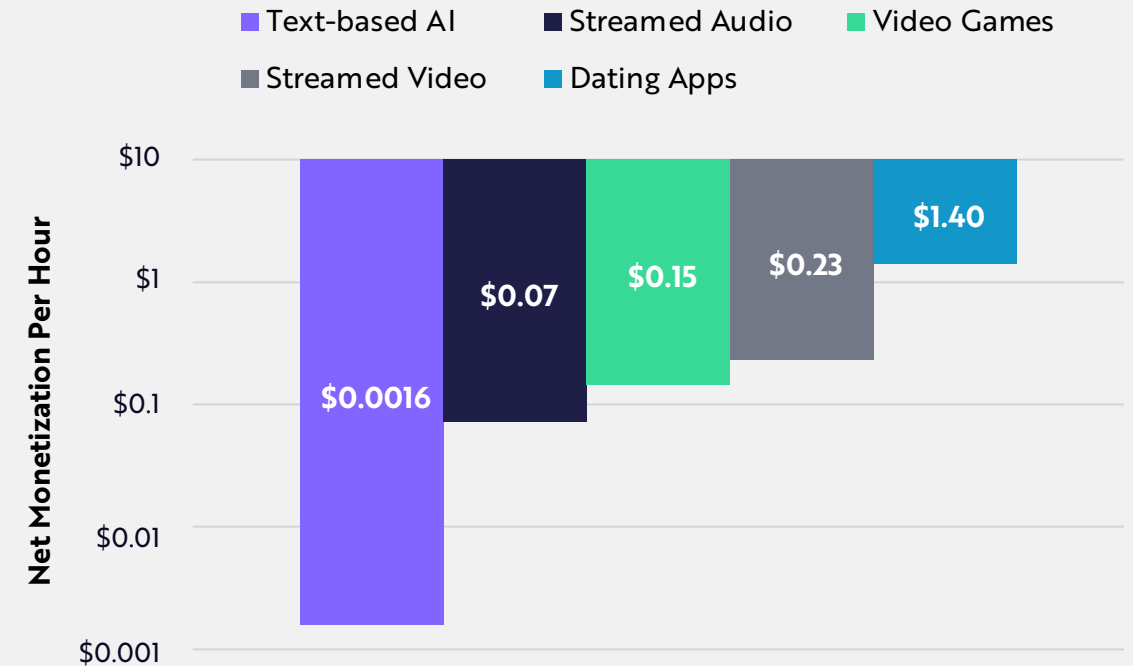
Streaming TV Is Displacing Linear TV

In just two years, streaming's share of overall TV consumption increased more than 10 percentage points to 39% as of July 2023, surpassing the shares of cable and broadcast, respectively. Ad spend on connected TV (CTV) is following eyeballs and is likely to grow 17% in real terms at an annual rate, from $25 billion in 2023 to $73 billion in 2030. If so, ad spend on CTV should surpass that on linear TV in 2027.

US TV Viewership Share*

— Streaming   — Cable   — Broadcast

US TV Ad Spend**

—●— Connected TV   —●— Linear TV
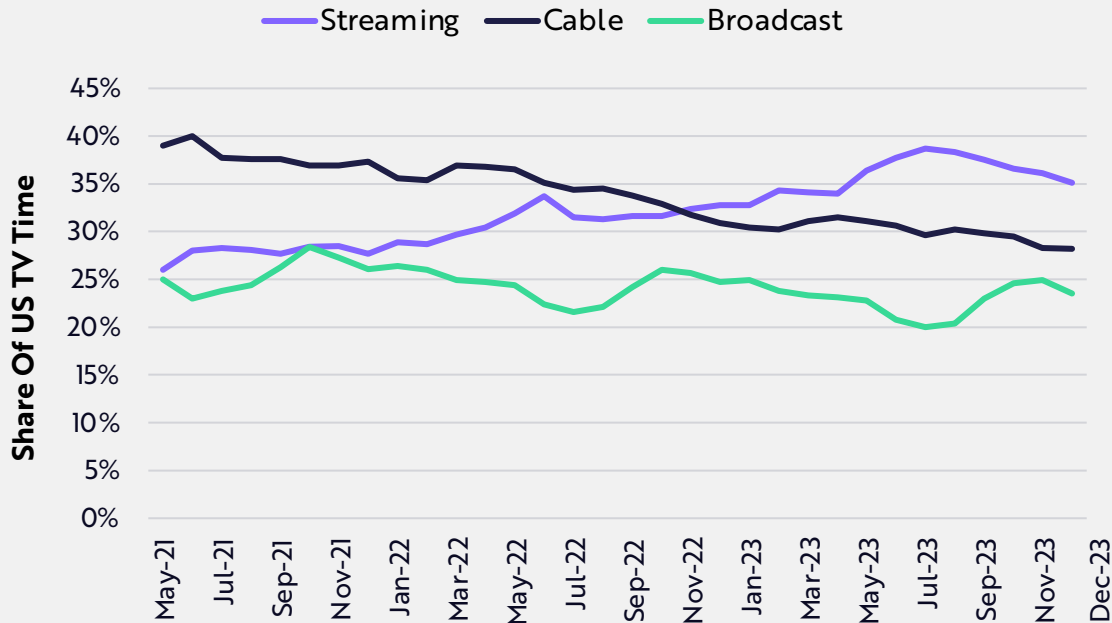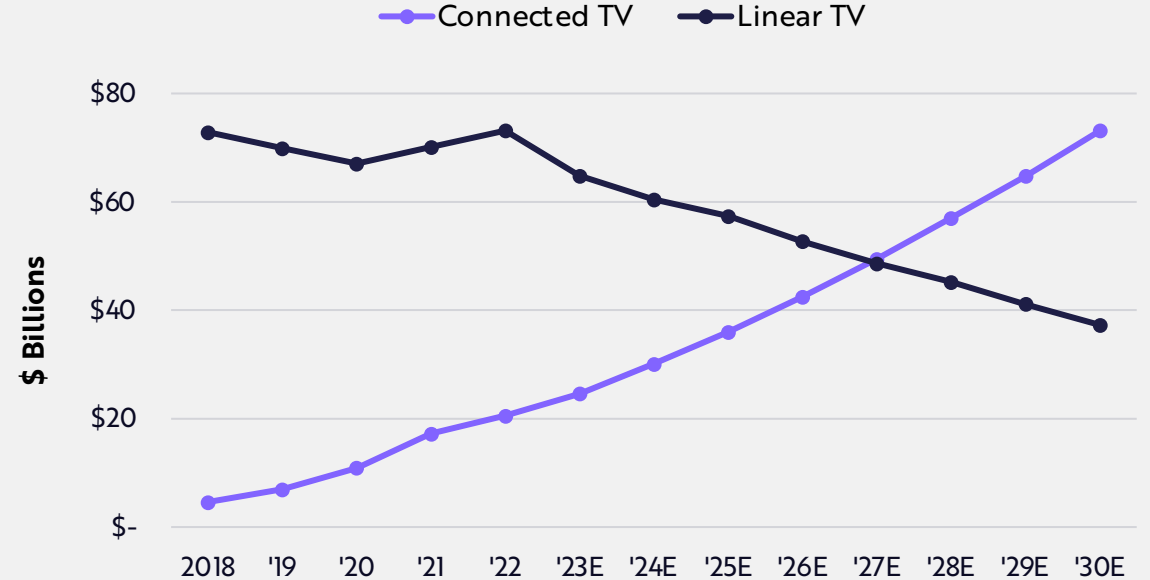
*The share of streaming, cable, and broadcast do not add up to 100%, as we exclude the portion of consumption that Nielsen categorizes as "Other," which includes time spent on unmeasured sources like video-on-demand (VOD), audio streaming, gaming, and other device use. **We define linear TV as traditional TV delivered via cable, satellite, or over-the-air. We define connected TV as streamed TV delivered over-the-top through smart TVs, streaming media devices, video game consoles, and other modern hardware. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources,, including Nielsen, Insider Intelligence, and MAGNA Global, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
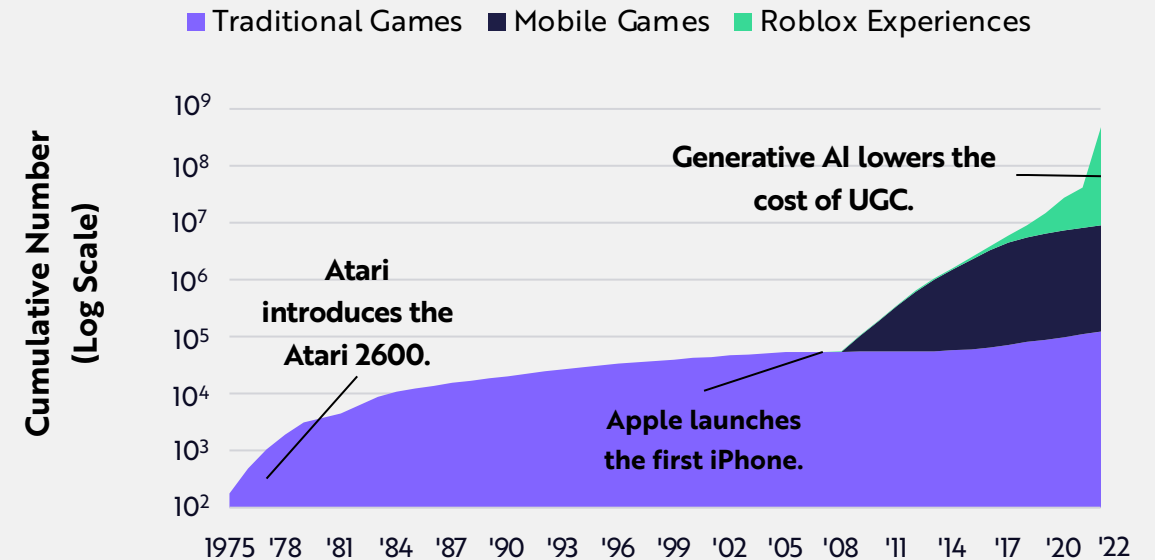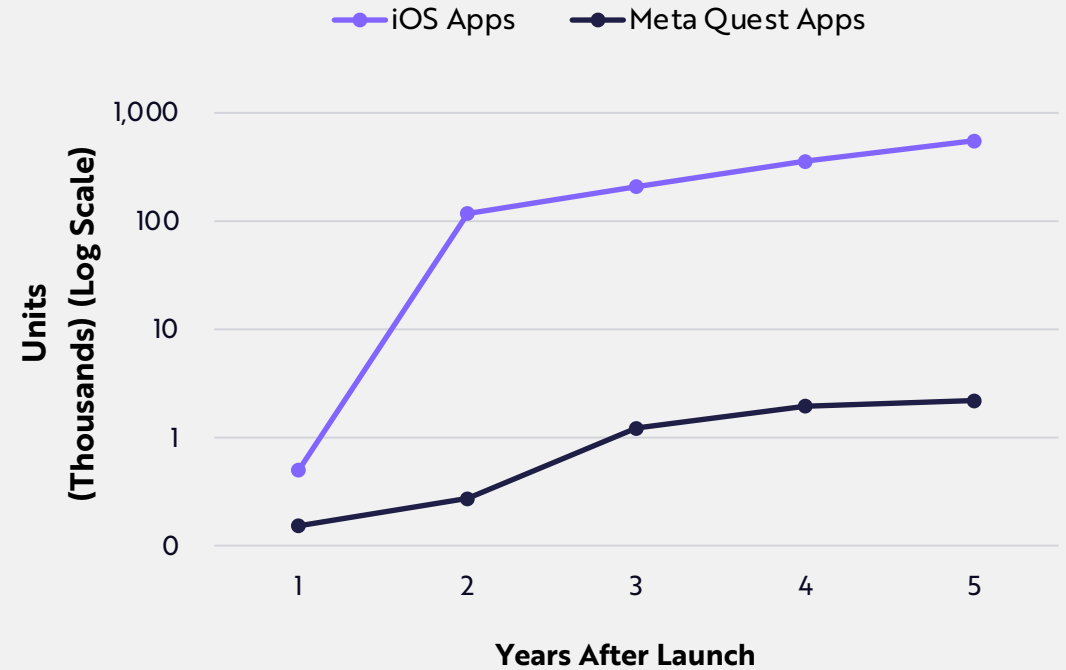
Social Commerce Merchants Can Sell to Anyone—Anytime, Anywhere

Social media platforms are increasing their monetization of global audiences with e-commerce. Thanks to omnichannel solutions—both physical and digital—social commerce could grow 32% at an annual rate, from $730 billion today to over $5 trillion in 2030.

DIGITAL CONSUMERS
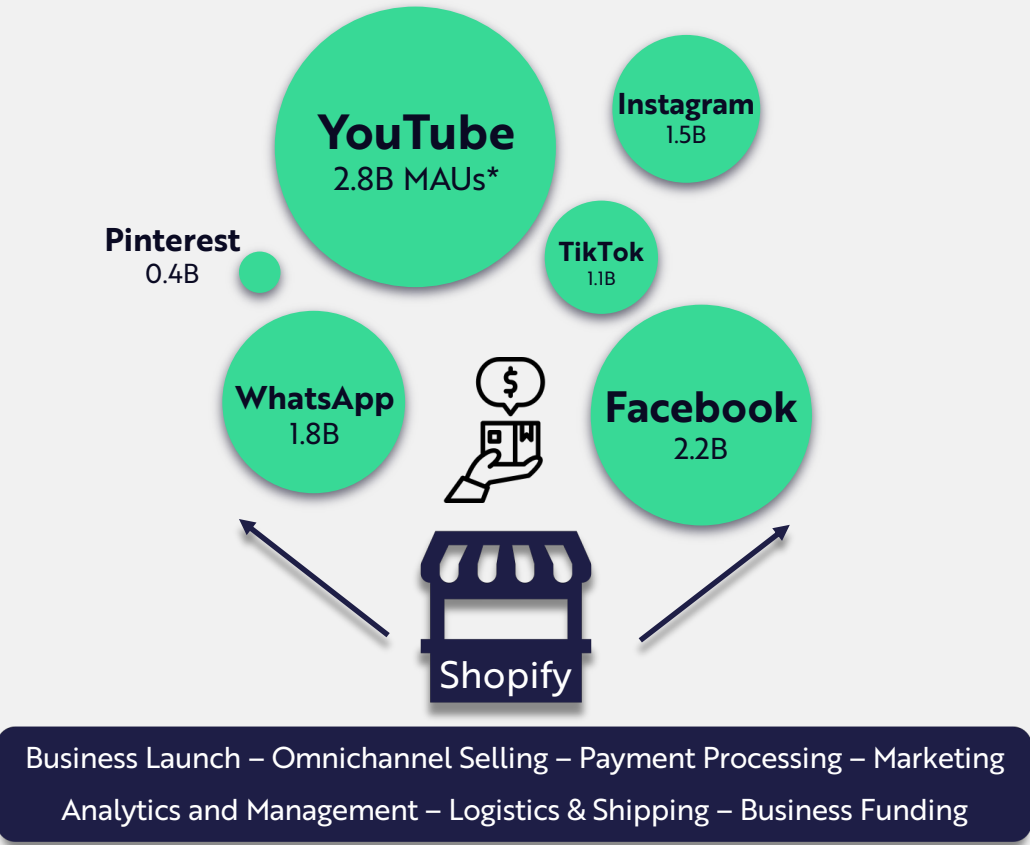
Global Social Commerce Sales
ARK Forecast
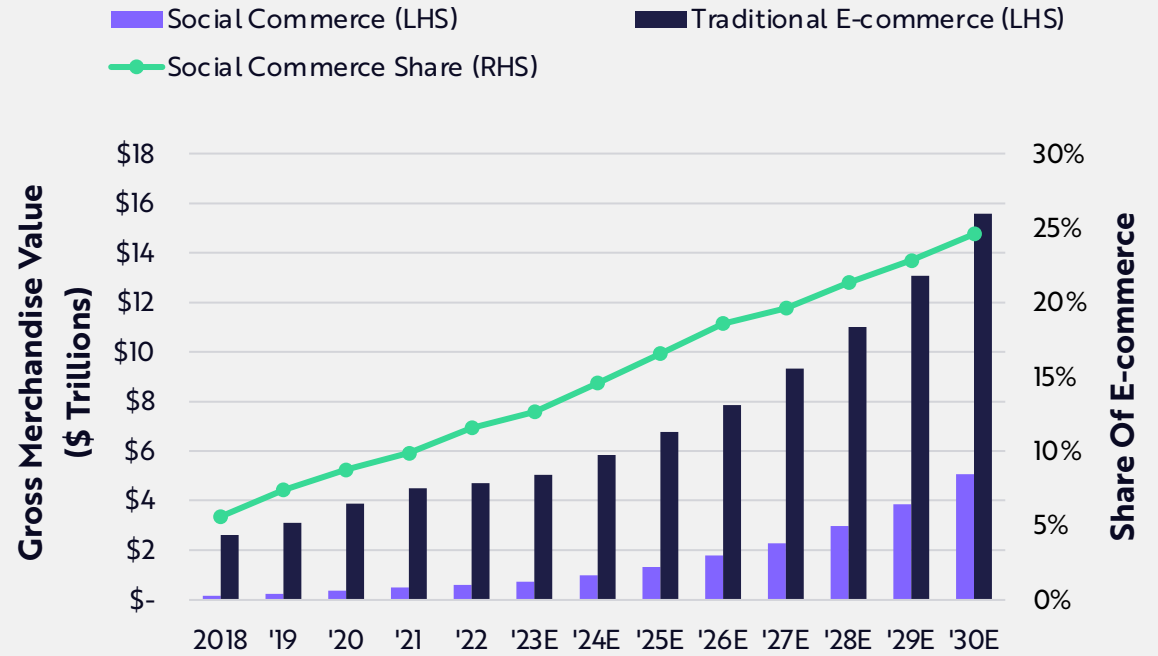
■ Social Commerce (LHS)   ■ Traditional E-commerce (LHS)
● Social Commerce Share (RHS)

Business Launch – Omnichannel Selling – Payment Processing – Marketing
Analytics and Management – Logistics & Shipping – Business Funding

Mobile Sports Betting Continues To Grow And Consolidate In The US

Thanks to legalization and consumer adoption, the winners in online sports betting are pulling away from the pack. As online sports betting surged 35% during 2023, DraftKings and FanDuel offered superior user experiences that helped take share from other sportsbooks. DraftKings and FanDuel grew their share of national deposits to 75% in 2023, while the long tail of sportsbooks lost 8 percentage points of share.

DIGITAL CONSUMERS

US Online Sports Betting Volume

Legalized States (LHS) Future Legalizations (LHS) Online Penetration (RHS)
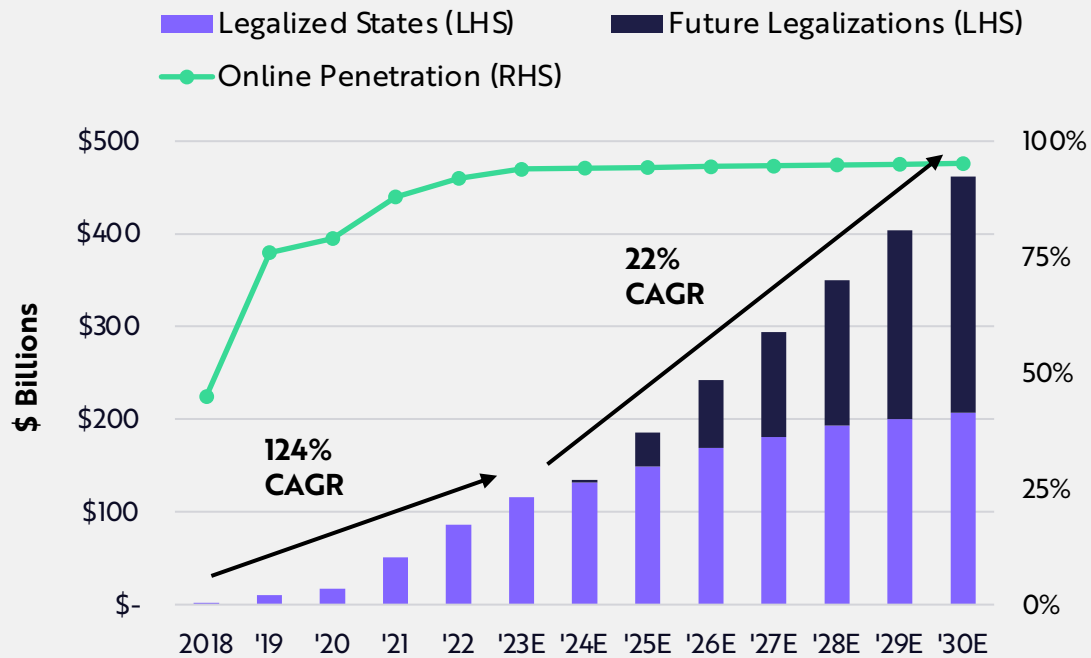
National Deposit Market Share
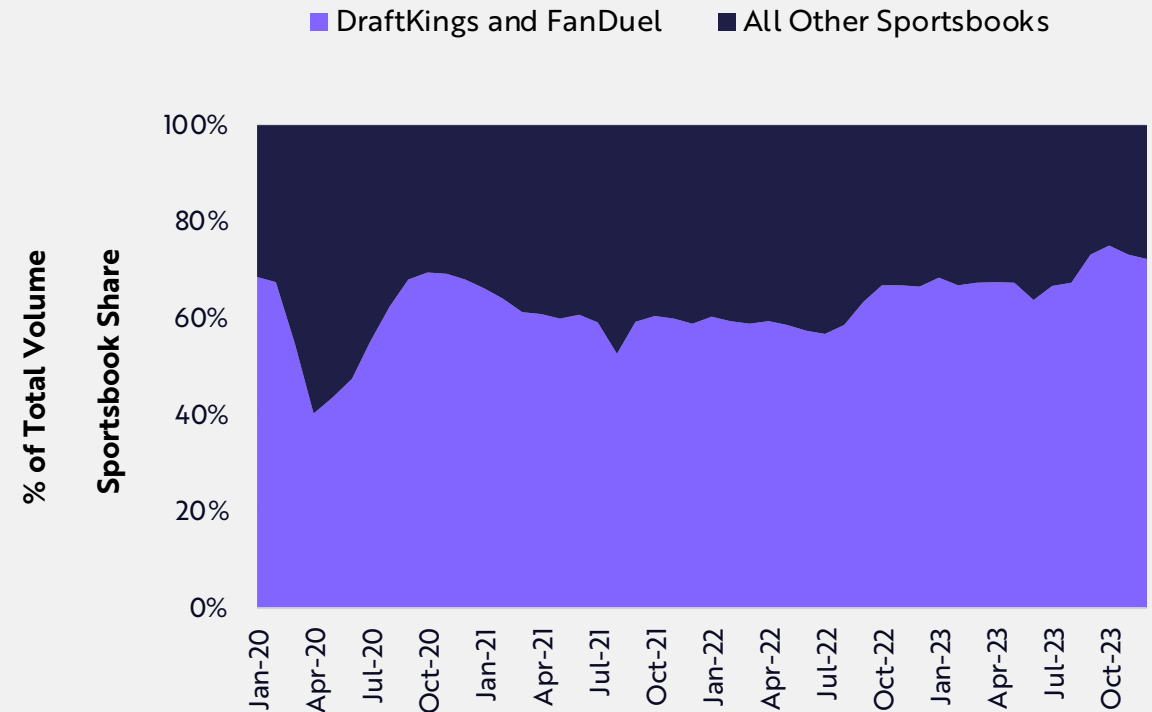
DraftKings and FanDuel All Other Sportsbooks

Online Experiences Are Becoming More Immersive And Monetizable

History suggests that deeper immersion leads to higher monetization. After computer graphics expanded the market beyond text-based adventure games in the 1980s, gaming revenue soared 19% at an annual rate, from $6 billion in 1985 to $24 billion in 1993. Now, multimodal AI—text, images, audio, and video—are creating more immersive and interactive experiences that should expand the market.

DIGITAL CONSUMERS

Video Games Evolution*

- Text Games (LHS)
- All Other Games (LHS)
- Gaming Revenue (RHS)

Gross Platform Monetization Rates**

- Text-based AI
- Streamed Audio
- Video Games
- Streamed Video
- Dating Apps

Net Monetization Per Hour

- Text-based AI: $0.0016
- Streamed Audio: $0.07
- Video Games: $0.15
- Streamed Video: $0.23
- Dating Apps: $1.40

*"Text games" refer to both text-based and spreadsheet-based games. "All other games" exclude arcade game releases. Gaming revenue captures PC and console gaming revenue only **We estimate various platforms' ability to monetize on direct consumer spend only.. ***Revenue figures have been inflation-adjusted to 2023 US Dollars. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Thanks To AI-Assisted Creation, Gamers Could Become Developers

AI-assisted game creation on user-generated content (UGC) platforms could cause an explosion in gaming content. According to our research, after normalizing for output quality, the cost of generating a single 3D asset has dropped ~99% at an annual rate to less than $0.06 since 2021. AI should democratize content creation and accelerate the growth in UGC. Roblox already has delivered more than ~470 million experiences globally, 52x the combined number of PC, console, and mobile app games.

DIGITAL CONSUMERS

Cost Decline In Generative AI For 3D Assets*

>99% Annualized Cost Decline

Dollar Cost per 3D Asset (Log Scale)

$1,000
$100
$10
$1
$0.1
$0.01

Oct-21　Feb-22　May-22　Aug-22　Dec-22　Mar-23

Date of Publication
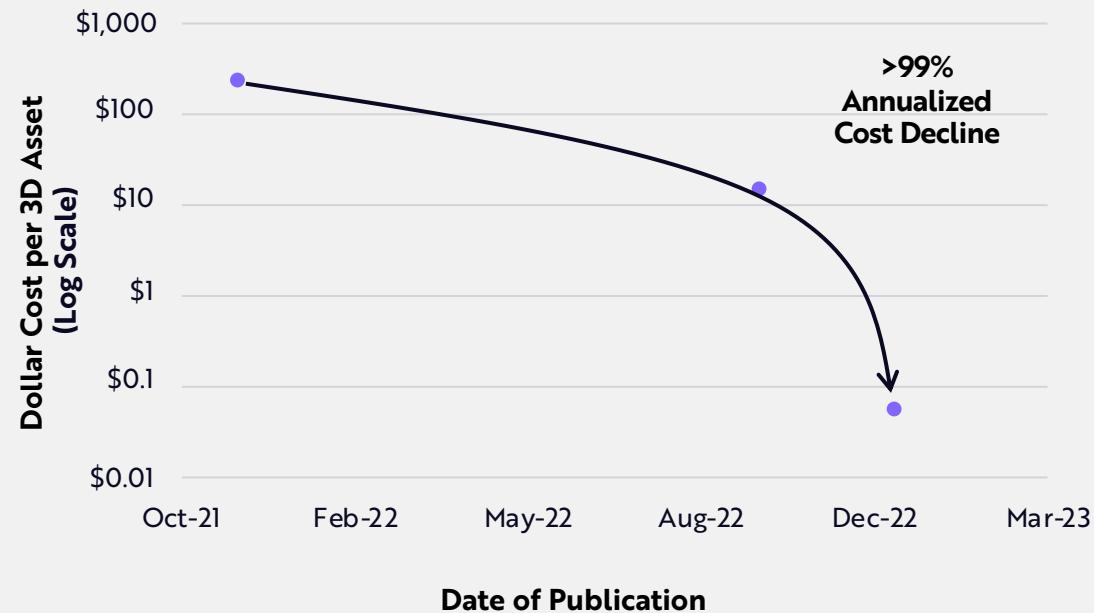
Number Of Video Game Releases

■ Traditional Games　■ Mobile Games　■ Roblox Experiences

Cumulative Number (Log Scale)

10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2

Atari introduces the Atari 2600.

Generative AI lowers the cost of UGC.

Apple launches the first iPhone.

1975　'78　'81　'84　'87　'90　'93　'96　'99　'02　'05　'08　'11　'14　'17　'20　'22

The Market For Virtual Reality Is Nascent

Despite significant headset improvements, including Apple's Vision Pro, developers have not flocked to support virtual reality (VR). Without compelling use cases, adoption has been slow. Meta Quest, for example, is offering only 2,200 apps—a fraction of the 553,000 the iPhone boasted five years after its launch. As a result, Meta has sold only 27 million Quest units, 18% of the 146 million iPhones Apple sold cumulatively five years after launch.

Apple iPhone vs. Meta Quest Headset Shipments
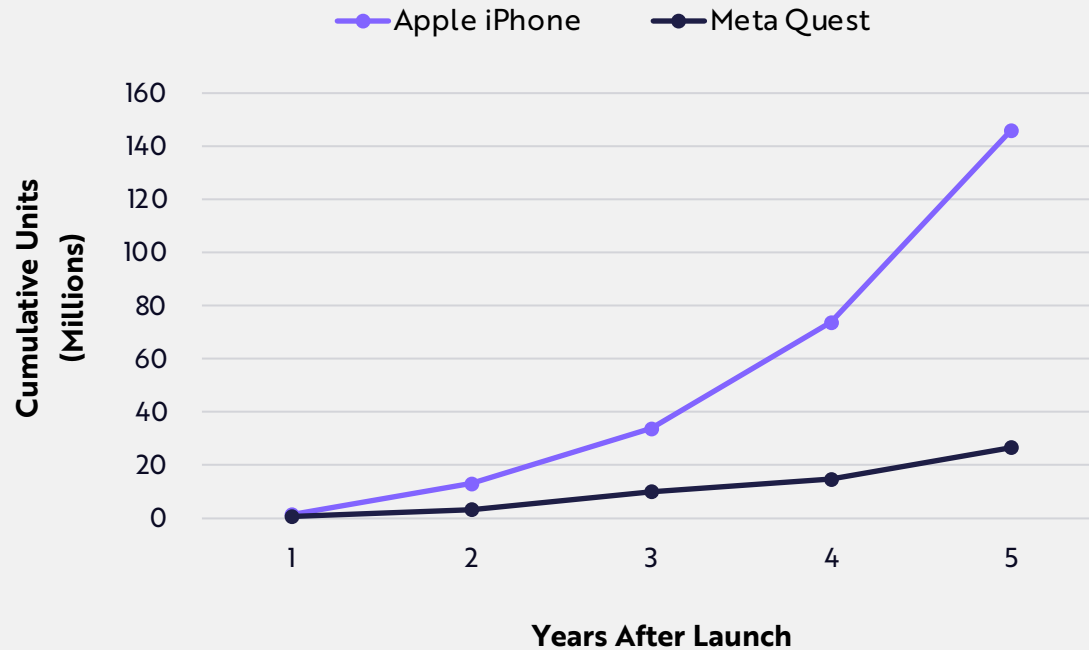
Apple iPhone — Meta Quest

Cumulative Units (Millions)

Years After Launch

iOS vs. Meta Quest Apps

iOS Apps — Meta Quest Apps

Units (Thousands) (Log Scale)

Years After Launch

AI Could Redefine Personal Computing

As computing transitioned, hardware cycles compressed from 35 years for the personal computer to 20 years for the smartphone, causing the consolidation of software players. More rapid adoption of AI-enabled hardware could accelerate the consolidation of software providers.

DIGITAL CONSUMERS

Time To Penetrate 75% Of The US Population

	Years
Computer	35
Smartphone	20
AI-Enabled Hardware	?

Software Expansion → **Operating System Consolidation**
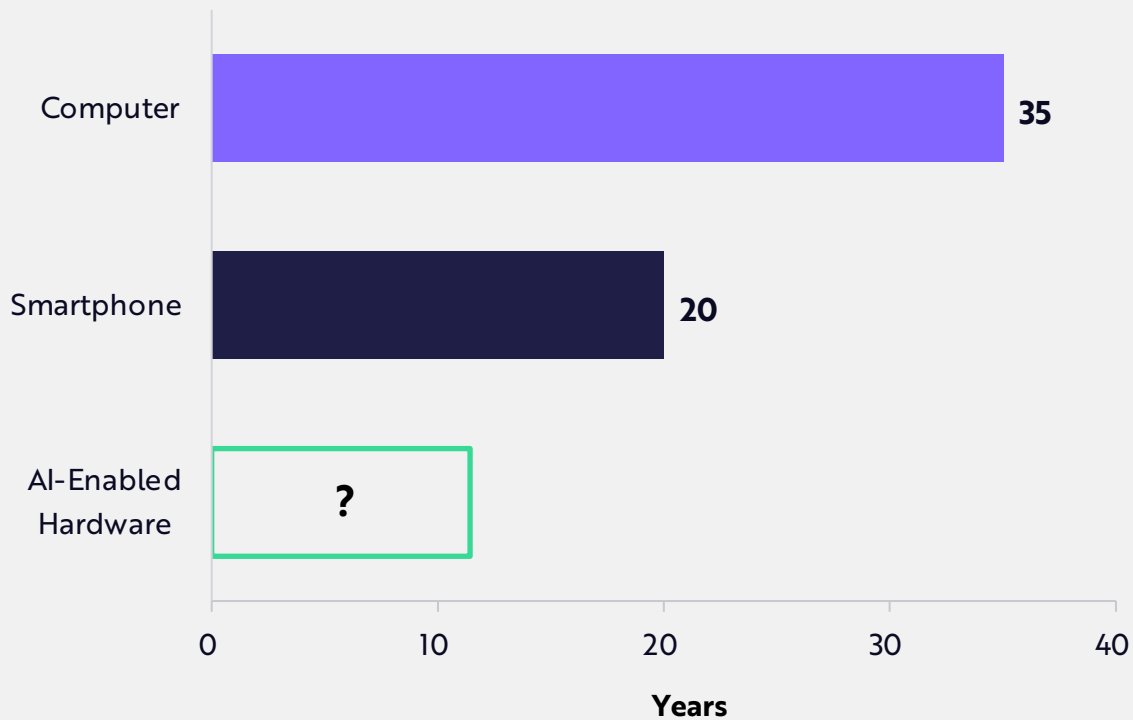
Software Expansion	Operating System Consolidation
Windows, Commodore 64 OS, Atari TOS, Amiga, Linux, MacOS...	Windows, MacOS, Linux
BB OS, Windows Phone, iOS, Symbian, Android, Palm OS...	iOS, Android
GPT-4, Claude 2, Mixtral, Llama 2, Grok...	?

Digital Consumption Is Outpacing Economic Growth

Globally, consumers spent 20% of their $34 trillion leisure budget on digitally-facilitated goods and services in 2023. Based on the shift toward digital leisure, real digital revenue* could increase 16% at an annual rate during the next seven years, from ~$1.8 trillion to $5 trillion, and account for 43% of all leisure spending in 2030.

DIGITAL CONSUMERS

Global Digital Leisure Spend**
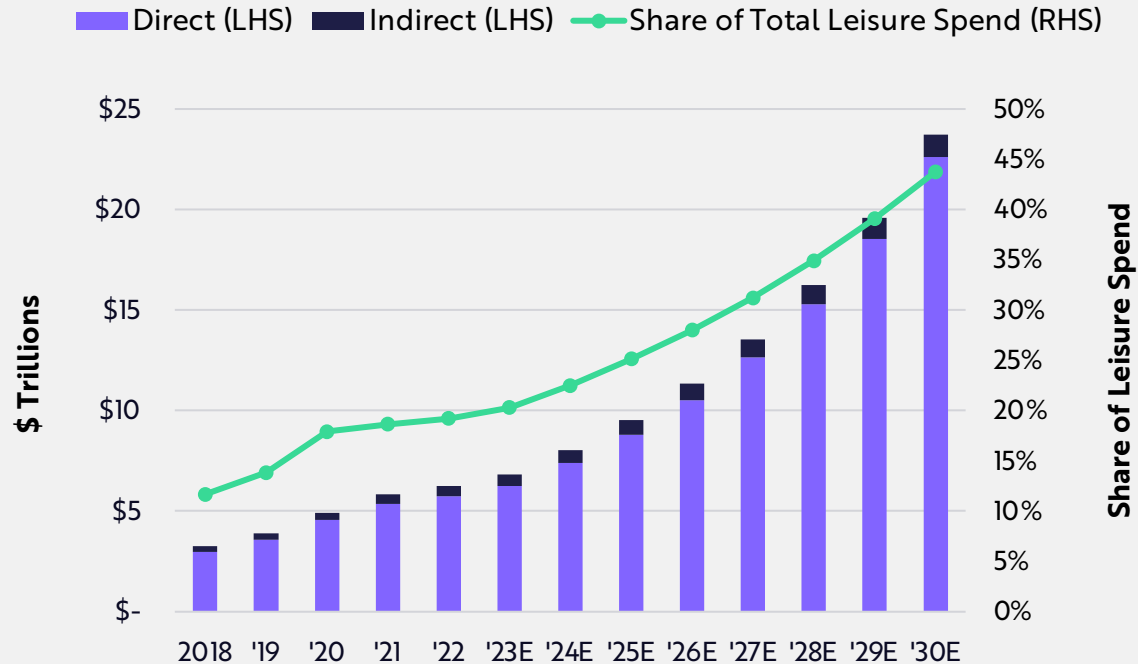
Global Digital Platform Revenue
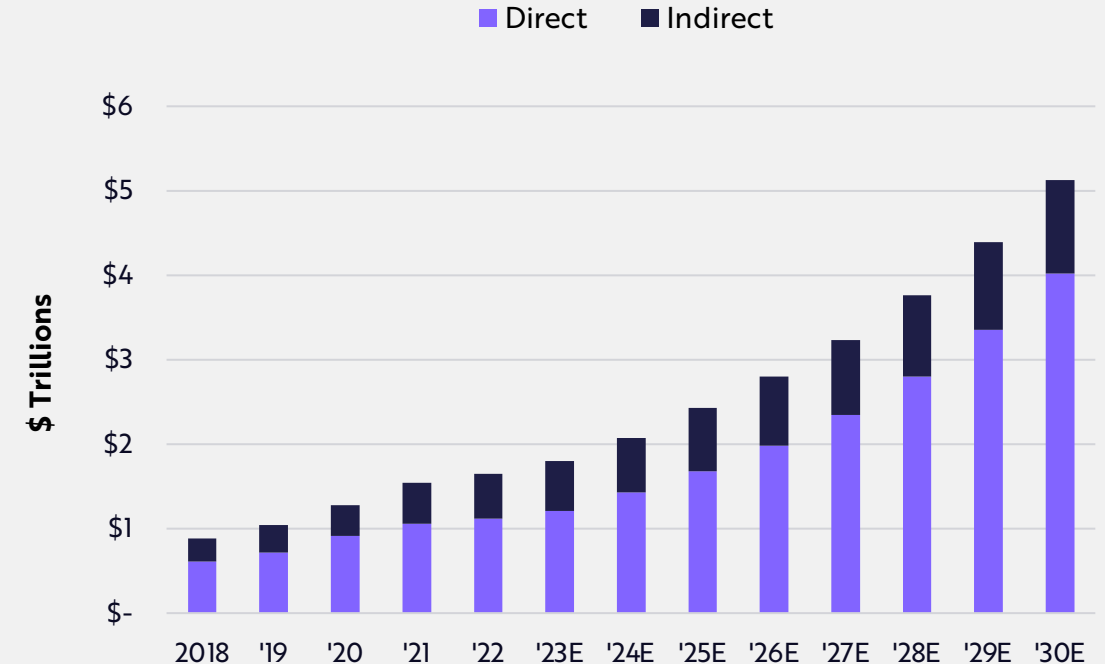
*We define digital platform revenue as the gross revenues of US sports betting, global video game software and services, global digital video, and global digital audio. We also include net e-commerce platform revenue and net NFT creator fees and platform revenue on a global basis. **Direct includes spend across e-commerce, video game software, digital video, digital audio, NFTs, and US mobile sports betting. Indirect includes spend across all digital ads. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Research By: **Andrew Kim**
Analyst

BIG IDEAS 2024

Digital Wallets

Closing The Loop With Two-Sided Networks

Vertical software refers to a suite of solutions tailored to the needs of specific industries. Leading vertical software platforms are expanding rapidly into financial services for consumers and merchants. With two-sided networks, such software could facilitate closed loop transactions from consumer to merchant, merchant to employee, and employee to merchant. ARK believes that digital wallets on these platforms will enable fully closed payment ecosystems.

Block, Shopify, and Toast are compelling platforms likely to use digital wallets as the nucleus of their consumer, merchant, and employee ecosystems. According to our research, closed loop consumer payments, merchant banking, and employee payroll/payments could increase their revenues by 22-33% at an annual rate during the next seven years, from $7 billion in 2023 to $27-$50 billion in 2030.*

*In this exercise, we forecast the core revenues of Block, Shopify, and Toast to grow 22% at an annual rate over the next seven years. Summing the mentioned revenue opportunities on top of our core revenues forecast increases the annual growth rate from 22% to 33% over the next seven years. We primarily model Block's historical revenue and future revenue opportunity across its Square merchant ecosystem and do not incorporate Cash App or Afterpay revenues independent of Square. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
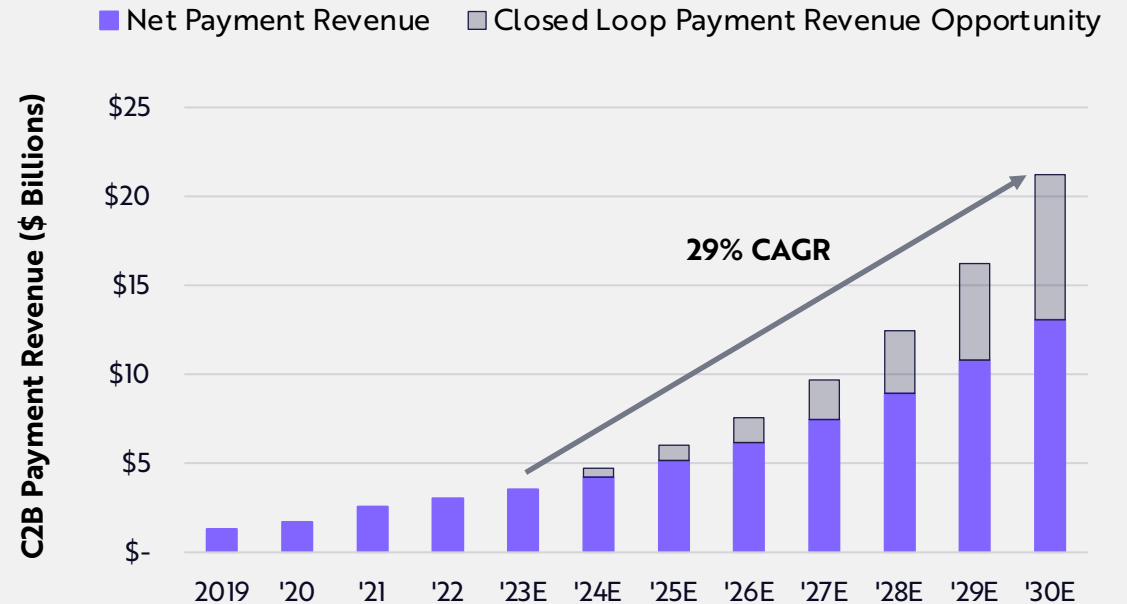
Vertical Software Platforms Are Consolidating Financial Services

In addition to enabling core business operations, vertical software providers like Block, Shopify, and Toast are consolidating financial services for merchants. With digital wallets at their core, and partnering with sponsor banks and fintech companies or activating their own banking charters, vertical platforms should eliminate myriad merchant interactions with less efficient legacy financial institutions.

DIGITAL WALLETS

	Consumer*	Merchant						
	Digital Wallet	Payroll	Checking	Savings**	Debit Card	Credit Card	Working Capital Financing	Bill Pay***
Block	✓	✓	✓	✓	✓	✓	✓	✓
Shopify	✓		✓	✓	✓	✓	✓	✓
Toast	✓	✓			✓		✓	✓

Vertical Software Platforms Are Consolidating Consumer Services

Vertical software platforms are not only enabling vast merchant networks but also building consumer networks using digital wallets. By scaling merchant and consumer networks simultaneously, vertical software platforms are becoming operating systems for these two-sided networks.

DIGITAL WALLETS

	Consumer*								Merchant
	Payments	Checking	Savings	Debit Card**	Buy Now Pay Later	Personal Lending	E-commerce	Loyalty	Digital Wallet
Block	✓	✓	✓	✓	✓	✓	✓	✓	✓
Shopify	✓				✓		✓	✓	✓
Toast	✓			✓			✓	✓	✓

*We consider Block's Cash App and Toast's MyToast mobile app as consumer digital wallets, and we consider Shopify's Shop mobile app and Toast's Toast Takeout mobile app as digital wallets in their early stages. **We consider the Toast Pay Card a form of consumer debit cards. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
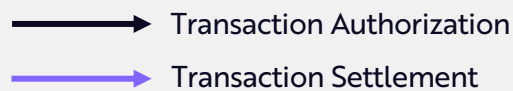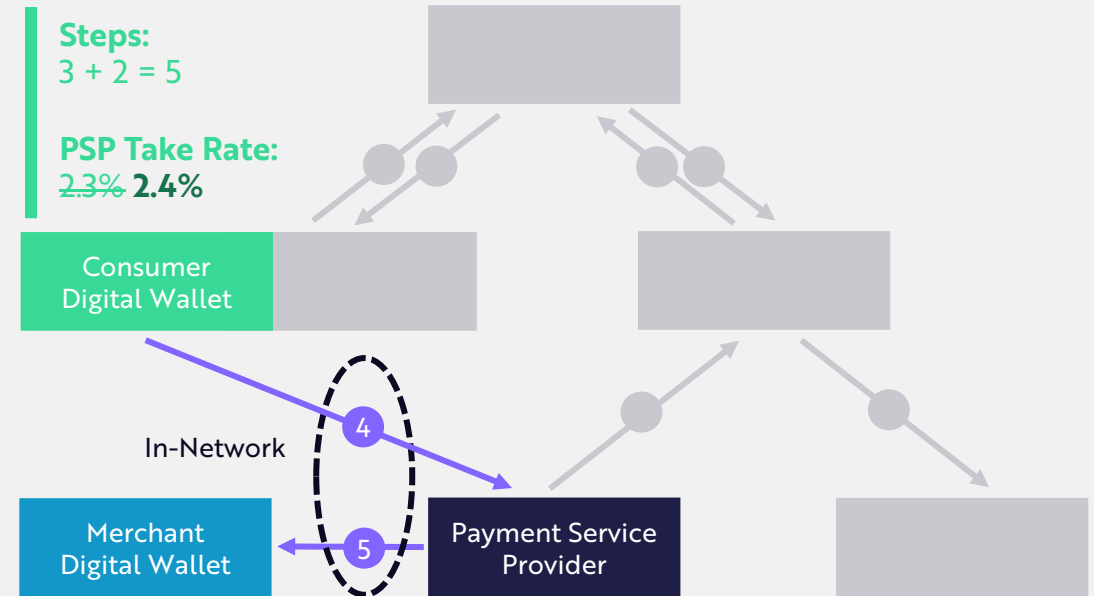
Two-Sided Networks Can Close The Financial Loop Between Consumers And Merchants

Closed-loop payment ecosystems incorporate in-network money transfers in three ways: from consumers to merchants, from merchants to employees, and from employees—cum consumers—to merchants. To build these payment ecosystems, platforms must have: 1) large and engaged two-sided networks, 2) end-to-end visibility over merchant operations and finances, and 3) vertical industry expertise.

DIGITAL WALLETS

Consumer

Merchants

In-Network Consumer Digital Wallet

$

Vertical Software Platform

$

In-Network Merchant Digital Wallet

In-Network Payroll Service Provider

$

$

Employees
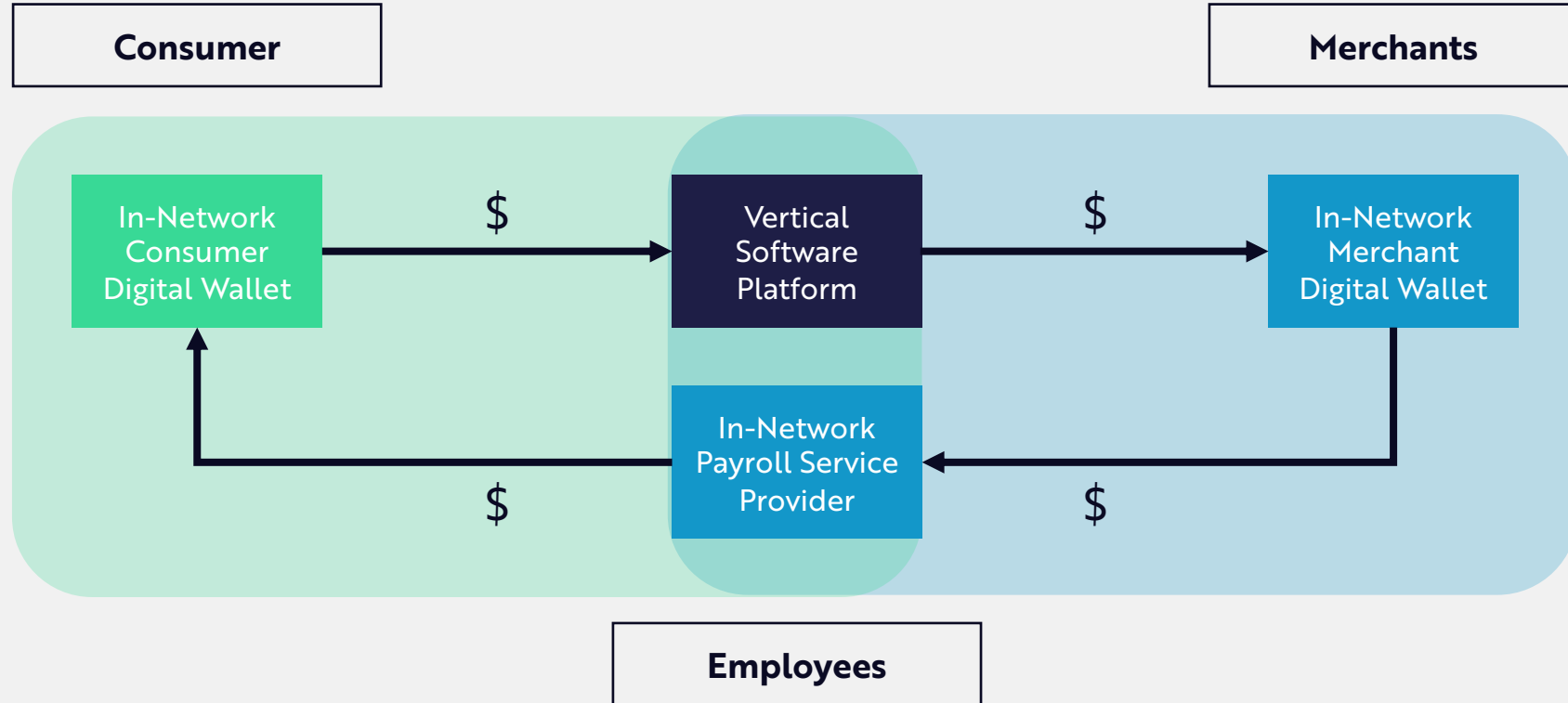
Digital Wallets Are Likely To Disintermediate Consumer-To-Business (C2B) Payment Ecosystems

Transactions funded with digital wallet balances bypass banks and card networks, saving interchange fees for payment facilitators, merchants, and consumers. In ARK's view, vertical software platforms with scaled consumer and merchant ecosystems will leverage digital wallets to facilitate closed-loop transactions.*

DIGITAL WALLETS

BEFORE: C2B Card Payment Authorization

Steps:
9

PSP Take Rate:
1.1%
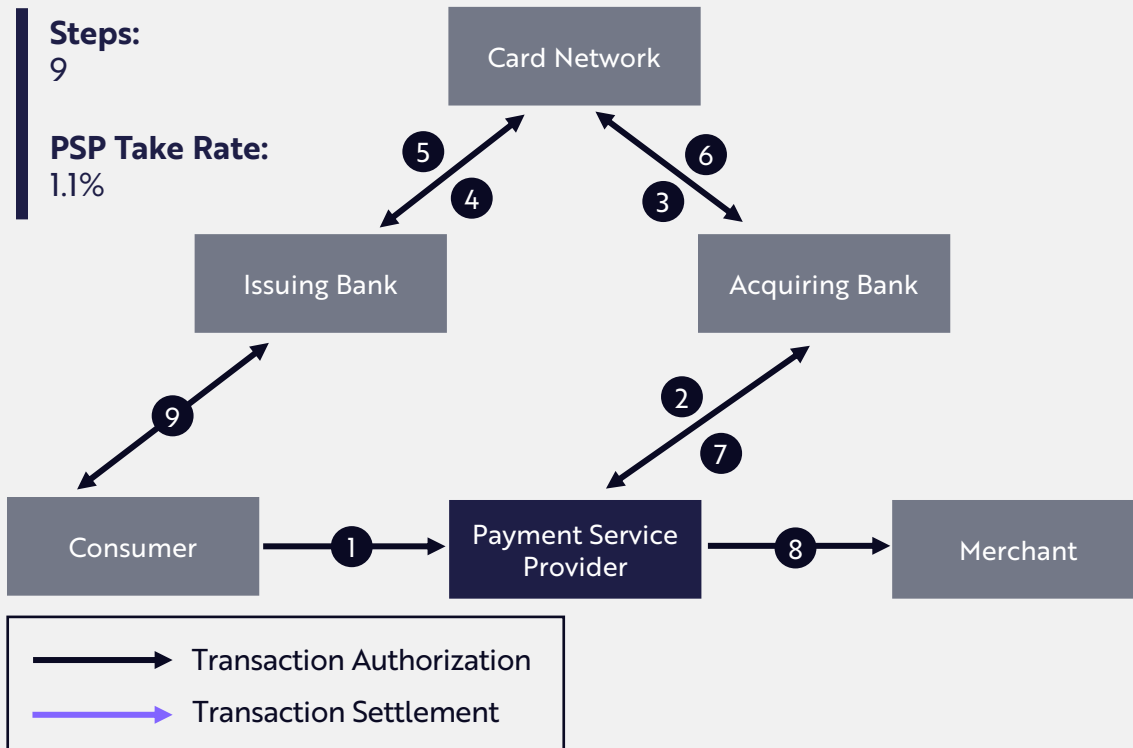
AFTER: C2B Closed-Loop Payment Authorization
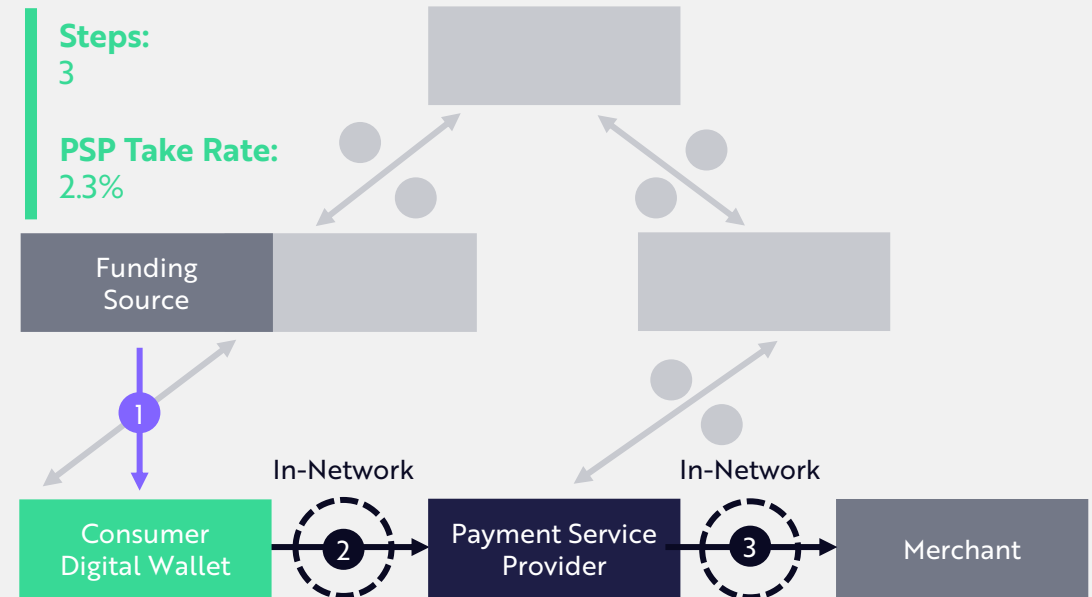
Steps:
3

PSP Take Rate:
2.3%

→ Transaction Authorization
→ Transaction Settlement

DIGITAL WALLETS

Closed-Loop Payment Volume In The US Could Increase 24-Fold By 2030

According to ARK's research, total C2B digital wallet payments should increase 20% at an annual rate during the next seven years, from ~$2 trillion in 2023 to ~$7 trillion in 2030. As a percent of the total, closed-loop payments should increase from ~4% to 25%, taking the payments revenue forecast for Block's Square, Shopify, and Toast from $3.5 billion to ~$21 billion, a 29% annualized rate of gain.**

US Digital Wallet Transaction Volume*

Legend: Open Loop, Closed Loop, % of PCE (RHS)

20% CAGR
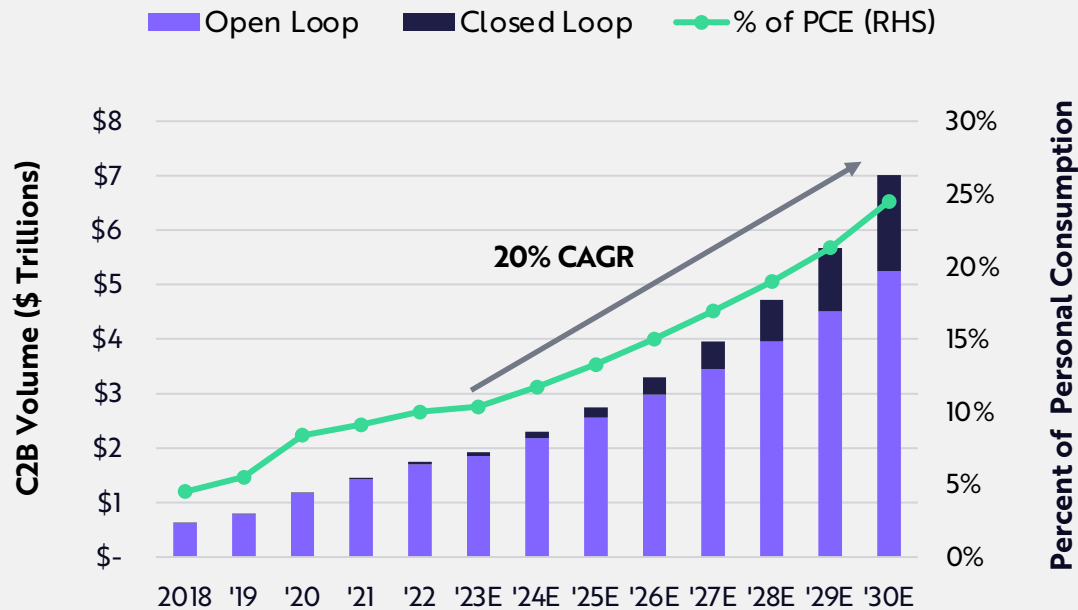
**US Payment Revenue
For Block's Square, Shopify, And Toast**

Legend: Net Payment Revenue, Closed Loop Payment Revenue Opportunity

29% CAGR

*We define closed-loop transactions as any consumer-to-buyer (C2B) digital wallet transaction that does not involve third-party issuers or card networks except for digital wallet balance top-ups. **Closed-loop payment revenue is represented on a gross basis and will be shared between the software platforms and all enabling market participants such as other fintechs or sponsoring financial institutions. We primarily model Block's historical revenue and future revenue opportunity across its Square merchant ecosystem and do not incorporate Cash App or Afterpay revenues independent of Square. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, including Worldpay 2019, 2020, 2021, 2022, 2023, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
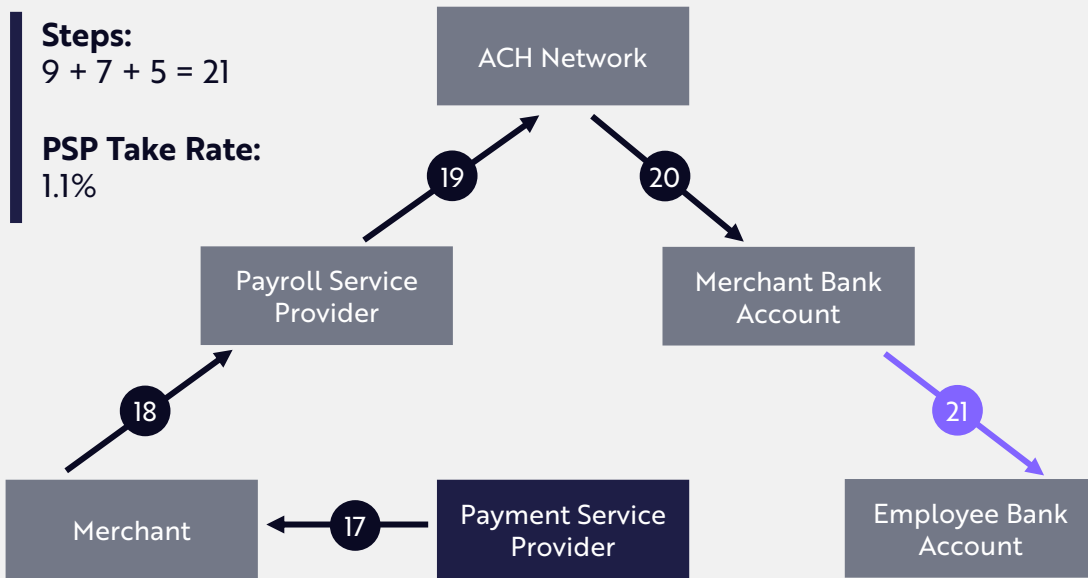
Digital Wallets Could Disintermediate Merchant Banking

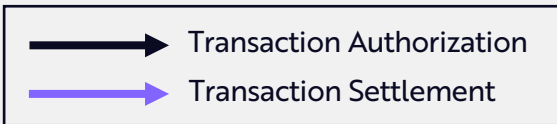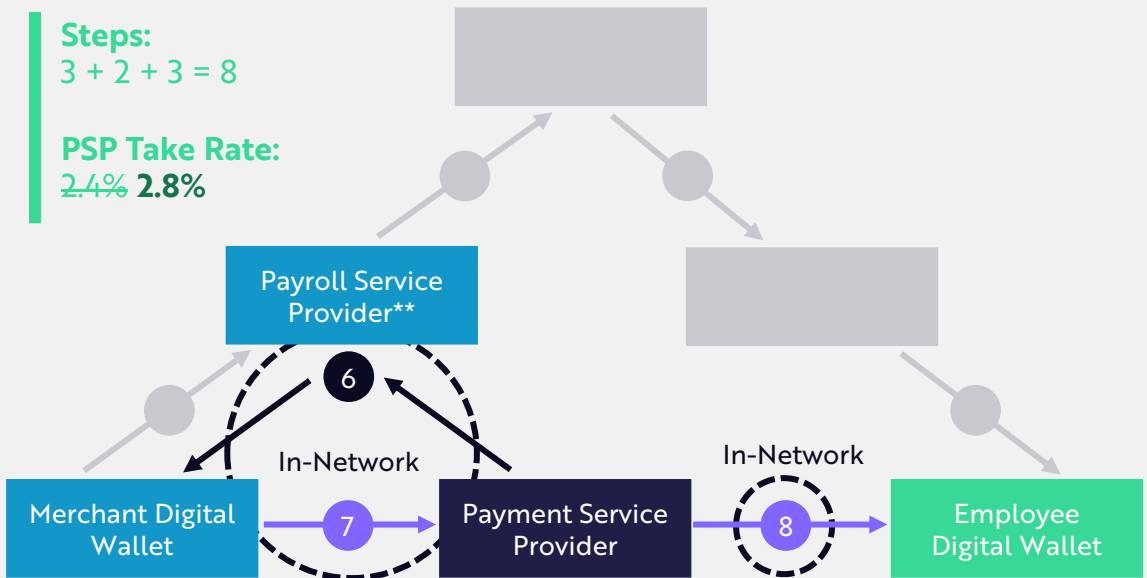Vertical software platforms can serve merchants with financial services. With digital wallets, these platforms not only enhance convenience but also monetize deposits, reducing the number of steps from payment authorization to merchant settlement from 16 to 5 and more than doubling the platform take rate.*

DIGITAL WALLETS

BEFORE: Status Quo Merchant Settlement
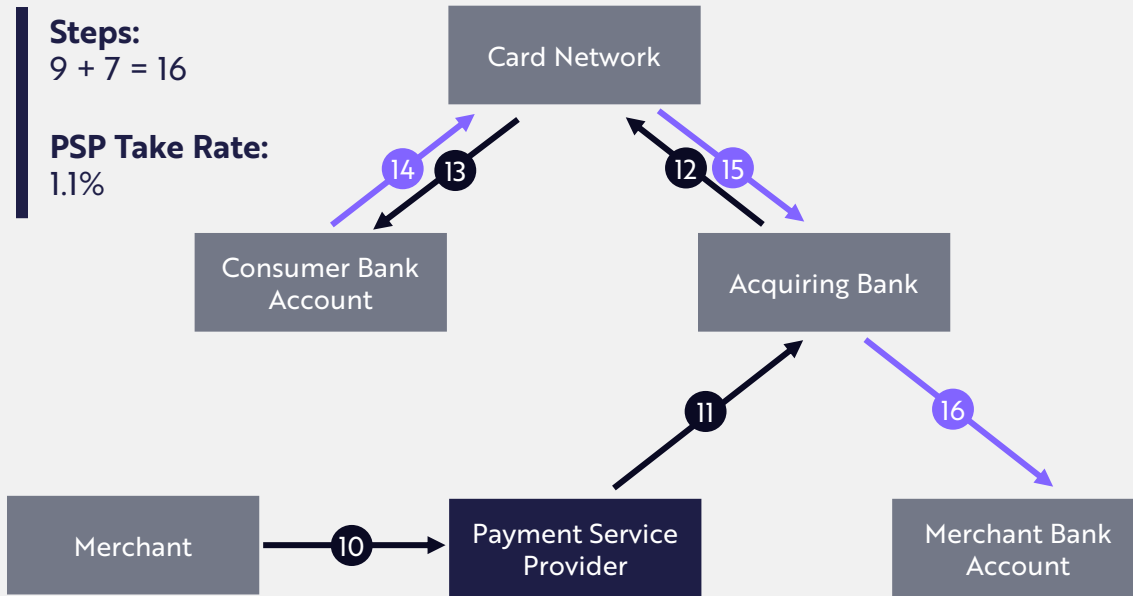
AFTER: Closed-Loop Merchant Settlement

Steps:
9 + 7 = 16

PSP Take Rate:
1.1%

Card Network

Consumer Bank Account

Acquiring Bank

Merchant

Payment Service Provider

Merchant Bank Account

10 11 12 13 14 15 16

Steps:
3 + 2 = 5

PSP Take Rate:
~~2.3%~~ **2.4%**

Consumer Digital Wallet

In-Network

Merchant Digital Wallet

Payment Service Provider

4 5

→ Transaction Authorization
→ Transaction Settlement

DIGITAL WALLETS

Merchant Digital Wallet Revenue Could Double By 2030

If net deposit yields were to equal those of large commercial banks, the merchant banking revenue associated with Block's Square, Shopify, and Toast could scale 40% at an annual rate during the next seven years, from $700 million in 2023 to $7 billion in 2030. At $7 billion, the three platforms would 5x their share of total commercial payments revenue in the US from ~0.3% today to ~1.6% in 2030.

Addressable US Merchant Banking Revenue
For Block's Square, Shopify, And Toast*

■ Merchant Lending   ▢ Incremental Banking Revenue
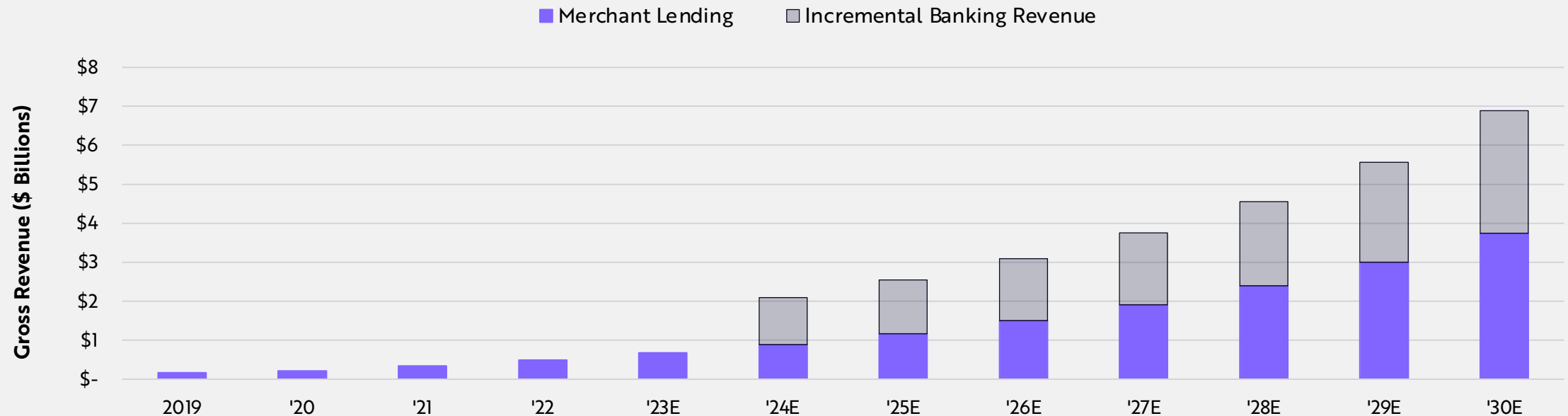
*Our incremental banking revenue forecast intends to capture both net interest income and noninterest revenue associated with merchant deposits and lending that are not already included in our forecast for Block, Shopify, and Toast's working capital financing business. Both line items are represented on a gross basis and will be shared between the software platforms and all enabling market participants such as other fintechs or sponsoring financial institutions. This forecast does not directly include revenue from instant transfers, corporate card issuance and spend management, or bill pay. We primarily model Block's historical revenue and future revenue opportunity across its Square merchant ecosystem and do not incorporate Cash App or Afterpay revenues independent of Square. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, including McKinsey & Company 2018, 2019, 2020, 2021, 2022, 2023, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Digital Wallets Could Disintermediate The Payroll Banking Opportunity

Vertical software platforms probably will use digital wallets to link merchants directly to employees, adding monetization opportunities with little to no cost of customer acquisition.*

DIGITAL WALLETS

BEFORE: Status Quo Payroll

AFTER: Closed-Loop Payroll

Steps:
9 + 7 + 5 = 21

PSP Take Rate:
1.1%

ACH Network

Payroll Service Provider

Merchant Bank Account

Merchant

Payment Service Provider

Employee Bank Account

Steps:
3 + 2 + 3 = 8

PSP Take Rate:
2.4% **2.8%**

Payroll Service Provider**

In-Network

Merchant Digital Wallet

Payment Service Provider

In-Network

Employee Digital Wallet

Transaction Authorization
Transaction Settlement

Employee Digital Wallets Represent A Potential $25 Billion Revenue Opportunity

Like their consumer counterparts, employee digital wallets could evolve into full-scale financial apps customized for specific industries. Employee payroll and payments could become compelling monetization streams for Block, Shopify, and Toast. According to our research, employee digital wallets could generate $25 billion of gross revenue on the $1 trillion in addressable payroll opportunities in 2030.* If these platforms were to capture 100% of this opportunity, employee digital wallet revenue could grow 123% at an annual rate during the next seven years.

US Employee Digital Wallet Revenue Opportunity For Block, Shopify, And Toast**

☐ Payroll Software Revenue   ☐ Employee Debit Revenue   ☐ Employee Credit Revenue

123% CAGR

~$100M

$15B
$6B
$5B

2023E   2030E

Gross Revenue ($ Billions)

$30
$25
$20
$15
$10
$5
$-
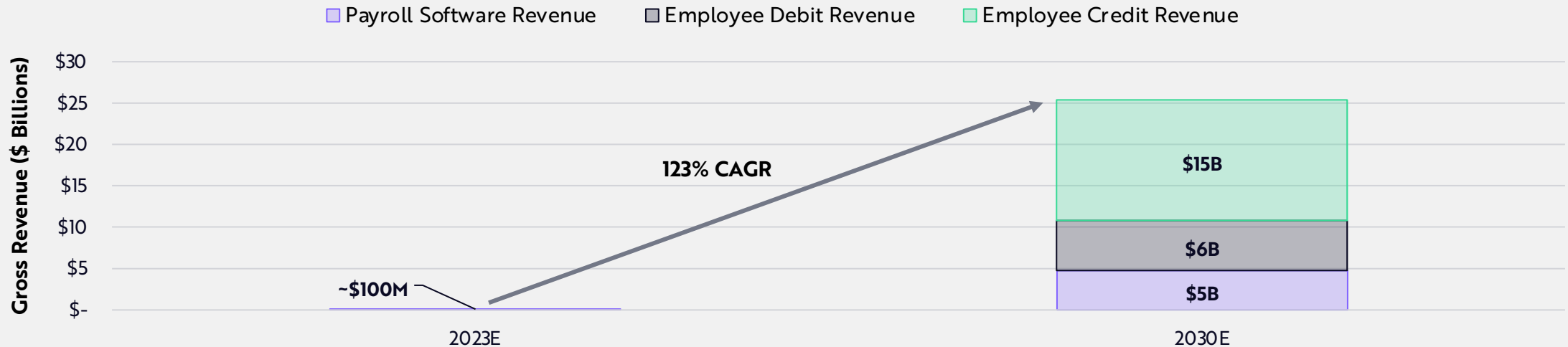
*Our forecasted ~$1 trillion in annual payroll aggregates our forecasts for Block, Shopify, and Toast's merchant base, employee base, and average payroll across addressable verticals such as retail, accommodations and food services, other consumer services, professional services, and other consumer entertainment. **All revenue is represented on a gross basis and will be shared between the software platforms and all enabling market participants such as other fintechs or sponsoring financial institutions. Payroll software revenue does not include float revenue, and we do not adjust for duplicate employee debit and credit revenues that may already be embedded in consumer payment revenue. We primarily model Block's historical revenue and future revenue opportunity across its Square merchant ecosystem and do not incorporate Cash App or Afterpay revenues independent of Square. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

DIGITAL WALLETS

Digital Wallets Could Generate $23 Billion In Vertical Software Revenue

According to ARK's research, the core revenue of Block's Square, Shopify, and Toast should increase 22% at an annual rate during the next seven years, from $7 billion in 2023 to $27 billion in 2030. Closed loop consumer payments, merchant banking, and employee payroll/payments could generate an additional $23 billion, accelerating revenue growth from 22% to 33% at an annual rate by 2030.

US Revenue Opportunities For Block's Square, Shopify, And Toast*

■ Core Revenues ☐ Closed Loop Payments ☐ Merchant Banking ☐ Payroll Software ☐ Employee Payments

33% CAGR
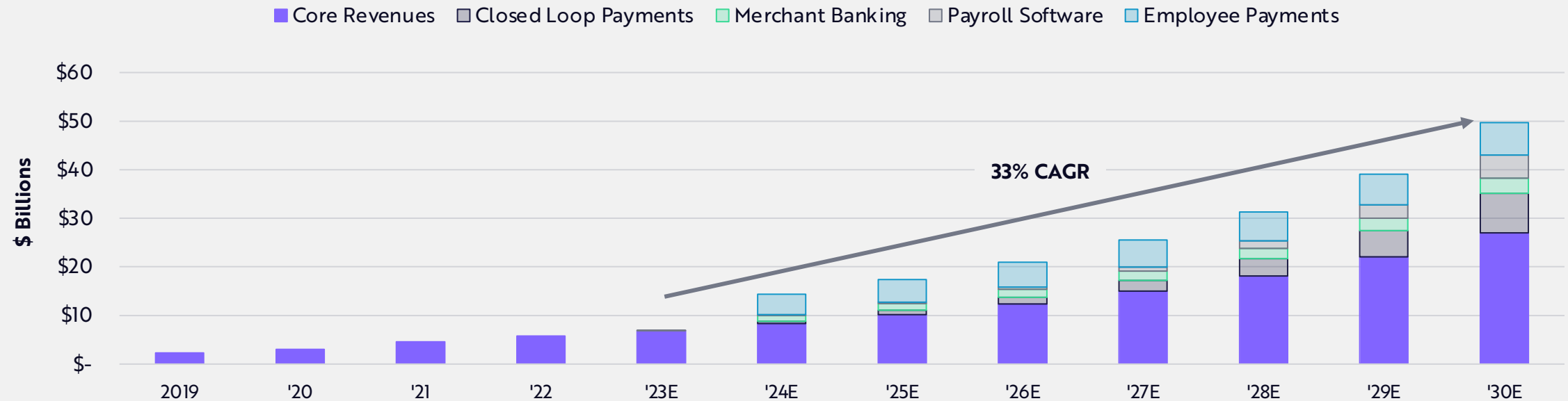
*Core revenues include software revenue, net open-loop payment revenue, merchant lending revenue, and revenue attributable to all other extant business lines. Merchant banking revenue includes both net interest income and noninterest revenue attributable to merchant deposits and lending not already captured by our forecast for Block, Shopify, and Toast's working capital financing business. All revenue segments excluding net open-loop payment revenue, closed-loop payment revenue, and employee payment revenue are represented on a gross basis, and all revenue will be shared between the software platforms and all enabling market participants such as other fintechs or sponsoring financial institutions. We use our status quo forecasts the software platforms' net take rates to estimate net employee payment revenue and do not explicitly estimate incremental cost synergies from employee closed-loop payments. We view all revenue segments except for core revenues not as explicit forecasts but as addressable opportunities in the US for Block's Square, Shopify, and Toast. We primarily model Block's historical revenue and future revenue opportunity across its Square merchant ecosystem and do not incorporate Cash App or Afterpay revenues independent of Square. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
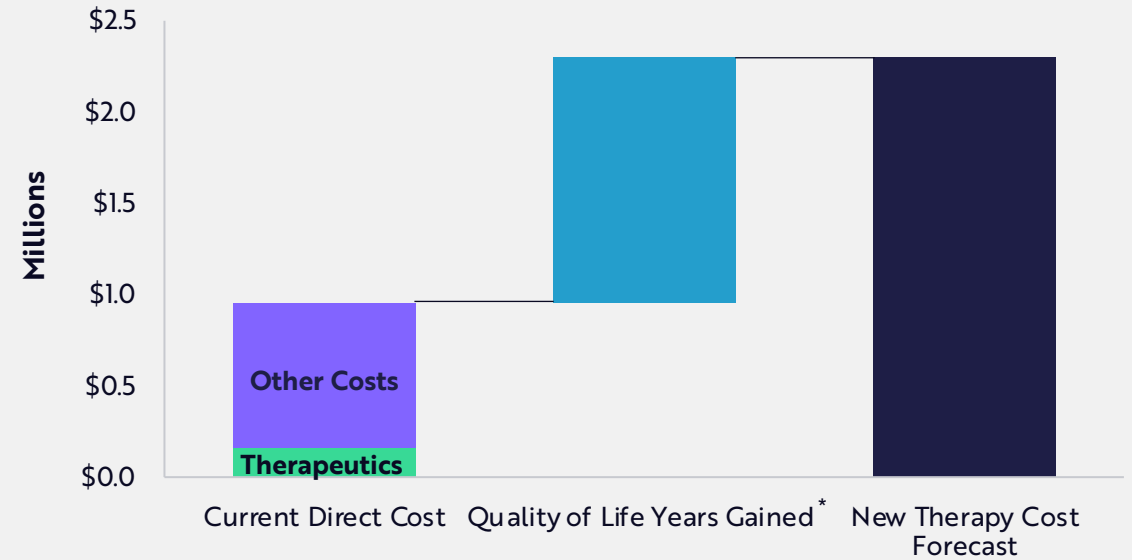
Research By:

Alexandra Urman
Analyst

Pierce Jamieson
Analyst

Rong Guo
Research Associate

BIG IDEAS 2024

Precision Therapies

Curing Disease More Efficiently And Less Expensively

During the past twenty years, new modalities for precision therapies, CRISPR gene editing, RNA therapeutics and targeted protein degradation have proliferated. Innovative therapies powered by artificial intelligence (AI), CRISPR gene editing, and new sequencing technologies have increased returns on research and development (R&D), while enabling undruggable targets to become druggable.

Increasingly, precision therapies are becoming multiomic and curative, with mechanisms of action spanning DNA, RNA, proteins, and more. Based on ARK's research, the enterprise value of companies focused on precision therapies could appreciate 28% at an annual rate during the next seven years, from ~$820 billion in 2023 to ~$4.5 trillion by 2030.

New Therapeutic Modalities Are Proliferating

During the last thirty years, the number of therapeutic modalities with entirely new mechanisms of action has proliferated. Not only have they expanded the number of treatable diseases, but they have also improved efficacy and safety. In 2023, more than 25% of clinical trials were harnessing new therapeutic modalities.

PRECISION THERAPIES

**Discovery of New Modalities Based On
Investigational New Drug Application Approval**

Base/Prime Editors*
TPDs
γδ T-cells
mRNA Vaccines
CRISPR/Cas9
iPSCs
TALENS
CAR-T
ZFNs
siRNA/RNAi
RNA Aptamers
ASOs

Antibiotics
Penicillin (1928)

Small Molecules
Aspirin (1899)

Proteins
Insulin (1921)

Small Peptides
Oxytocin (1953)

Antibody-Drug Conjugates
Monoclonal Antibodies
TILs
Prodrugs

1900   1920   1940   1960   1980   2000   2020

*This timeline is not exhaustive.

Watson & Crick (1953)

Recombinant DNA (1972)

Sanger Sequencing (1977)

Polymerase Chain Reaction (1982)

Sequencing by Synthesis (1996)

Single Molecule Real Time Sequencing (2011)

Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of external sources, including Biomedtracker, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Precision Therapies Could Reverse The Downtrend In Returns On Research And Development (R&D)

Given regulatory bottlenecks and legacy drug discovery methods, the return on therapeutic R&D has been falling for nearly 25 years. According to our research, novel therapeutic modalities and R&D methods, coupled with regulatory approval of "precision" therapies, could reverse the downward trend in return on investment in the pharmaceutical industry.

Average Annual R&D And Incremental Revenue Attributable To Drugs Released

■ R&D Devoted to Drugs Released   ■ Incremental Revenue Yield
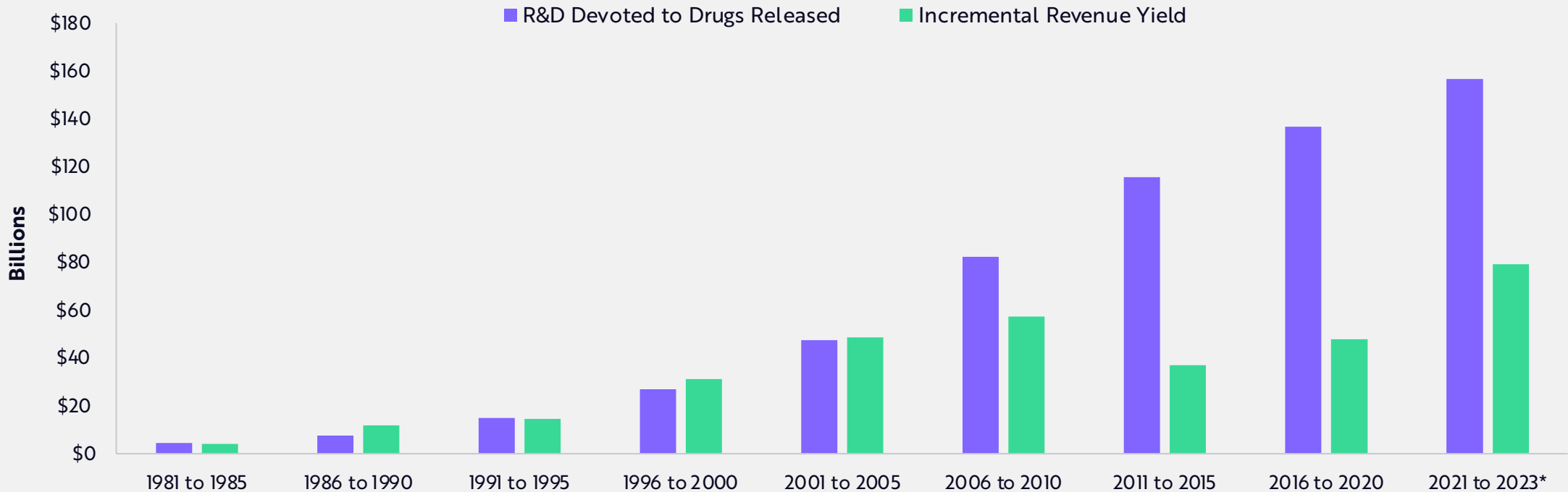
*Shorter time frame. Data impacted due to COVID.

Precision Therapies Could Reverse The Downtrend In Returns On R&D

Given regulatory bottlenecks and legacy drug discovery methods, returns on therapeutic R&D declined on balance for ~35 years through 2020. Regulations permitting novel therapeutic modalities and R&D methods enabling "precision" therapies could reverse the downtrend during the next five to ten years.

PRECISION THERAPIES

Ratio Of Incremental Revenue To Related R&D Spend

Precision Therapies Are Helping Treat Diseases That Were Previously Undruggable

Precision therapies, including RNA-based medicines and "targeted protein degraders" (TPDs), are expanding not only the number of druggable proteins in the human genome, but also the number of treatable tissue types.

TPDs Are Expanding The Druggable Proteome

Legend: ■ FDA Approved ■ Druggable ■ Undruggable

Y-axis: % of Human Protein-Coding Genes

Conventional: 79% (Undruggable), 17% (Druggable), 4% (FDA Approved)
TPD-Enabled: 44% (Undruggable), 56% (Druggable)

Precision Therapies Are Reducing The Number Of Duplicative Trials

Y-axis: Duplicative Trials per Unique Target

General vs Precision: -77%
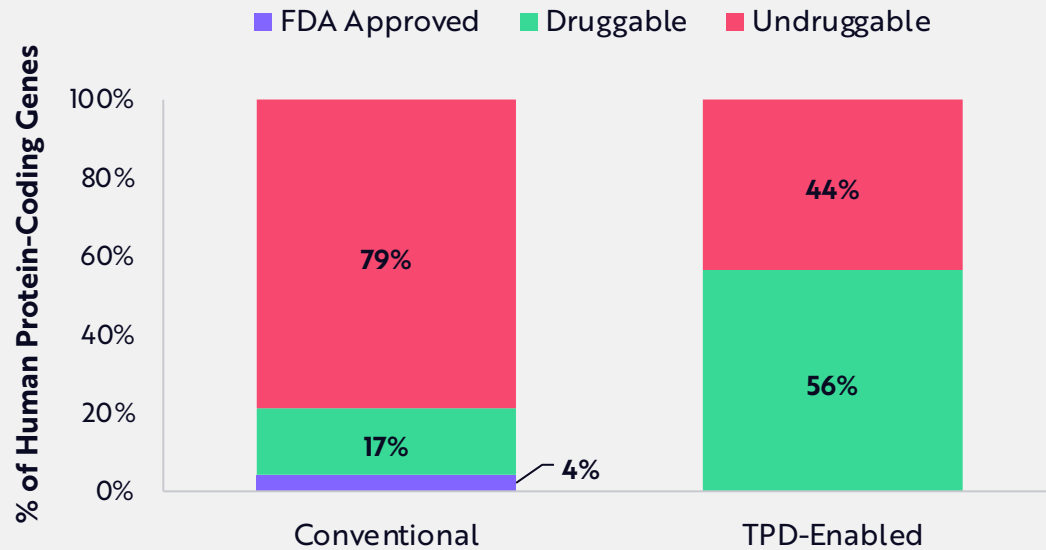
The human genome contains ~20,000 protein-coding genes, of which only 864 (4.3%) are associated with drugs that the FDA has approved. Human Protein Atlas estimates that 79% (~15,800) of human proteins are undruggable. Our research indicates that TPDs and adjacent technologies could treat 56% (~11,200) of human protein-coding genes.

Advanced precision therapy trials are testing a wider variety of biological targets than was possible with status quo treatments, lowering the number of duplicative trials by 77%. As a result, scientists are testing more biological targets per dollar of R&D, increasing the probability of identifying unique and successful therapies.

The Value Of Curing Rare Diseases Like Sickle Cell Anemia Is High

Among precision therapies, gene editing medicines like CRISPR-Cas9 have the potential to cure rare genetic diseases such as Sickle Cell Disease (SCD). SCD is an inherited red blood cell disorder that affects more than 100,000 people in the US and 20 million people globally, primarily in Africa. Today, therapeutics account for ~16% of the total spent on treating SCD disease in the US, but they have done little more than manage symptoms, as the life expectancy of SCD patients is only 56% that of the general population.

SCD Healthcare Costs Over Average Patient Lifetime
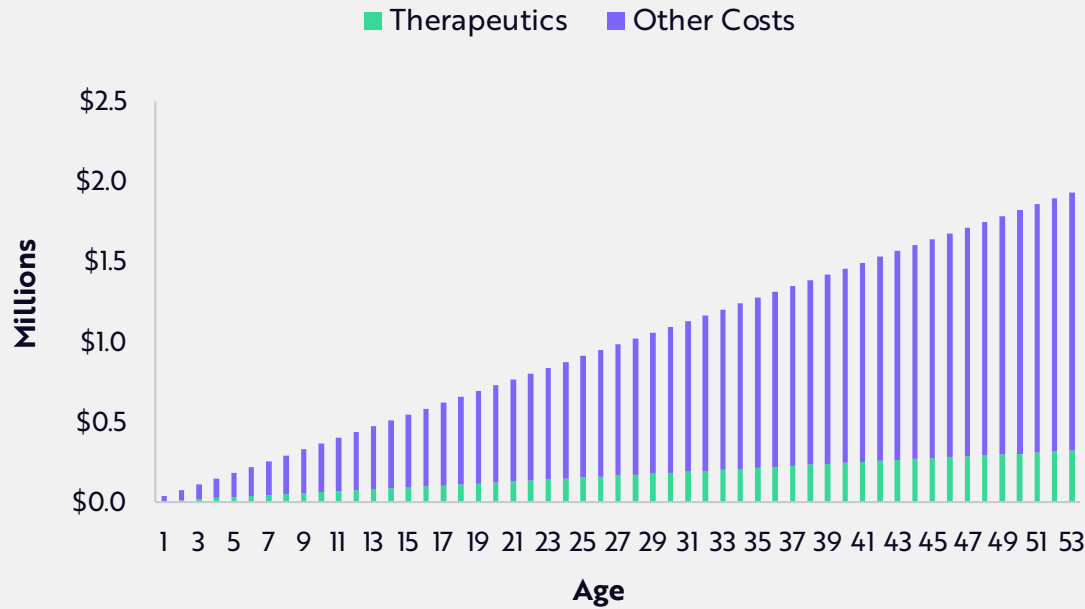
Reasonable Cost For Sickle Cell Disease Cure

*Quality of Life Years Gained = Health Utility * Duration
For Health Utility, 0 means dead and 1 means full health

Curing All Rare Diseases Would Be Valuable

The US healthcare system spends approximately $450 billion per year on the treatment of rare diseases. To manage patients with rare diseases throughout their lifetimes, the cost could mount to $20 trillion, of which less than half would be for medication. Theoretically, curing all rare diseases would shift most of the costs to medication, obviating the need for in- and out-patient disease management, underscoring the value of a cure.

Aggregate US Rare Disease Healthcare Costs

■ Medication Costs ■ Other Costs
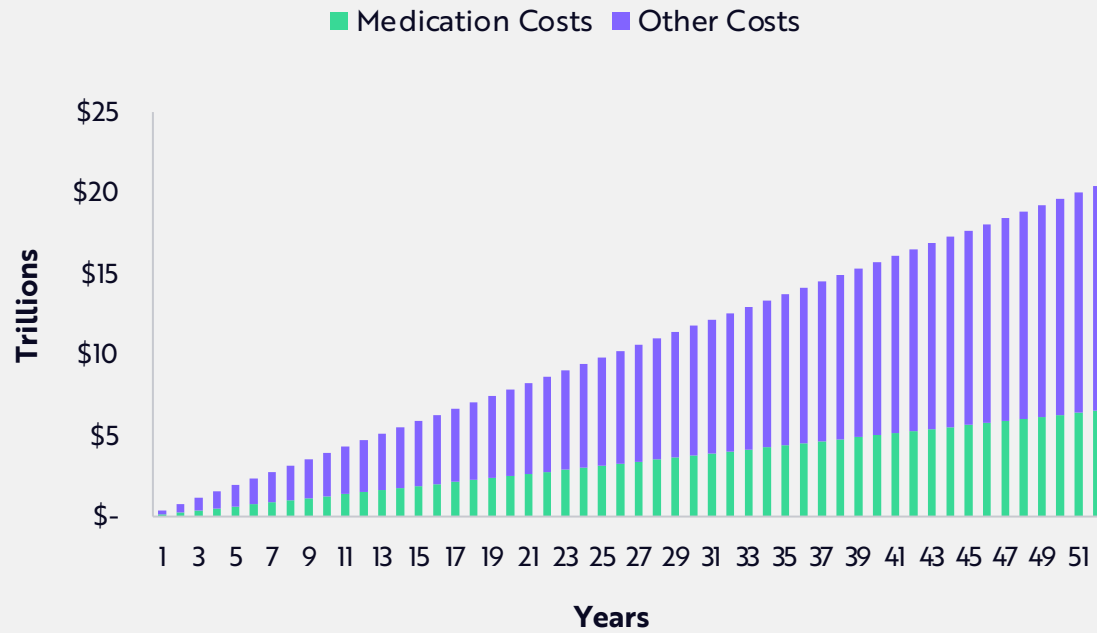
Forecasted Value of Rare Disease Cures To Healthcare System Over 50 Years
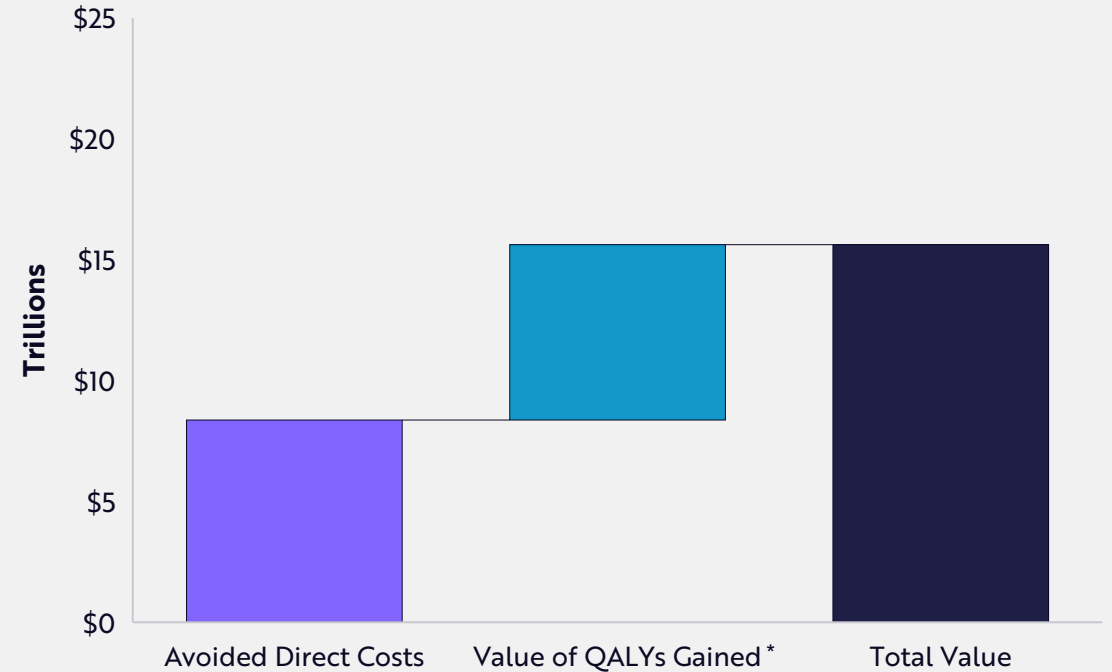
*Quality of Life Years Gained = Health Utility * Duration
For Health Utility, 0 means dead and 1 means full health

Data are as of December of 2023
Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of external sources, including Orphanet 2023, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Sizing the Opportunity: Precision Therapies

Based on our research, as technologies like CRISPR gene editing, sequencing, and artificial intelligence (AI) create precision therapies, the enterprise value of precision therapy companies should appreciate at a ~28% compound annual growth rate (CAGR) during the next seven years, from ~$820 billion in 2023 to ~$4 trillion by 2030.

Precision Therapy Enterprise Value Should Appreciate 28% Annual Rate Through 2030
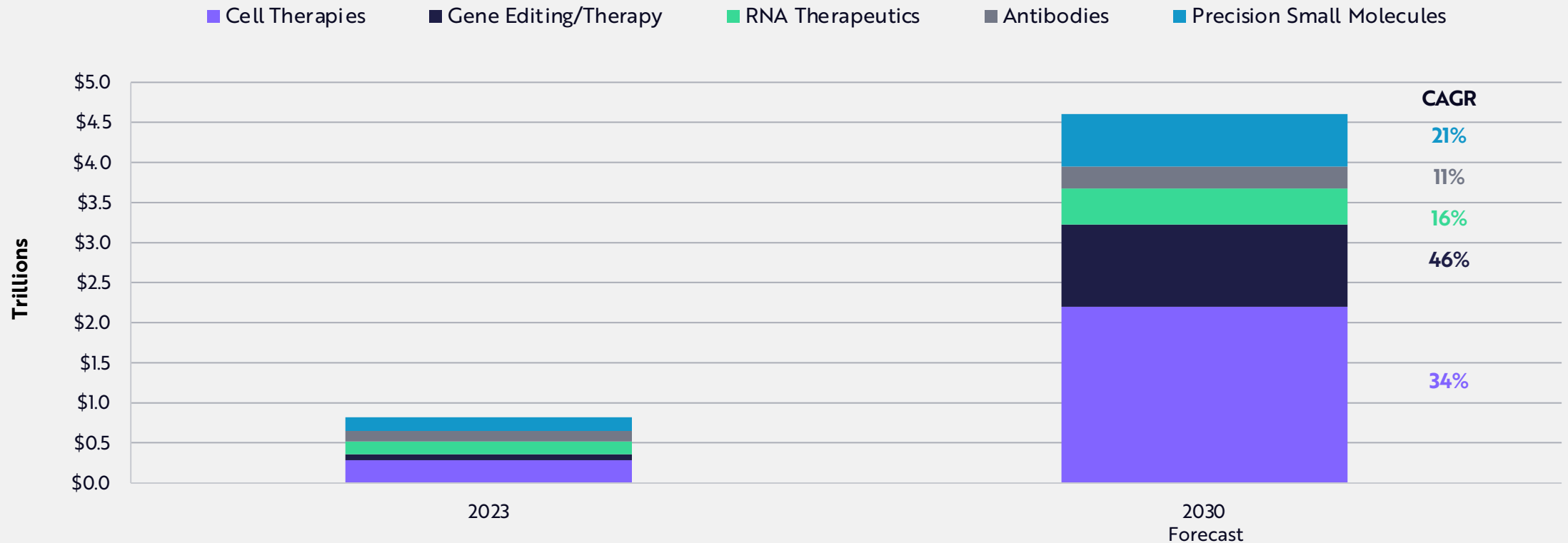
Legend: Cell Therapies · Gene Editing/Therapy · RNA Therapeutics · Antibodies · Precision Small Molecules

CAGR:
- 21%
- 11%
- 16%
- 46%
- 34%

Research By:

Pierce Jamieson
Analyst

Nemo Marjanovic
Research Associate

BIG IDEAS 2024

Multiomic Tools And Technology

Translating Biological Insights Into
Better Healthcare And Economic Value

Over the past decade, the number of biological tools and techniques has proliferated, their capability having improved remarkably. Among others, three enabling technologies stand out: high-throughput proteomics, artificial intelligence, and single-cell sequencing. Their convergence is increasing productivity and efficiency, enhancing precision in healthcare applications, and unlocking substantial economic value.

According to ARK's research, these technologies could reduce research and development (R&D) spending per drug by more than 25%, potentially increasing the enterprise value of the precision therapy space 26% at a compound annual rate during the next seven years, from ~$820 billion in 2023 to ~$4.5 trillion in 2030.

Proteomic Throughput And Depth Are Improving Exponentially

Advances in mass spectrometry and bioinformatics have improved proteomic analysis dramatically over the past decade, increasing resolution, accuracy, and the capacity to analyze multiple samples simultaneously. Not only have these developments enabled detailed exploration of the proteome in health and disease, but they also have accelerated the discovery of cancer biomarkers and the development of targeted therapies.

MULTIOMIC TOOLS AND TECHNOLOGY
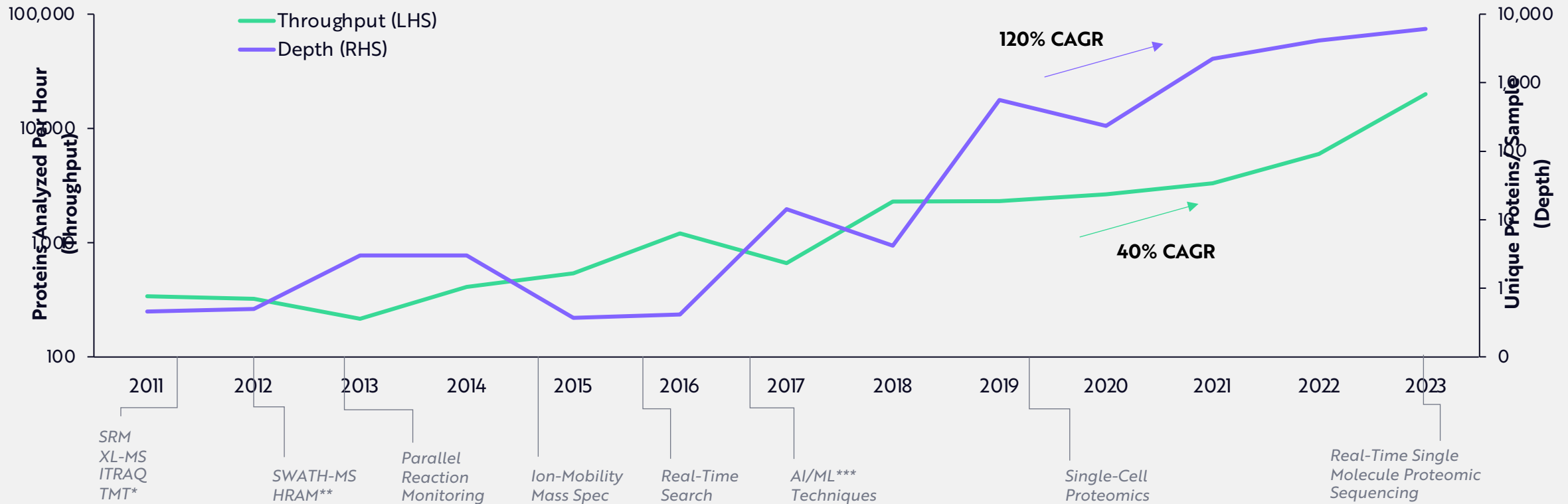
*SRM: Single reaction monitoring; XL-MS: cross-linking mass-spectrometry; ITRAQ: isobaric tagging; TMT: tandem mass spectrometry. **SWATH-MS: sequential window acquisition of all theoretical fragment ion spectra mass spectrometry. ***AI/ML: Artificial Intelligence/Machine Learning. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of external sources, including Peters-Clarke et al. 2023, and Zhang and Cui 2022, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Wright's Law* Has Predicted The Cost Decline Of Proteomics

As the number of proteomes analyzed by mass spectrometry has increased, costs have dropped dramatically, unlocking new possibilities in medical research and diagnostics. Our research suggests that for untargeted proteomics using mass spectrometry, the cost per sample is declining 23% at an annual rate, or ~11% for each cumulative doubling in the number of proteomes sequenced. Proteomic discoveries are paving the way for the identification of novel biomarkers, enabling the earlier detection and treatment for unique cancer subtypes.

MULTIOMIC TOOLS AND TECHNOLOGY

Wright's Law Has Predicted The Cost Decline For Untargeted Proteomics
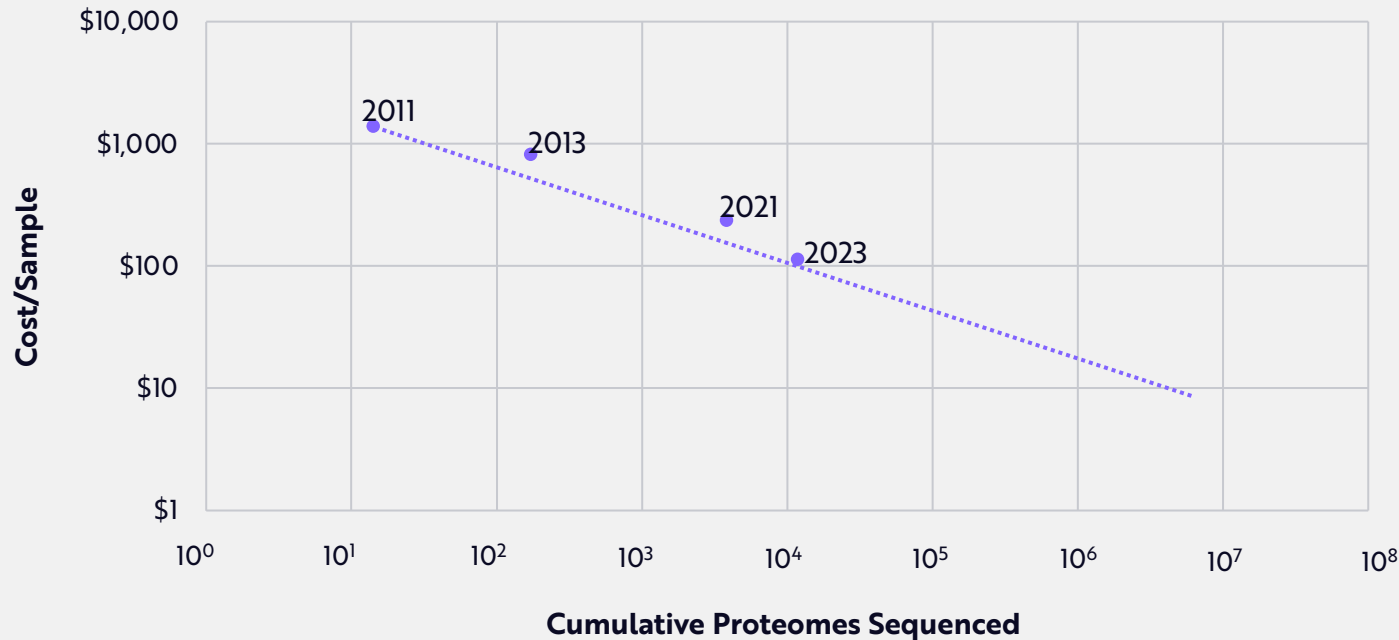
US Trials With Patient Biomarkers
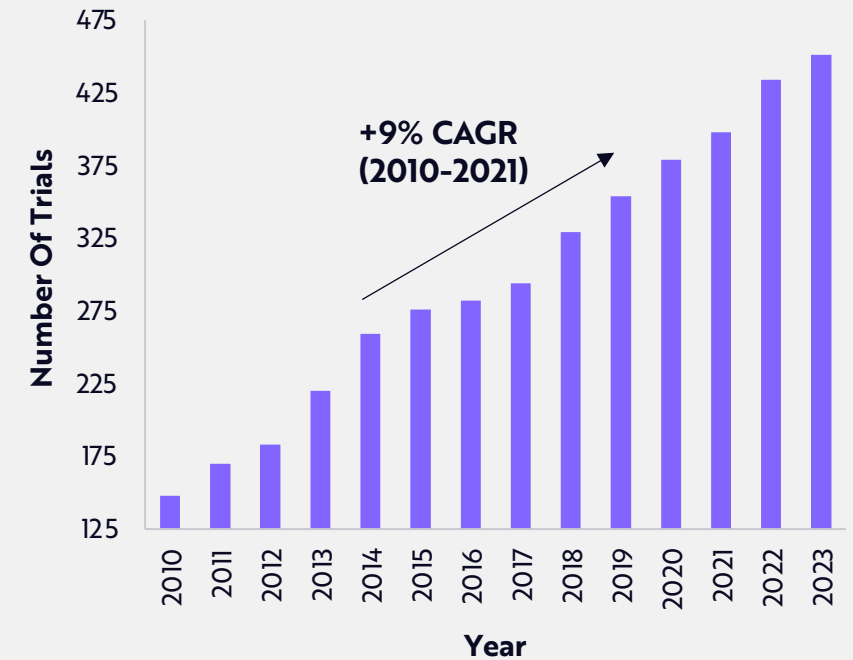
Wright's Law states that for every cumulative doubling of units produced, costs will fall by a constant percentage. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
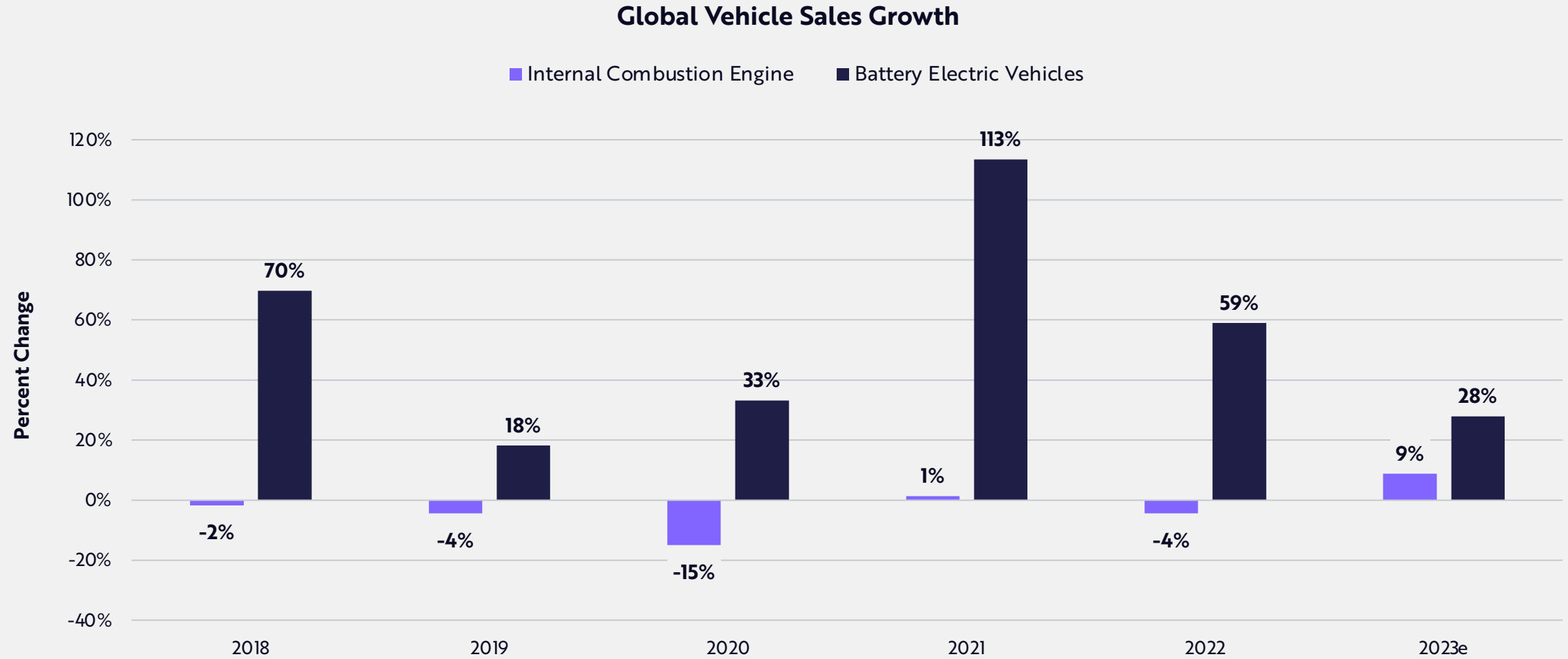
Single-Cell RNA Sequencing Is Revolutionizing Our Understanding Of Cancer

While traditional gene expression analysis using RNA-seq can measure only the expression of genes in a mixture of different cell types, single-cell RNA-seq (scRNA-Seq) can delineate the expression of different cell types in a complex tissue sample. Theoretically, linking gene expression to specific cells increases the accuracy of measuring by 10x and cuts costs per gigabyte by 76%.

MULTIOMIC TOOLS AND TECHNOLOGY

Cancerous Tissue

RNA Sample

Bulk RNA-Seq

Expression

Cancer   Normal

Gene 1
Gene 2
Gene 3
Gene 4

No expression changes are evident in cancerous tissue relative to normal cells.

Single-Cell RNA

Multiple Cell Types

Expression

Cancer   + -   + -   + -   + -
Cell Type 1   Cell Type 2   Cell Type 3   Cell Type 4

Cancerous mutations are causing overexpression of "Gene 4" in "Cell Type 3"

AI And Automation Are Empowering Drug Discovery

MULTIOMIC TOOLS AND TECHNOLOGY

The implementation of Artificial Intelligence/ Machine Learning (AI/ML) in the drug discovery process has increased the number of potential active compounds that drug developers can screen from virtual and physical libraries.

High-throughput automated workflows like drug microsynthesis and *in-vitro/in-vivo* assays are critical to leveraging AI-enabled drug discovery.

Within the next decade, companies implementing AI/ML drug discovery methods and automated workflows are likely to double their probability of clinical success from Phase 1 to approval. Earlier in the process, eliminating compounds and increasing productivity should cut the cost of a single drug approval in half.

Forecasted Reduction In Cost/Approval Attributable To AI/Automation
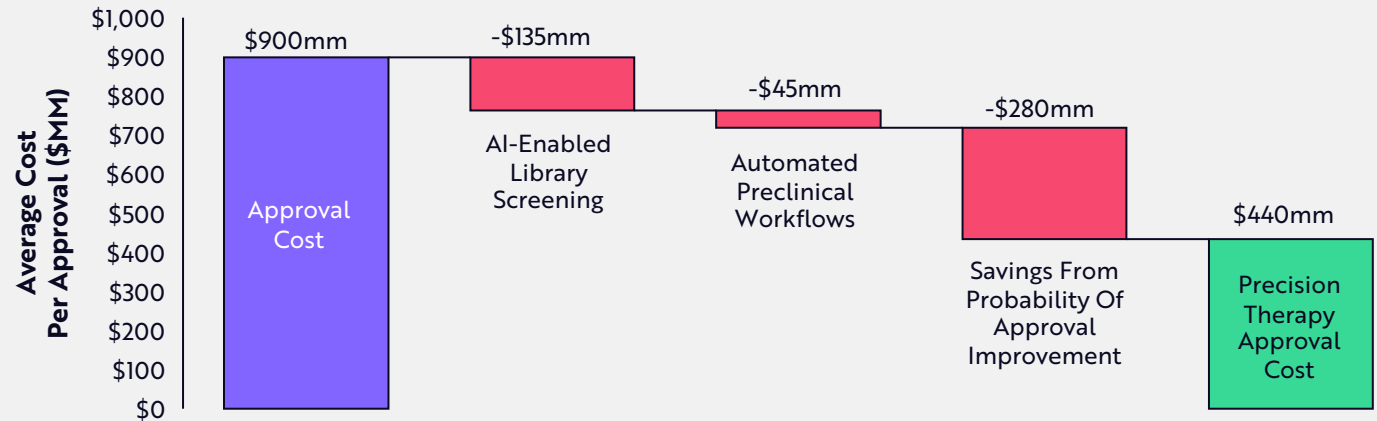
Forecasted Probability Of Clinical Success
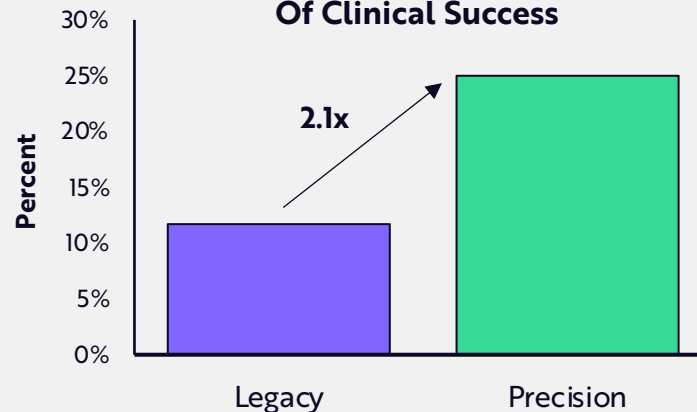
Forecasted Cost Per Approval
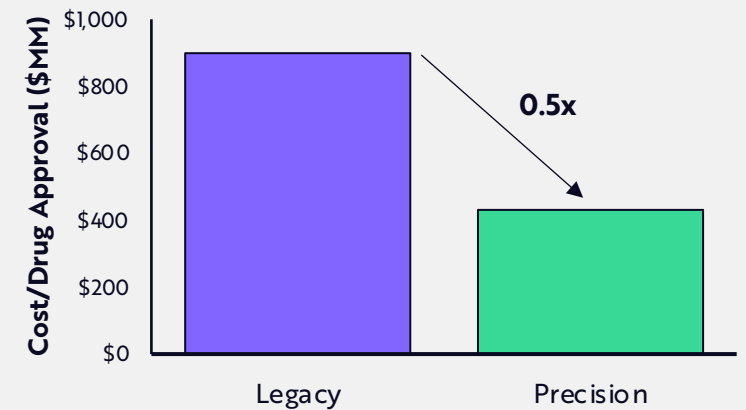
Drug Development Costs Could Drop Precipitously

Advances in fundamental biology, artificial intelligence, automation, and trial design should lower preclinical drug development costs significantly. They enable methods that eliminate less-promising candidates early in the drug development process, prevent downstream misallocation of R&D capital, and create a larger chemical search space early in the discovery phase. During the next decade, companies leveraging these techniques fully could lower costs per approval by almost 50%, in part by more than doubling the odds of success for those drug candidates that do enter clinical trials.

Efficiency Innovations

Innovative Trial Design
+ Adaptive Clinical Trial Design
+ Precision Biomarkers
+ Decentralized/Virtual Trials

Fundamental Biology
+ Single-Cell Biology
+ Proteomic Techniques
+ Virtual Compound Libraries
+ Biomarker Development
+ Humanized animal models

Automation
+ Automated Liquid Handling
+ Automated Invivomics
+ Automated Microsynthesis
+ CRISPR "Perturb-Seq" Screens
+ Organ-on-a-chip Technology

Artificial Intelligence
+ AI-Enabled Pathway Analysis
+ AI-Enabled Toxicity Prediction
+ In-Silico Molecular Modeling
+ ML-Driven Compound Screens

R&D Cost Per Drug Approval (Including Failures)

($ Millions)

-48%

Legacy — Precision
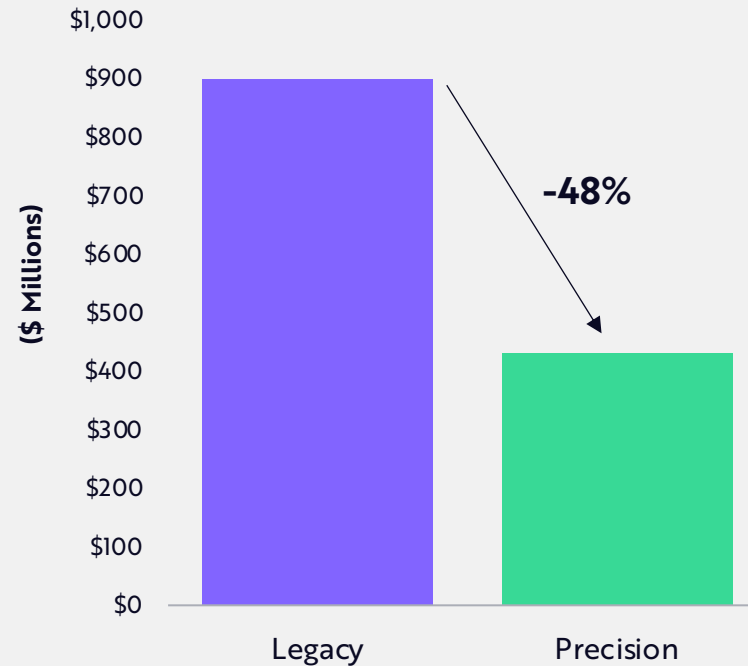
Clinical Success Probability
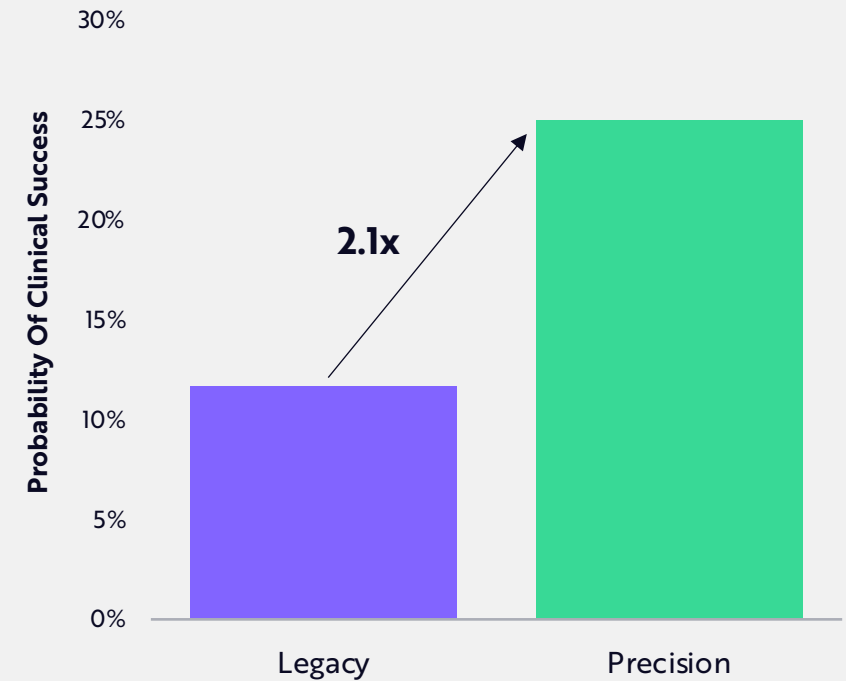
Probability Of Clinical Success

2.1x

Legacy — Precision

Technological Advances Should Lower R&D Costs For Each Drug

During the past decade, R&D spending per drug in development has declined by 3% at an annual rate. According to our research, this decline should continue, if not accelerate, thanks to groundbreaking advancements in fundamental biology, single-cell sequencing, proteomics, automation and artificial intelligence. Together, these efficiencies should contribute $1.5 trillion, or ~40%, to the increase in enterprise value for precision therapies by 2030.

MULTIOMIC TOOLS AND TECHNOLOGY

Projected Average Annual R&D Spending Per Drug In Development Pipeline
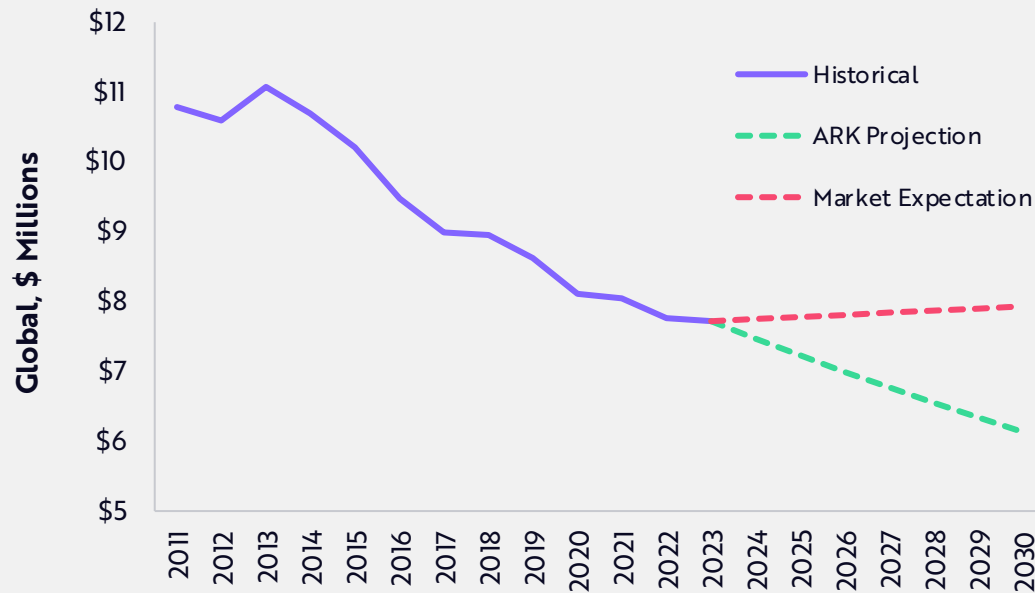
Precision Therapy Sales Could Grow 30% Annually Into 2030
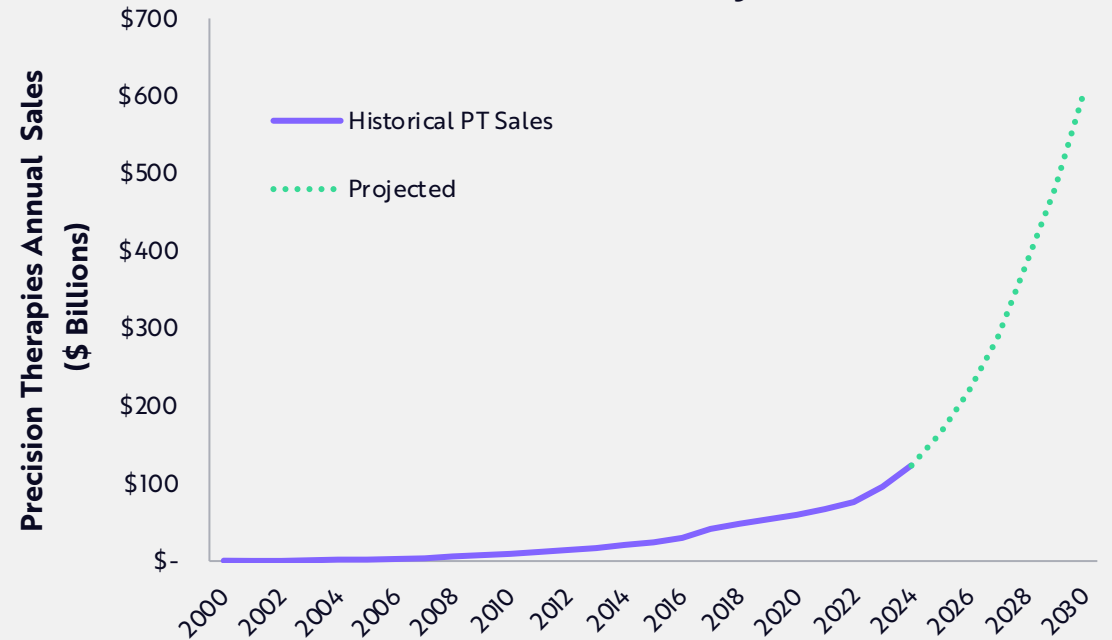
Research By:

Sam Korus
Director of Research,
Autonomous Technology
& Robotics

Daniel Maguire, ACA
Research Associate

Electric Vehicles

Lower Battery Costs
Powering EV Adoption

ELECTRIC VEHICLES

After increasing in response to supply chain disruptions, battery costs now are falling in line with Wright's Law, leading to lower electric vehicle (EV) sticker prices.

If robotaxi platforms proliferate, EVs could account for 95-100% of vehicle sales in 2030.

ARK forecasts that electric vehicle sales will scale 33% at an annual rate during the next seven years, from roughly 10 million in 2023 to 74 million in 2030.

Electric Vehicles Continue To Take Share From Internal Combustion Engine Vehicles

ELECTRIC VEHICLES

Global Vehicle Sales Growth

■ Internal Combustion Engine   ■ Battery Electric Vehicles

Percent Change

Year	ICE	BEV
2018	-2%	70%
2019	-4%	18%
2020	-15%	33%
2021	1%	113%
2022	-4%	59%
2023e	9%	28%

The Auto Industry Is Likely To Consolidate

If EV adoption continues to gain traction, traditional automakers may be forced to restructure and consolidate.

GM Delays EV Truck Production At Michigan Plant By Year

—Reuters Oct 17, 2023

VW Group Delays EV Battery Plant In Europe Amid "Sluggish" EV Demand

"There is for the time being no business rationale for deciding on further sites," Volkswagen Group CEO Oliver Blume said.

—InsideEVs Nov 2, 2023

Ford Will Cut Weekly Production Of F-150 Lightning In Response To Slowing Demand

—The Verge Dec 11, 2023

Global Battery Electric Vehicle Sales Market Share*

Bar chart showing Percent (y-axis) by year (x-axis) from 2013 to 2023e. Values rise from near 0% in 2013 to approximately 12% in 2023e.
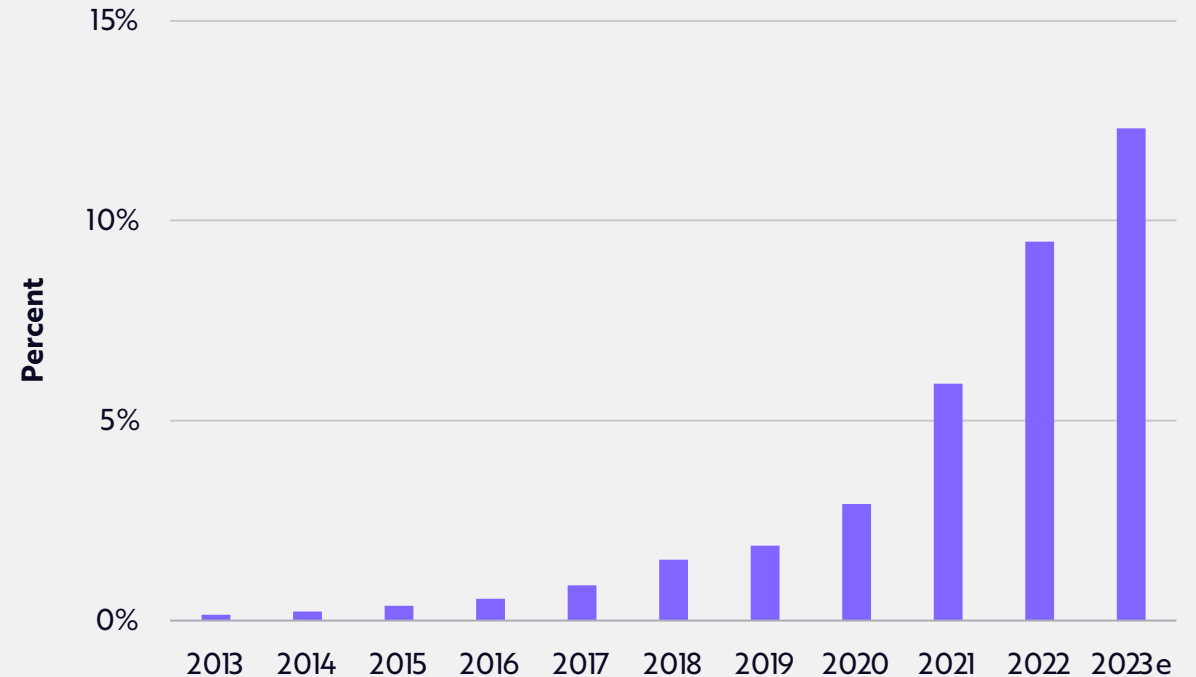
*BEV market share is calculated relative to all "light vehicles", which are vehicles with a maximum Gross Vehicle Weight Rating (GVWR) of < 8,500 lbs. Sources: ARK Investment Management LLC, 2024, based on data from EVVolumes.com 2023, Hawkins 2023, Mihalascu 2023, Shepardson & Klayman 2023, Rosevear 2023, Transport Policy 2023. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
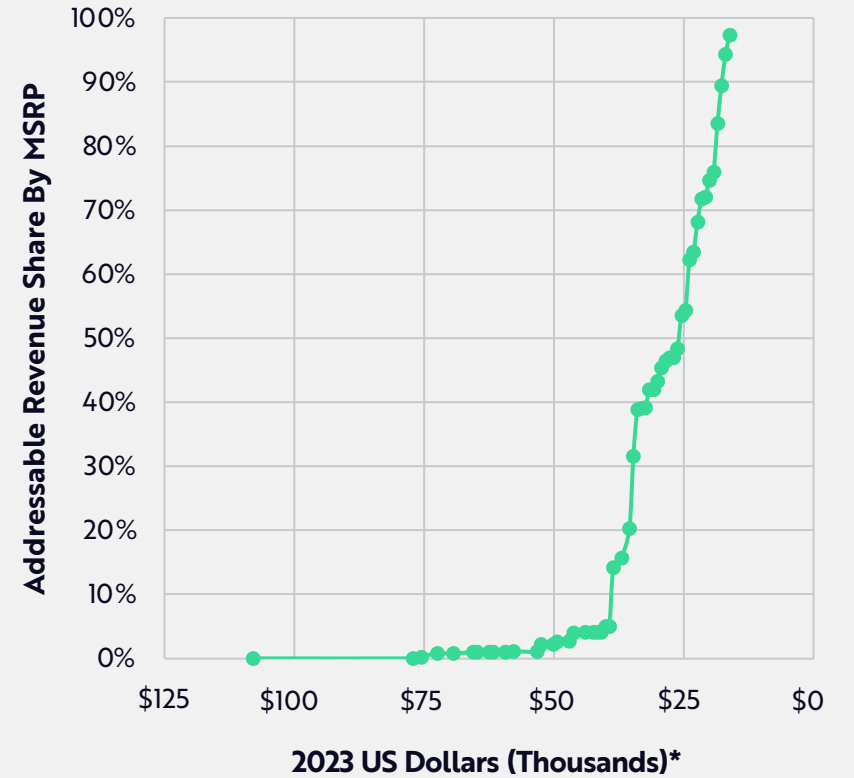
ELECTRIC VEHICLES

Wright's Law Has Modeled The Decline In Battery Costs Accurately

According to Wright's Law, for every cumulative doubling in the number of kWh produced, battery costs will fall by 28%. Lithium iron phosphate (LFP) cells are taking share from nickel-rich cells, illustrating the difficulty of forecasting commodity prices as battery chemistries change over time.

Battery Cost Decline

● Nickel Cells[*] ● Nickel Forecast ● LFP Cells[*] ● LFP Forecast

$/kWh

Cumulative kWh
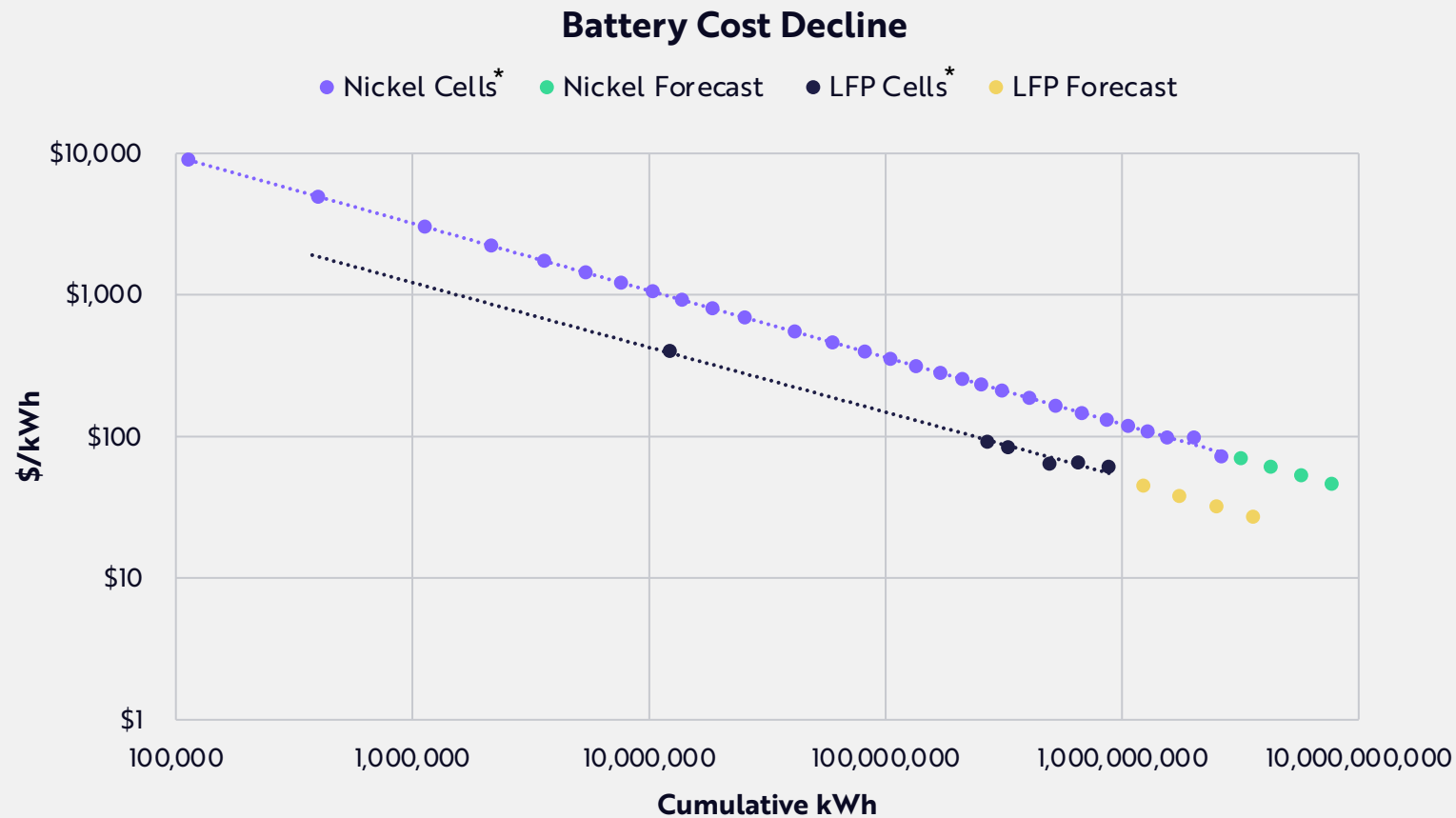
Global LFP Cathode Chemistry Share Of Passenger EV Sales
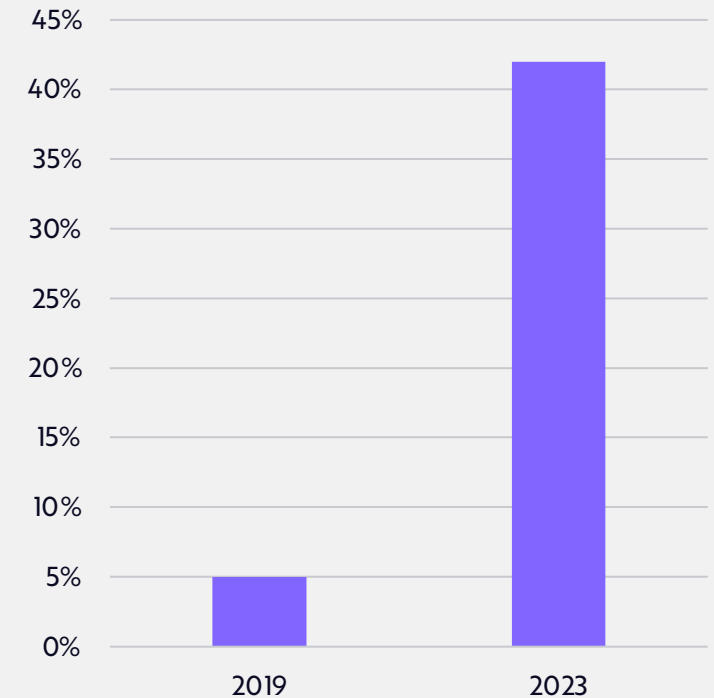
Wright's Law Points To Faster EV Charging Rates

The EV charging rate seems to be a good proxy for overall performance, including efficiency, range, and power. In the past five years, charging rates for 200 miles of range have improved nearly three-fold, from 40 minutes to 12, and could drop another three-fold to 4 minutes over the next five years. As EV charging reaches acceptable rates, manufacturers are likely to optimize for other features, including autonomous driving, safety, and entertainment.

EV Charging Rates For 200 Miles Of Range
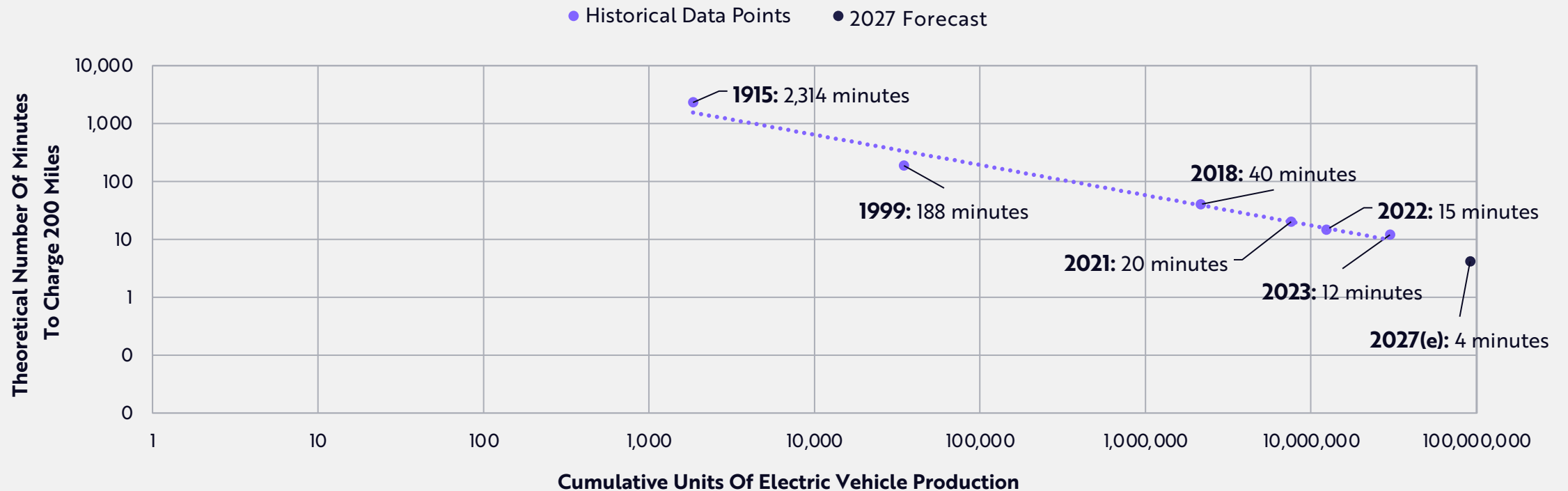
● Historical Data Points   ● 2027 Forecast

Y-axis: Theoretical Number Of Minutes To Charge 200 Miles (10,000; 1,000; 100; 10; 1; 0; 0; 0)

X-axis: Cumulative Units Of Electric Vehicle Production (1; 10; 100; 1,000; 10,000; 100,000; 1,000,000; 10,000,000; 100,000,000)

Data labels:
1915: 2,314 minutes
1999: 188 minutes
2018: 40 minutes
2021: 20 minutes
2022: 15 minutes
2023: 12 minutes
2027(e): 4 minutes

Many EV Manufacturers Are Struggling To Scale Profitably

In the absence of an EV supply chain, Tesla had little choice but to vertically integrate. Now that the supply chain is evolving, other auto manufacturers will reach profitability if they scale. Many are pulling back from the market, however, because the—already profitable—market leaders are cutting prices aggressively.

ELECTRIC VEHICLES

Global Luxury BEV Unit Sales At Various Price Points*
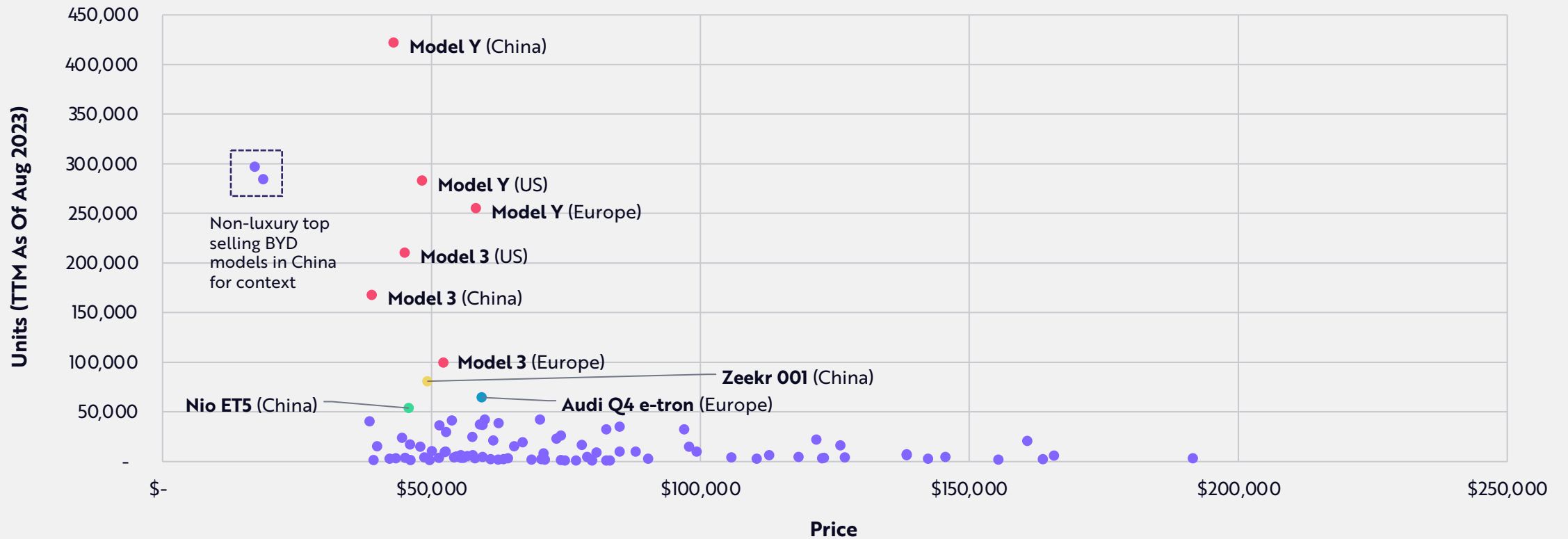
*Data may not be exhaustive. "TTM" (trailing twelve months). "BEV" (battery electric vehicle). Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, including Piper Sandler 2023, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

EVs Have Hit Price-Parity With Internal Combustion Engine Vehicles

As battery costs continue to decline, EV prices should fall, potentially driving exponential growth in unit sales.

ELECTRIC VEHICLES

US New Vehicle Transaction Price

- New-Vehicle Transaction Price Before Supply Chain Bottlenecks
- New-Vehicle Transaction Price (Average)
- ········ Linear (New-Vehicle Transaction Price Before Supply Chain Bottlenecks)

Luxury Car
Full-Size Pickup Truck
Luxury Compact SUV/Crossover
Electric Vehicle
Tesla Model Y
Tesla Model 3
Compact Car
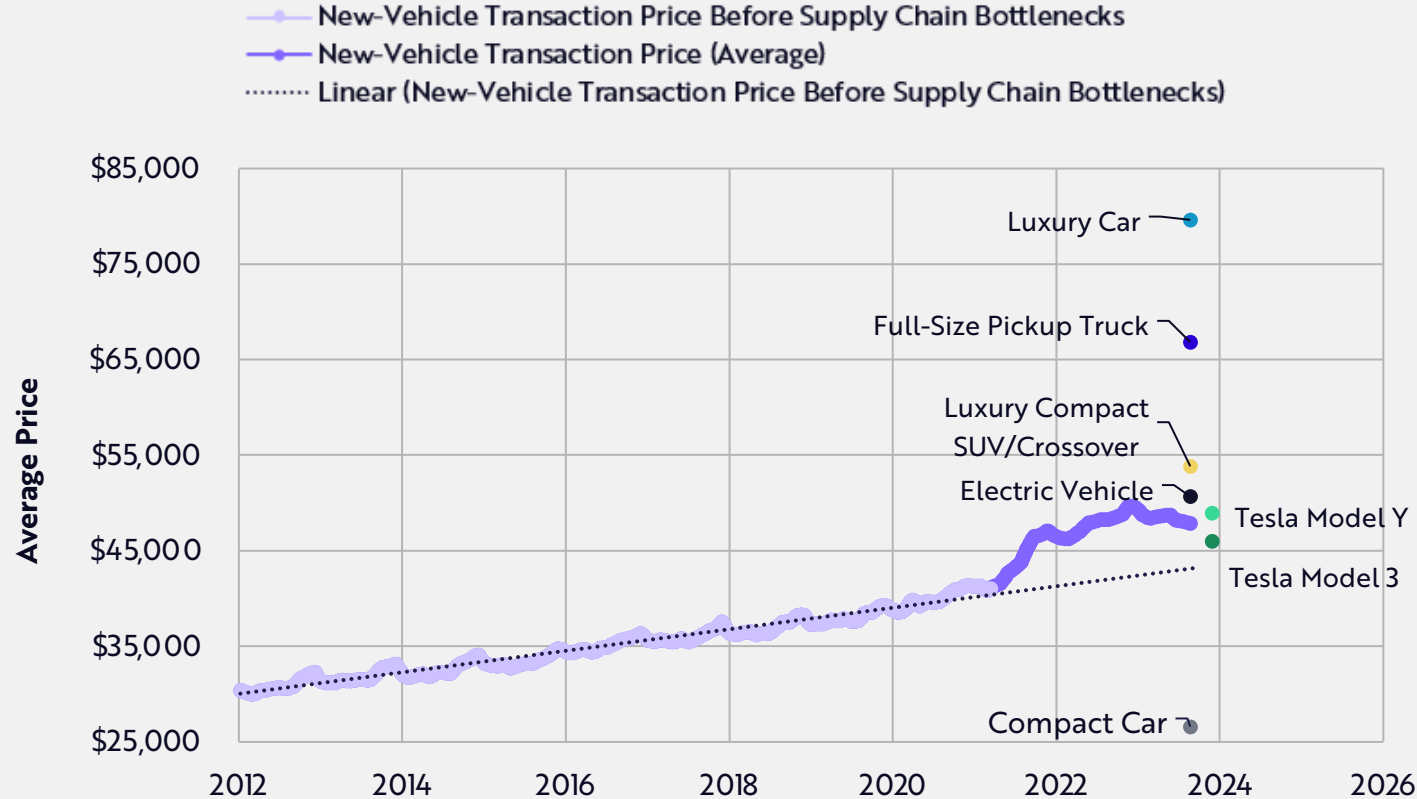
Vehicle Price vs Addressable Market

Internal Combustion Engine Vehicles Should Lose Significant Share

If EVs continue to gain share, as we believe they will, then used cars and new EVs will make more economic sense than new internal combustion engine (ICE) vehicles, perhaps causing a death spiral for incumbent auto manufacturers. As EV and used car prices fall, consumers could delay purchases, waiting for even lower price points.
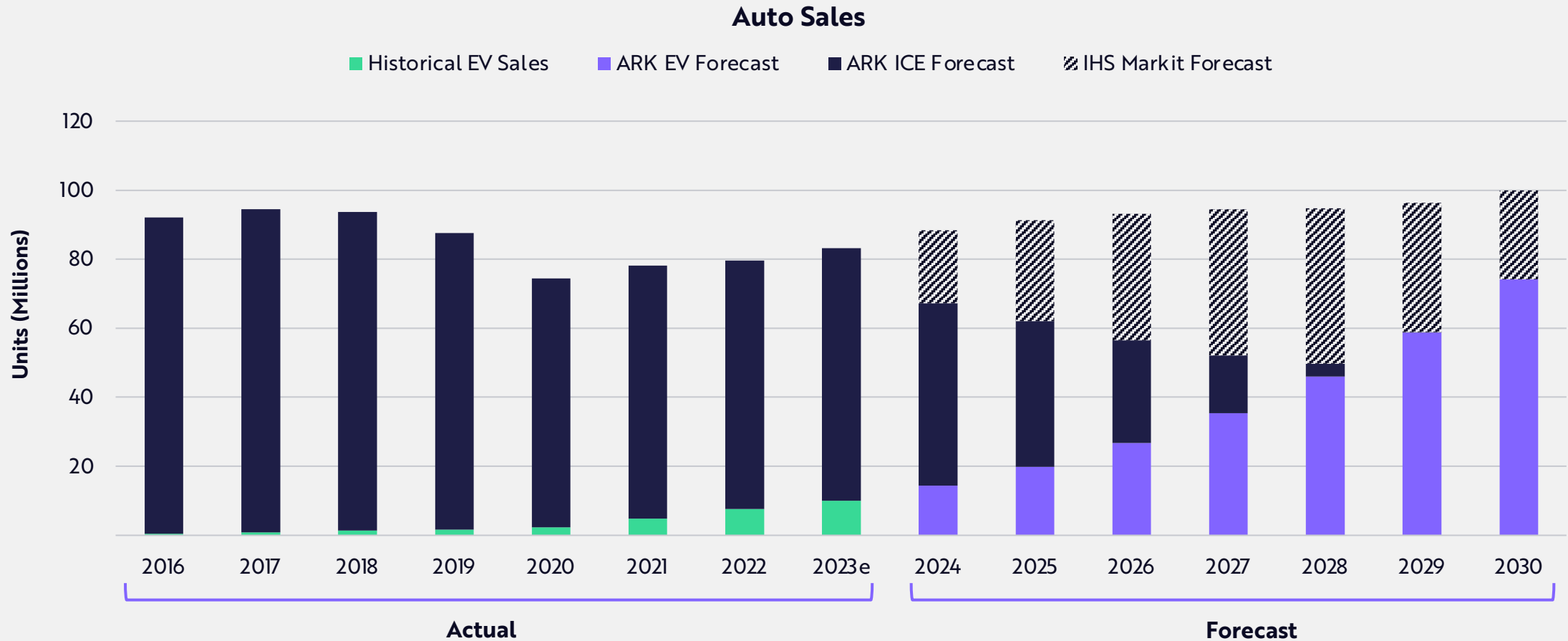
ELECTRIC VEHICLES

Auto Sales

■ Historical EV Sales   ■ ARK EV Forecast   ■ ARK ICE Forecast   ▨ IHS Markit Forecast

Actual

Forecast

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Sam Korus
Director of Research,
Autonomous Technology
& Robotics

Daniel Maguire, ACA
Research Associate

BIG IDEAS 2024

Robotics

Generalizing Automation Thanks To The
Convergence Of AI Software And Hardware

ROBOTICS

The convergence of AI and hardware should enable generalizable robotics.

Robots are outperforming humans in factory settings and should do so in many domains. As hardware and software costs decline according to Wright's Law, AI should continue to improve productivity and create a new market opportunity for generalizable robotics that, at scale, exceeds $24 trillion in revenue annually.

Thanks To AI And Computer Vision, Robots Should Be Able To Operate Cost-Effectively In Unstructured Environments
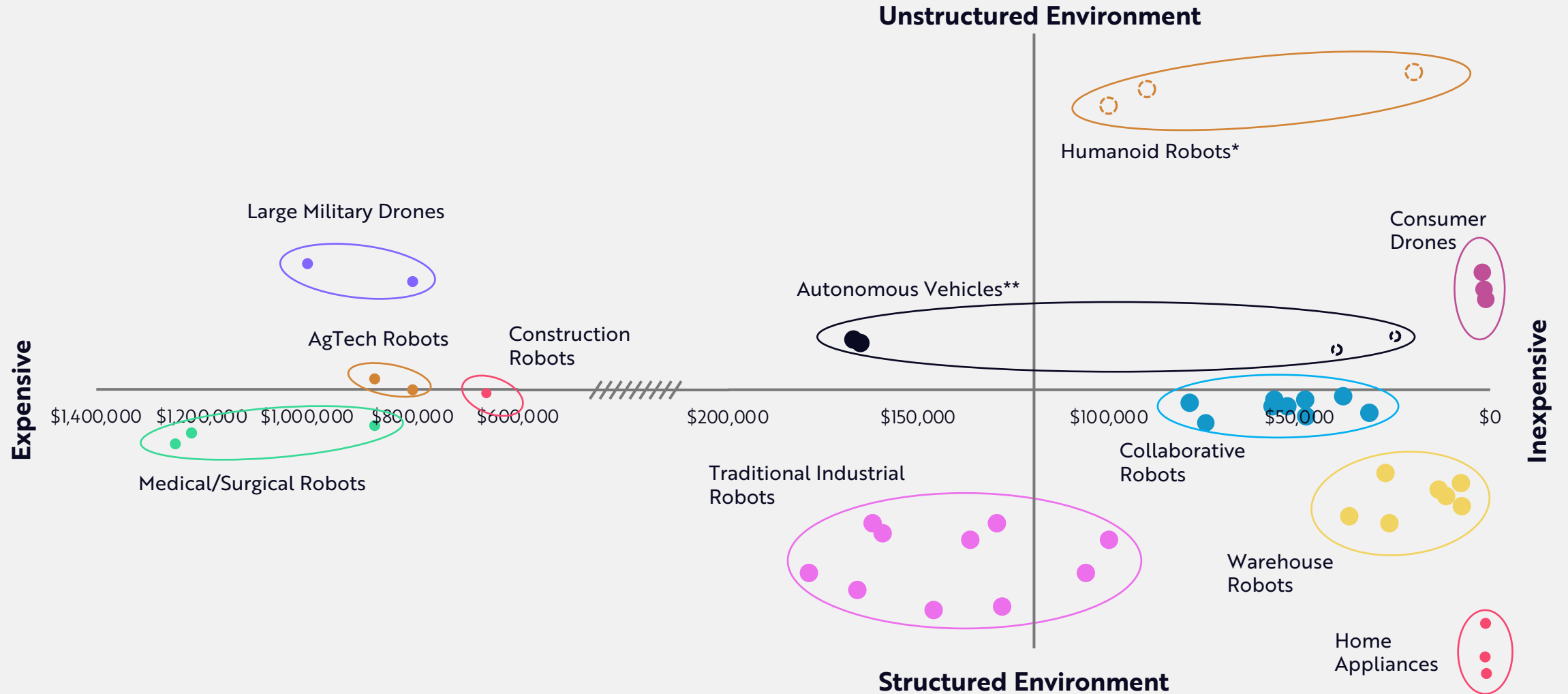
The points in each category represent real world products with the exception of humanoid robots and autonomous vehicles *These figures are estimated costs of humanoid robots that we expect to hit the market. **These figures are for both current operating and future robotaxis. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Lower Prices Are Stimulating Demand For Industrial Robots

Industrial robot costs have been dropping 50% for every cumulative doubling in production.

Industrial Robots: Price Elasticity Of Demand

Legend: ◆ 1996-2002 ■ 2002-2010 ✕ 2010-2015 ✳ 2016-2018 ▲ 2009, 2019 and 2020 ◆ 2021 ● 2022
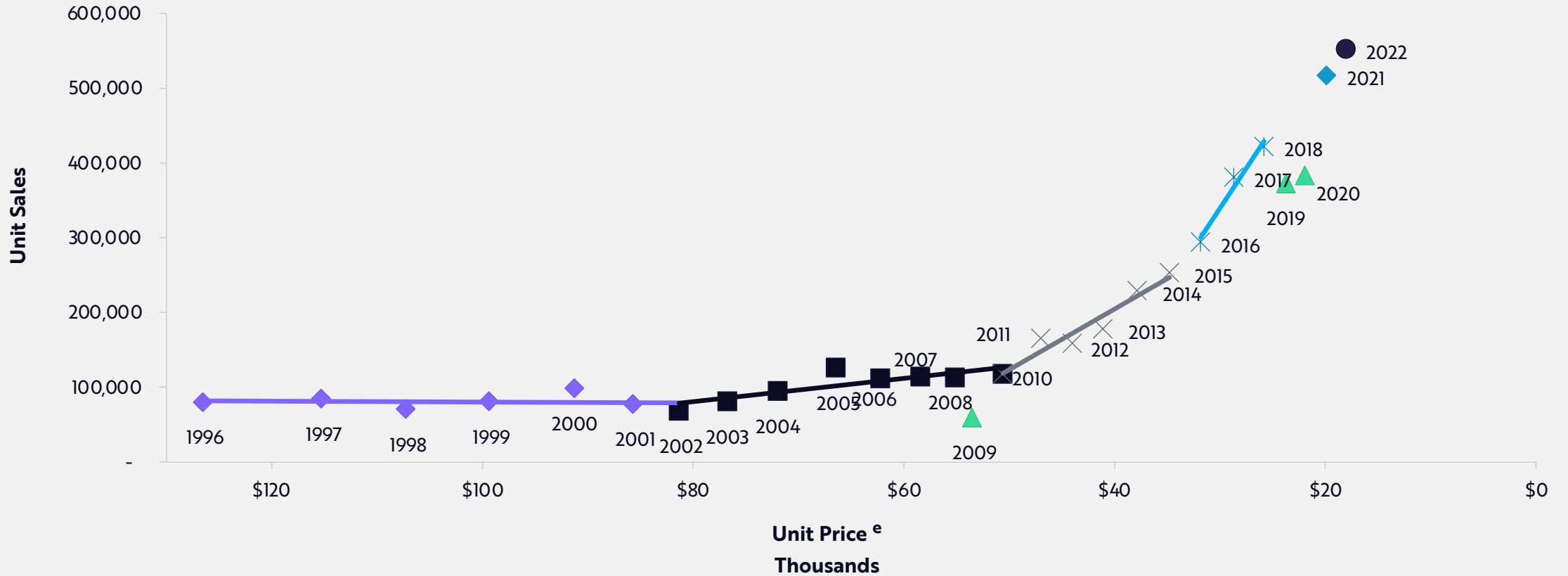
Increased Performance Is Stimulating Demand For Industrial Robots

Advances in computer vision and deep learning have improved robot performance 33-fold in seven years. Robots are already surpassing human performance by greater than a factor of two and it's unclear where the upper limit will be.

ROBOTICS

Items Picked And Placed Per Hour
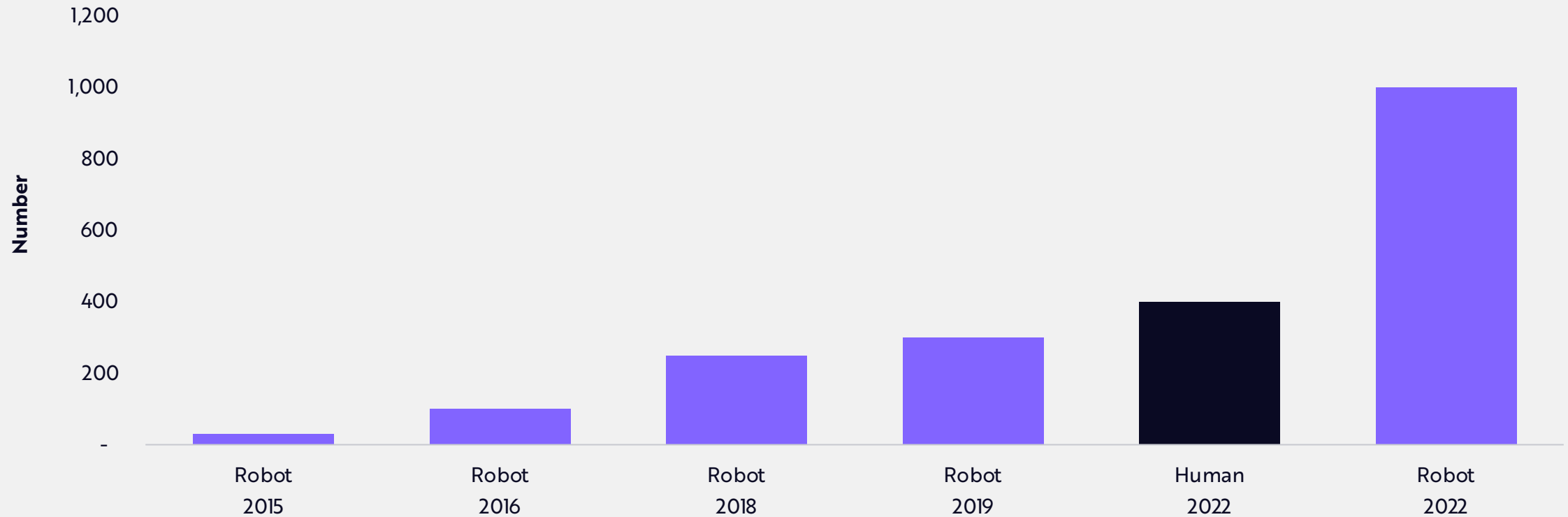
Collaborative Robots Are Entering The Sweet Spot Of The Adoption Curve

Collaborative robots and humans are likely to operate together, whether on the road, in factories, or at home. Historically, S-curves reach tipping points when the adoption of new technologies approaches 10-20% market share.[*]

Industrial Robot Sales
- Collaborative Robots
- Traditional Robots
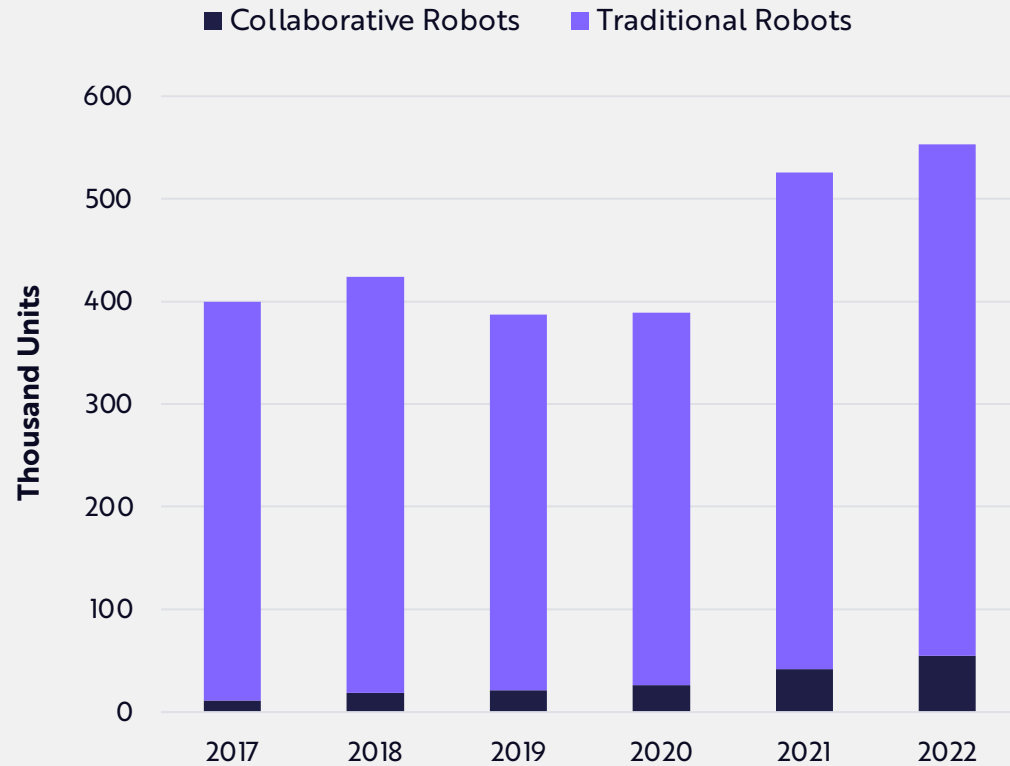
Unit Sales Of Collaborative Robots As A Percent Of Total Industrial Robot Sales
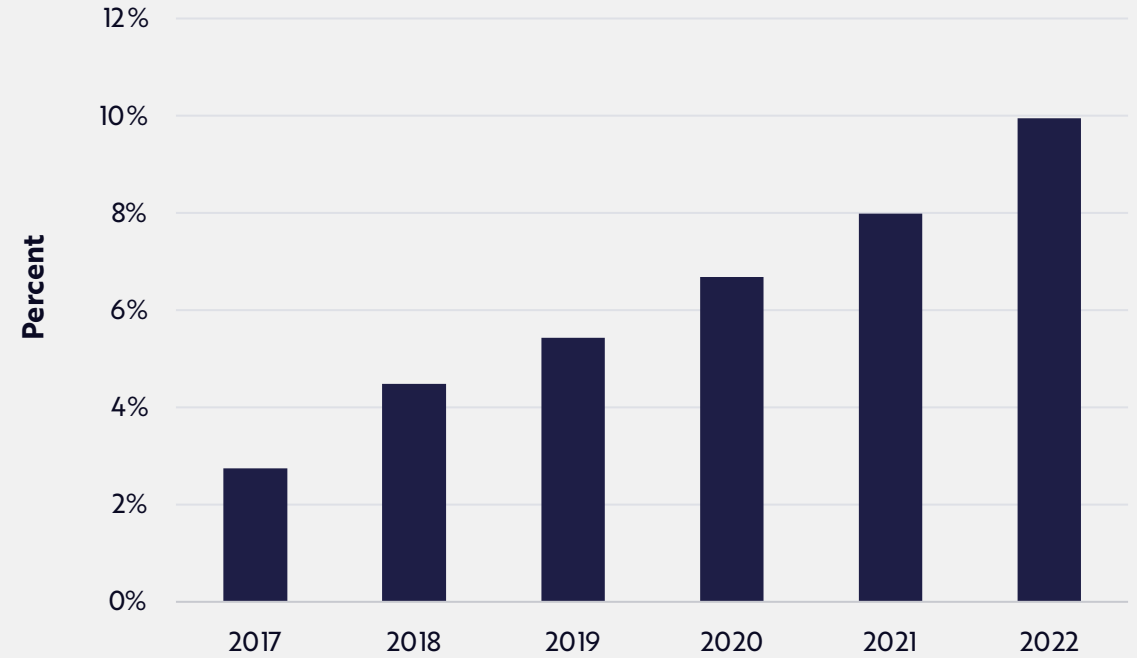
*S-Curve refers to the typical technology adoption curve, which looks like an "S" when plotted over time. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, including International Federation of Robotics 2023 and Citi Research 2023, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
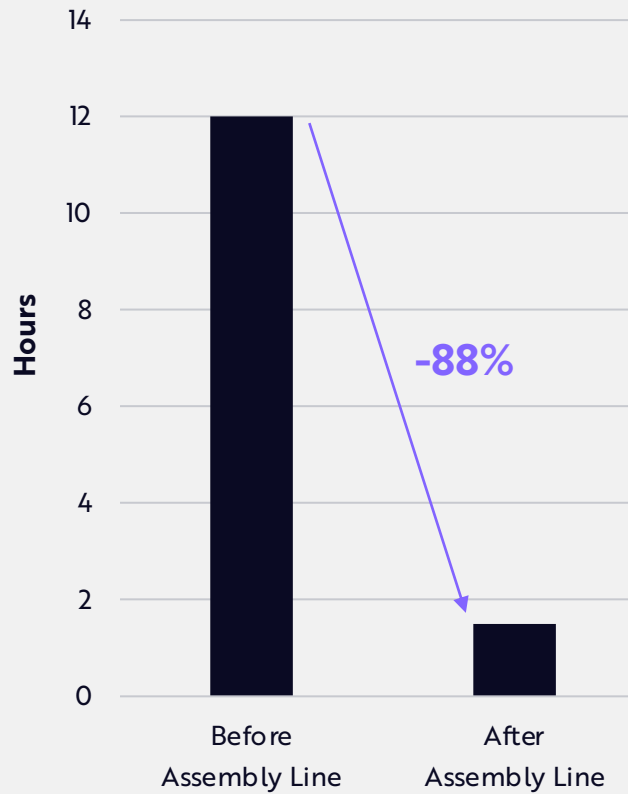
Many Companies Are Likely To Deploy More Robots Than Humans

Robots are freeing humans from tedious physical tasks.

ROBOTICS

Amazon Robots And Employees

■ Robots   ■ Employees (at start of year)
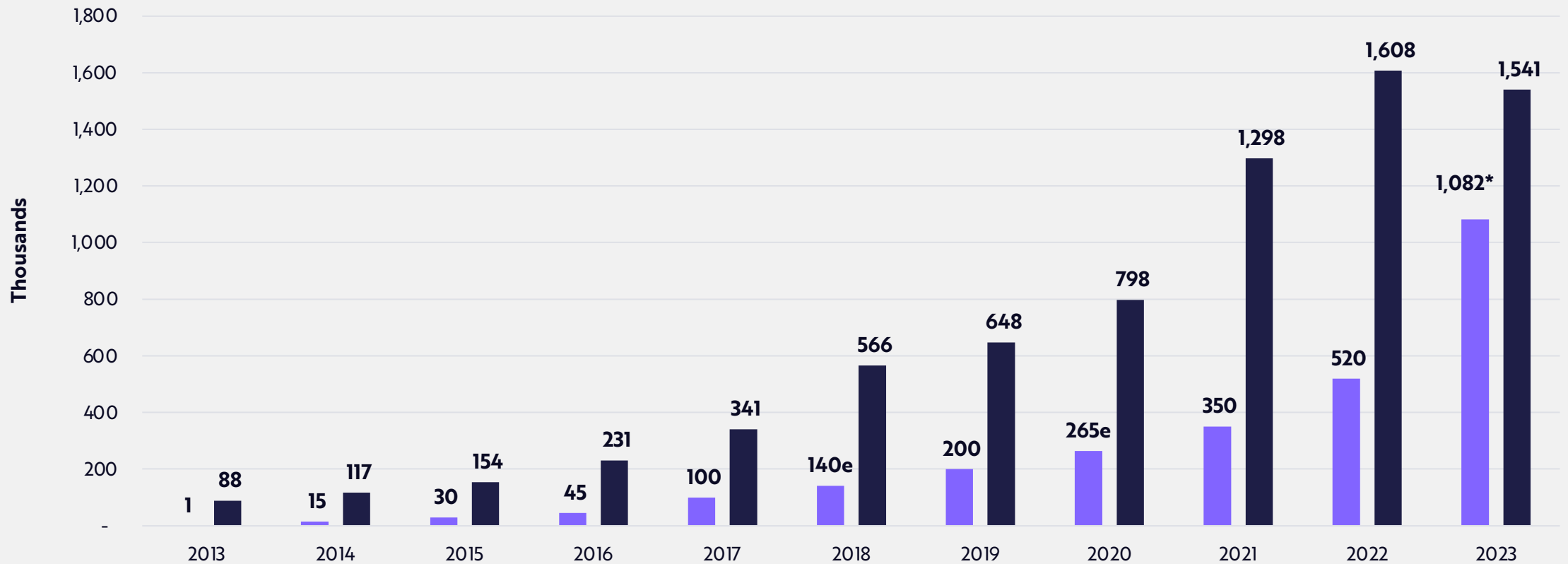
*Modeled/annualized. Figures denoted with an "e" are ARK estimates. Sources: ARK Investment Management LLC, based on data from Amazon 2023 as of June 26, 2023. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Automation's Impact On Productivity Has Transformed Industries

ROBOTICS

Time To Do Laundry

Hours

16 — 14 — 12 — 10 — 8 — 6 — 4 — 2 — 0

-87%

Before Washing Machines · After Washing Machines
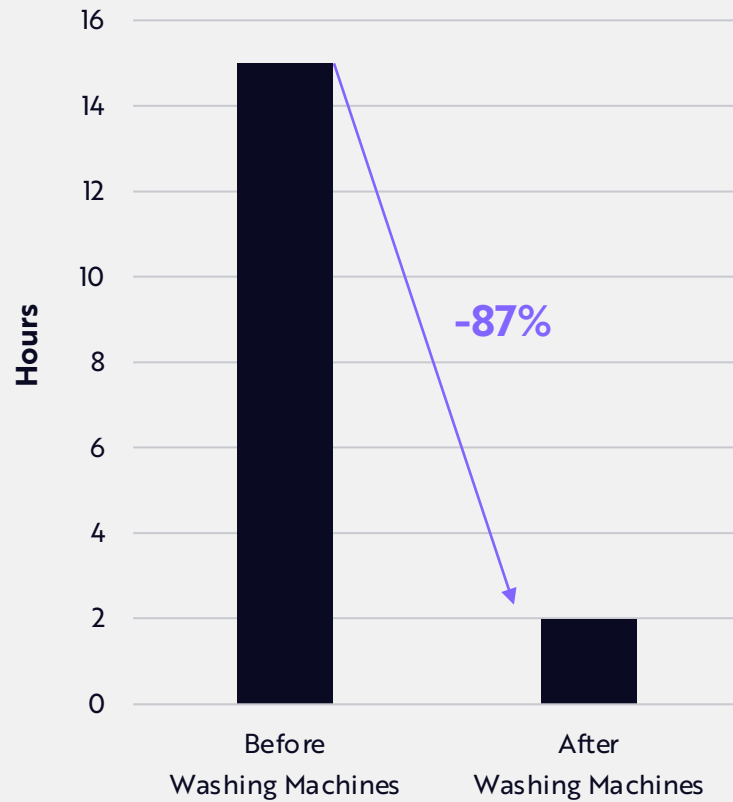
Time To Manufacture A Car

Hours

14 — 12 — 10 — 8 — 6 — 4 — 2 — 0

-88%

Before Assembly Line · After Assembly Line

Time From Click To Ship At An Amazon Warehouse
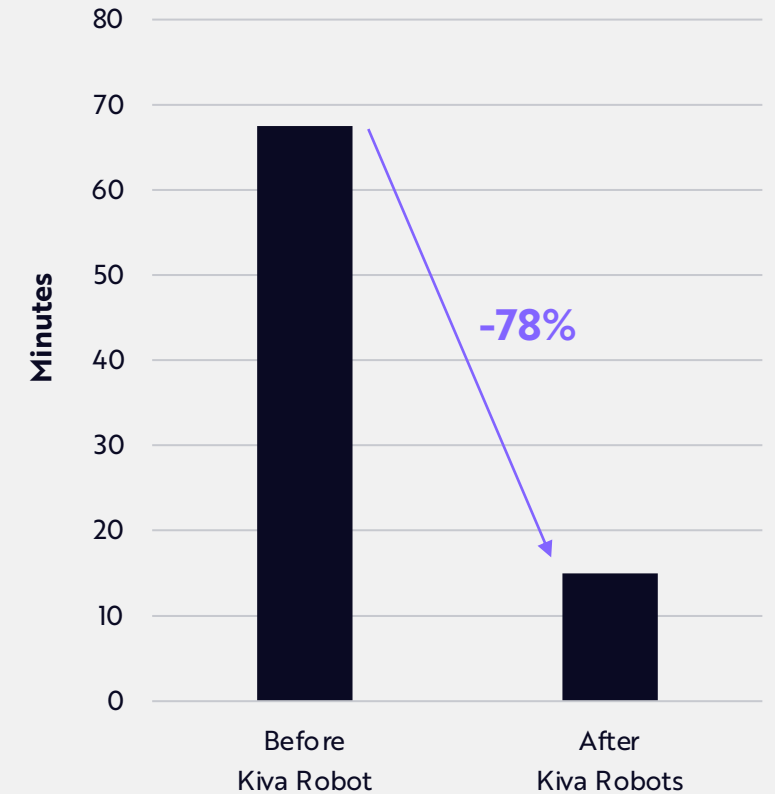
Minutes

80 — 70 — 60 — 50 — 40 — 30 — 20 — 10 — 0

-78%

Before Kiva Robot · After Kiva Robots

Generalizable Robotics Represent A Potential $24+ Trillion Global Revenue Opportunity

Household Robotics

~2.3 Hours of Unpaid Work per Day

✕

~2.8 Billion Working Age Population

✕

~$10.75 Weighted Average Hourly Wage

✕

½ Value Attributed to Free Time vs Paid Time

=

~$12.5 Trillion Opportunity

Manufacturing Robotics

ARK Forecasts Global Manufacturing GDP
At ~$28.5 Trillion In 2030

		Productivity Uplift					
		10%	25%	50%	100%	200%	400%
Take Rate	10%	286	714	1,429	2,857	5,715	11,430
	20%	571	1,429	2,857	5,715	11,430	22,860
	50%	1,429	3,572	7,144	14,287	28,575	57,149

Revenue Opportunity*
(Billions)

=

~$12+ Trillion Opportunity
(Average Of The Green Cells)

*Note: the cells highlighted in green represent what ARK believes to be a reasonable or likely outcome. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

Research By:

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BIG IDEAS 2024

Robotaxis

Transforming Urban Transit Safely And Affordably

ROBOTAXIS

Thanks to breakthroughs in AI, robotaxis are beginning to revolutionize urban travel and could accelerate the unraveling of the auto loan sector.

Safer than human drivers, robotaxis hold the promise of safer and cleaner streets. Robotaxi platform pioneers should enjoy the higher prices associated with early adoption.

According to ARK's research, robotaxi platforms could redefine personal mobility and generate $28 trillion in enterprise value during the next five to ten years.

Autonomous Ride-Hail Is Likely To Increase Access To Convenient Point-to-Point Transportation

Adjusted for inflation, the cost of owning and operating a personal car has not changed since the Model T rolled off the first assembly line more than 100 years ago. ARK estimates that autonomous taxis at scale could cost consumers as little as $0.25 per mile, spurring widespread adoption.

ROBOTAXIS

**Cost Per Mile Of A Personally Owned Vehicle
(2020 $)**
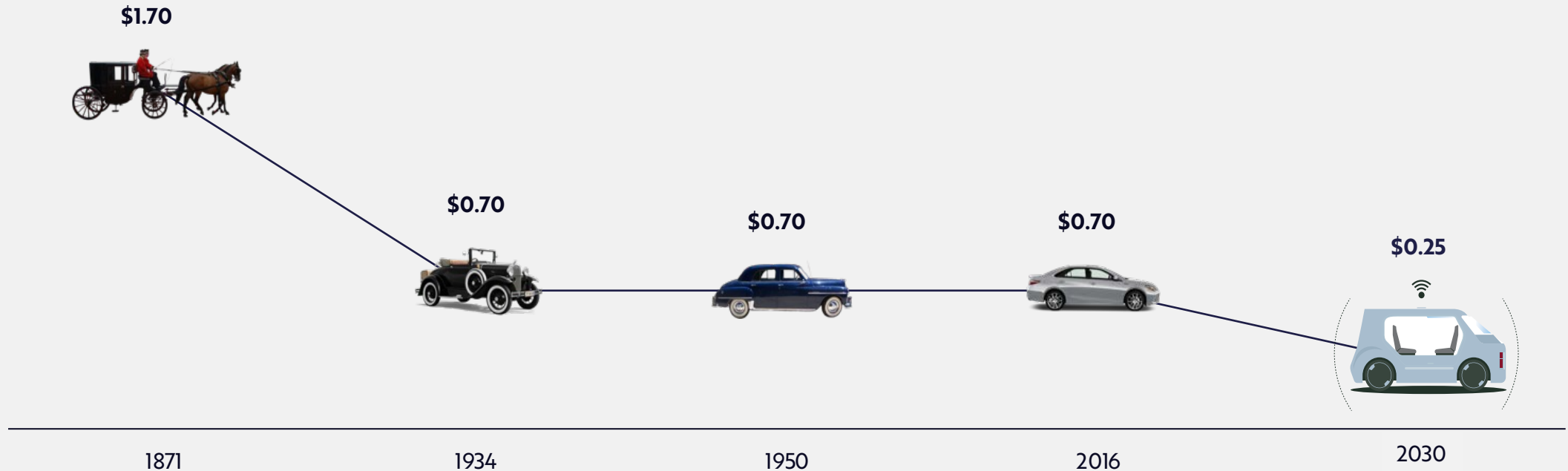
$1.70

$0.70

$0.70

$0.70

$0.25

| 1871 | 1934 | 1950 | 2016 | 2030 |

Robotaxi Passenger Trips Annualized At A Rate of ~2 Million Late Last Year

Robotaxis are operating in ~20 cities globally, with fully driverless commercial options in at least 7 cities. In 2023, Baidu was operating at a run rate of 1.6 million autonomous trips,* triple those of Waymo. Cruise has ceased US operations. With access to 50x more driving data than Baidu and 280x more than Waymo, Tesla has a massive data advantage as it prepares to launch its robotaxi service, the largest AI project in the world.

ROBOTAXIS

Autonomous Rides Run Rate
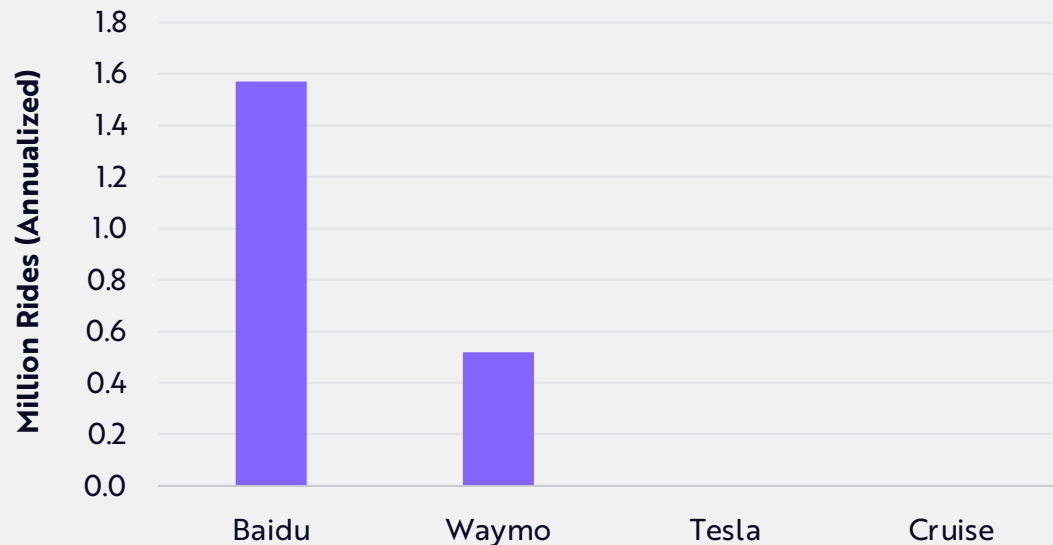
Autonomous Miles Run Rate
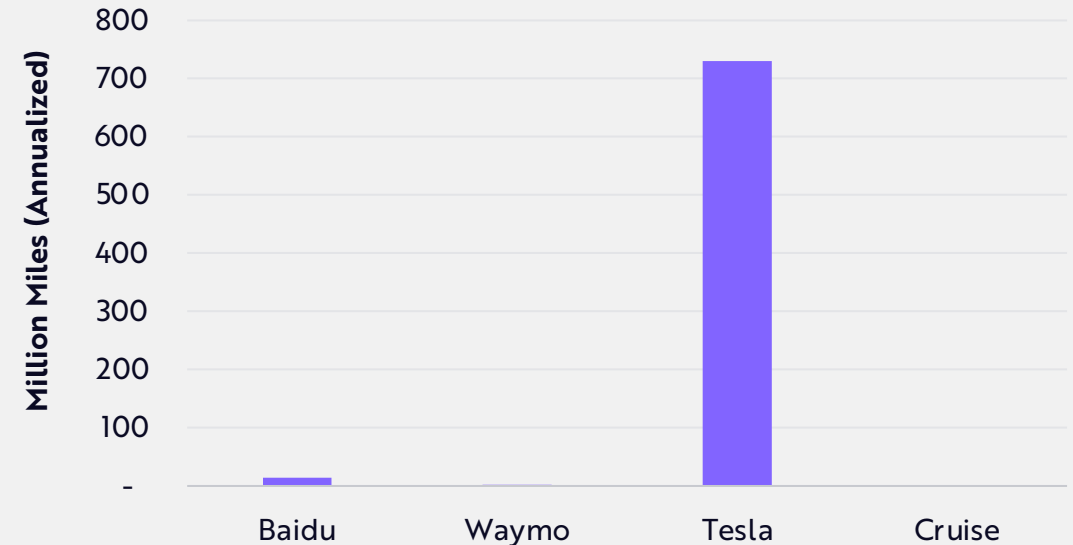
*This includes only the 55% of rides that are fully autonomous at Baidu. The chart on the right assumes 5 miles per trip for Waymo, Cruise, and Baidu. Tesla miles in righthand chart are FSD miles and still require a human behind the wheel.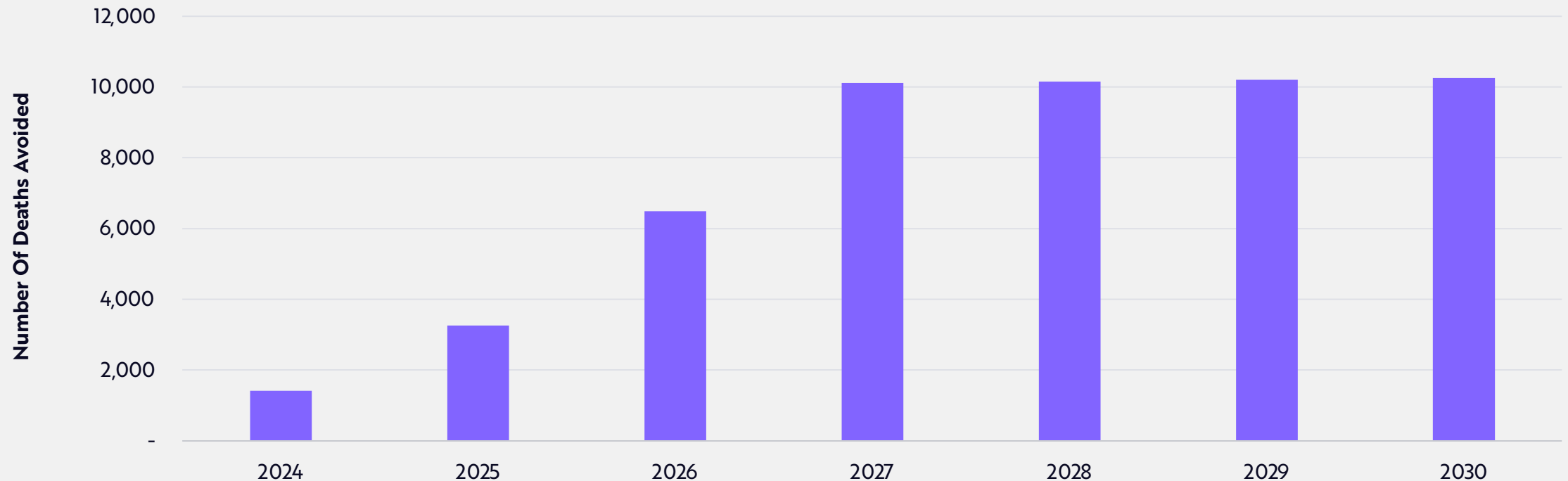 Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

ROBOTAXIS

Autonomous Vehicles Are Safer Than Human-Driven Vehicles

In 2015, ARK estimated that the rate of autonomous vehicle accidents would be ~80% lower than that associated with human drivers, reducing the ~40,000 auto-related fatalities per year in the US and the ~1.35 million globally. Current data support our original estimates.

In full self driving (FSD) mode on surface streets, a Tesla appears to be ~5x safer than a Tesla in manual mode, and ~16x safer than the national average. Waymo's autonomous cars are ~2-3x safer than the national average, while Cruise—now sidelined by regulators—seems to have underperformed the national average considerably.

Miles Between Crashes On Surface Streets Only (Thousands)
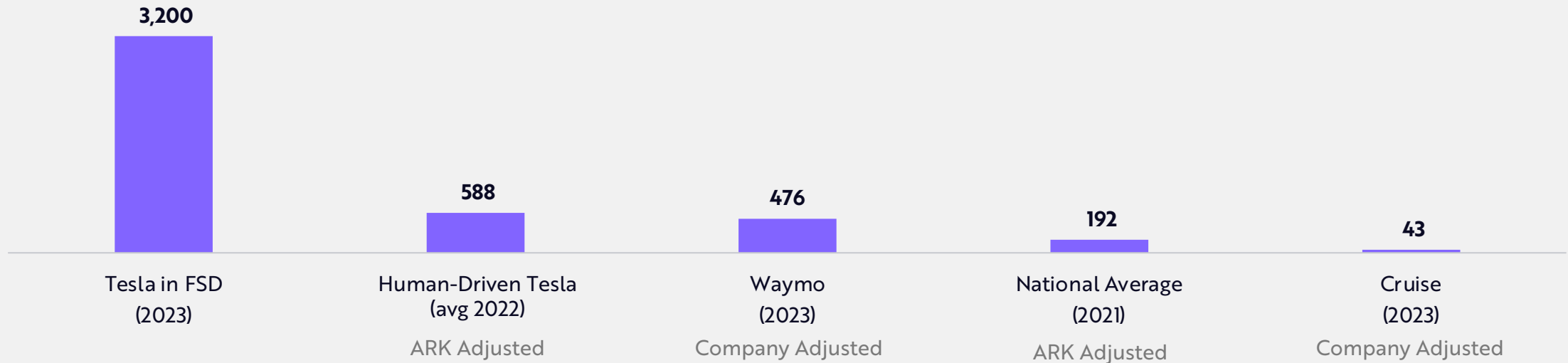
Tesla in FSD (2023)	Human-Driven Tesla (avg 2022) ARK Adjusted	Waymo (2023) Company Adjusted	National Average (2021) ARK Adjusted	Cruise (2023) Company Adjusted
3,200	588	476	192	43

Autonomous Electric Transport Should Save The ~10,000 US Lives Per Year Lost To Vehicle Emissions

Air pollution from gas-powered passenger vehicles is associated with 9,700 deaths in the US annually. According to ARK's research, autonomous electric vehicles should prevent ~10,000 deaths in 2030.*

ROBOTAXIS

Incremental Lives Saved In The US By Lower Emissions Associated With Electric And Autonomous Vehicles

*This analysis is based on ARK's autonomous electric vehicle adoption forecast and adjusted for population growth. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, including Thakrar et al. 2020, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

ROBOTAXIS

Large Language Models and Generative AI Should Accelerate The Progress In Robotics

Trained by GPT-4 to perform robotics tasks, a neural network performed better than human expert coders on 83% of tasks, with the margin of improvement averaging 52%.

Large Language Models (LLMs) enable text-based training, validation, and self-explanations, which should facilitate regulatory approval.

Multimodal models can train autonomous vehicles with images and text, which could result in better performance.

Generative AI can train and validate autonomous vehicle safety through simulation.

LLM-Driven Reinforcement Learning Outperforms Expert Human Coders Across Various Robotics Tasks, Environments, And Morphologies

Legend:
- Eureka (LLM-based reward design with little manual input, zero-shot rewards)
- L2R (LLM-based reward design with manual reward templates, few-shot examples)
- – – – Human

Human Normalized Score

	Eureka	L2R
Task 1	12.65	12.64
Task 2	2.07	1.24
Task 3	2.06	-2.04
Task 4	1.66	-1.04
Task 5	1.42	0.88
Task 6	1.09	0.99
Task 7	1.06	0.56
Task 8	1.00	1.00
Task 9	1.00	1.00
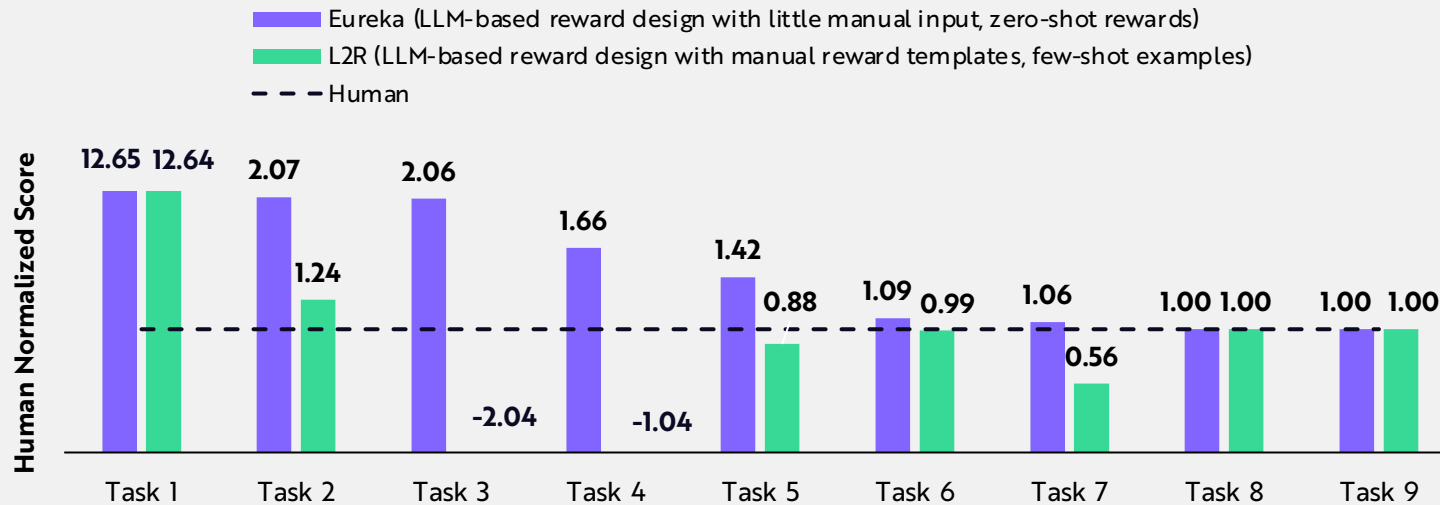
Task Legend:

Task 1: To open the cabinet door
Task 2: To make the hand spin the object toward a target.
Task 3: To make the humanoid run as fast as possible.
Task 4: To make the ant run forward as fast as possible.
Task 5: To make the shadow hand spin the object toward a target.
Task 6: To make the quadruped follow randomly chosen x, y and yaw target velocities.
Task 7: To make the quadcopter reach and hover near a fixed position.
Task 8: To balance a pole upright on a cart.
Task 9: To stabilize a ball on the table-top.

Ride-Hail Is Likely To Create An $11 Trillion Addressable Market

At $0.25 cents per mile, autonomous transportation could serve a wider population than human-driven ride-hail does today. In the meantime, based on the value that consumers place on their time, demand at higher price points could be significant.
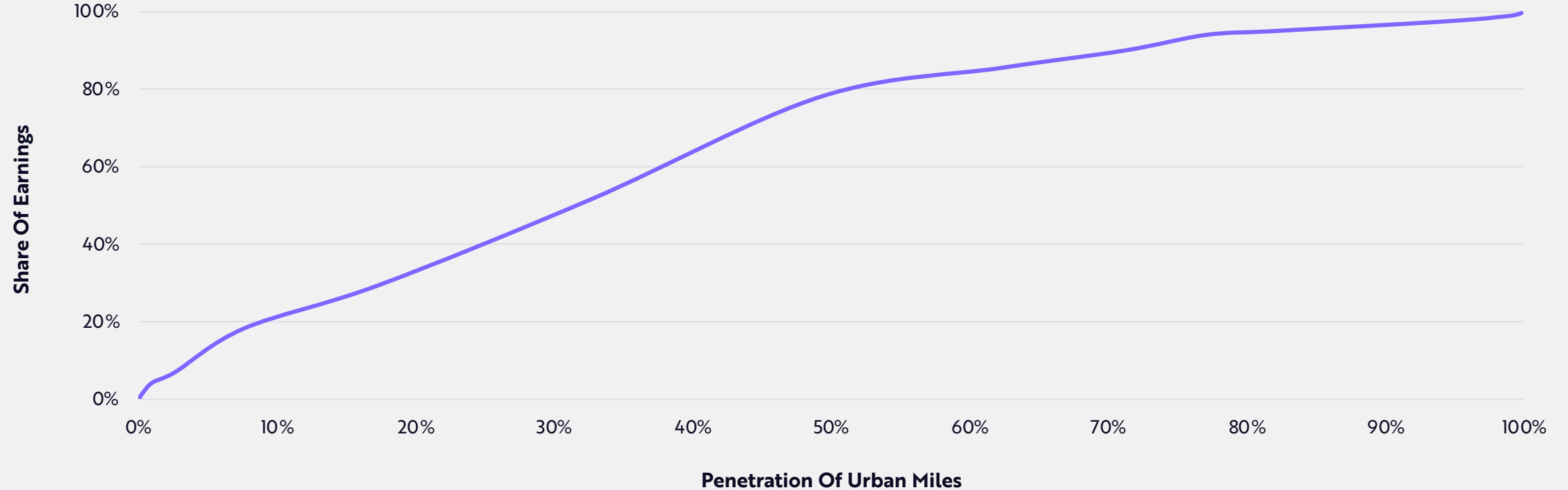
ROBOTAXIS

Ride-Hail Addressable Market*

Price Points ($):

■ 4.00   ■ 3.00   ■ 2.00   ■ 1.10   ■ 0.60   ■ 0.50   ■ 0.25

$4B

$30B

$100B

$34B: Existing addressable market for ride-hail companies in Western markets charging $2-$4 per mile

$1T: Addressable ridership in Western markets at ~$1

$2.4T: Non-commuting miles in higher income countries priced at ~$0.60 per mile

$2.75T: Long tail of demand priced at human driven ride-hail prices of $0.50 per mile in lower income countries

$5T: Low cost, accessible autonomous travel at $0.25 per mile

Price Per Mile (y-axis: $0.00, $0.50, $1.00, $1.50, $2.00, $2.50, $3.00, $3.50, $4.00, $4.50)

Miles (Trillions) (x-axis: 0, 1, 5, 10, 30)

Platforms Facilitating The First 50% Of Urban Autonomous Miles Should Generate The Bulk Of Earnings

ROBOTAXIS

Autonomous Platforms' Share Of Earnings Potential
Vs. Penetration Of Urban Miles

Share Of Earnings

Penetration Of Urban Miles

Autonomous Electric Vehicle Adoption Could Disrupt The US Auto Loan Industry

During the past three years, interest rate hikes have increased new vehicle monthly car loan payments by ~27%, from $581 to $739. As a result, the number of subprime auto loans delinquent by 60+ days recently hit an all-time high.

Thanks to Wright's Law, EV prices should continue to fall, shifting more miles onto electric platforms and decreasing the value of gas-powered vehicles. As a result, the ~$1.6 trillion in auto loans currently sitting on financial institution balance sheets, issued predominantly for gas-powered vehicles, could be at risk over the next 10 years.

ROBOTAXIS

Auto Loan 60+ Delinquency

— Subprime — Prime
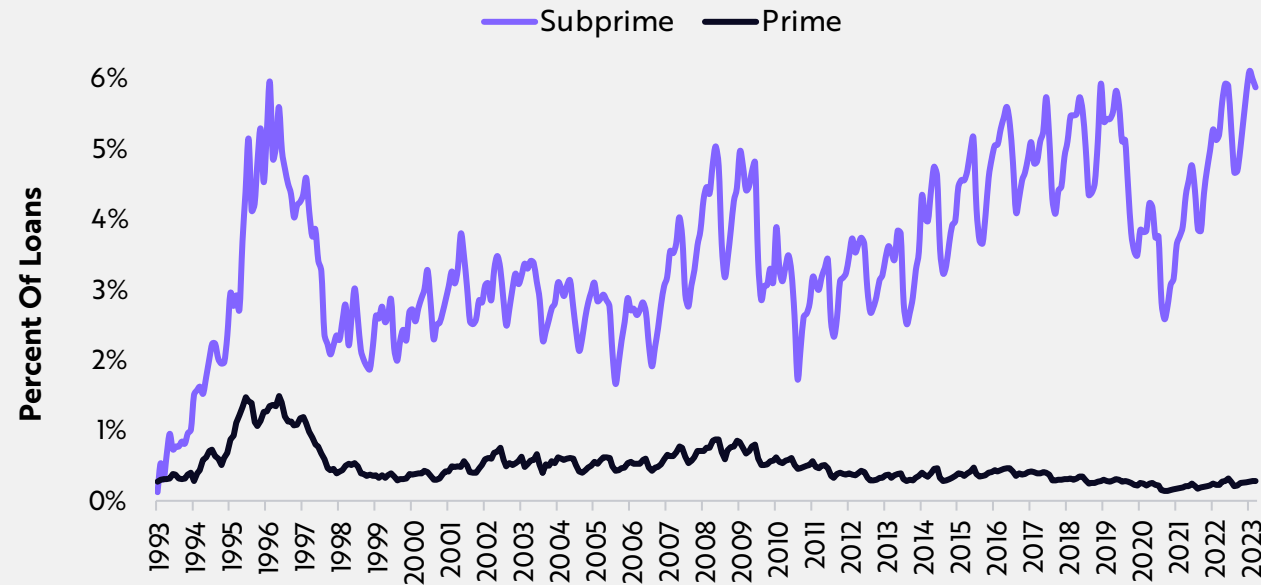
Auto Vehicle Fleet Composition (Trillions Of Dollars)*

■ Motor Vehicle Loans Owned And Securitized By Banks
■ Motor Vehicle Loans On Consumer Balance Sheets (ARK Estimate)

$1.3 T $1.6 T
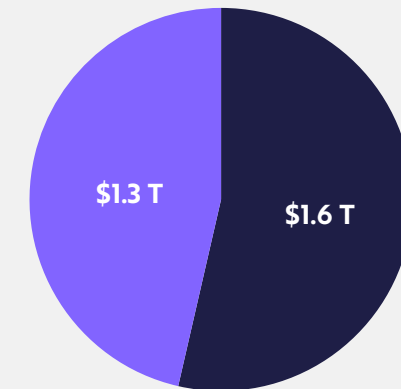
Note: Wright's Law states that for every cumulative doubling of units produced, costs will fall by a constant percentage. *Motor Vehicle Loans Owned and Securitized data as of Q3 2023. ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, as of January 3, 2024, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
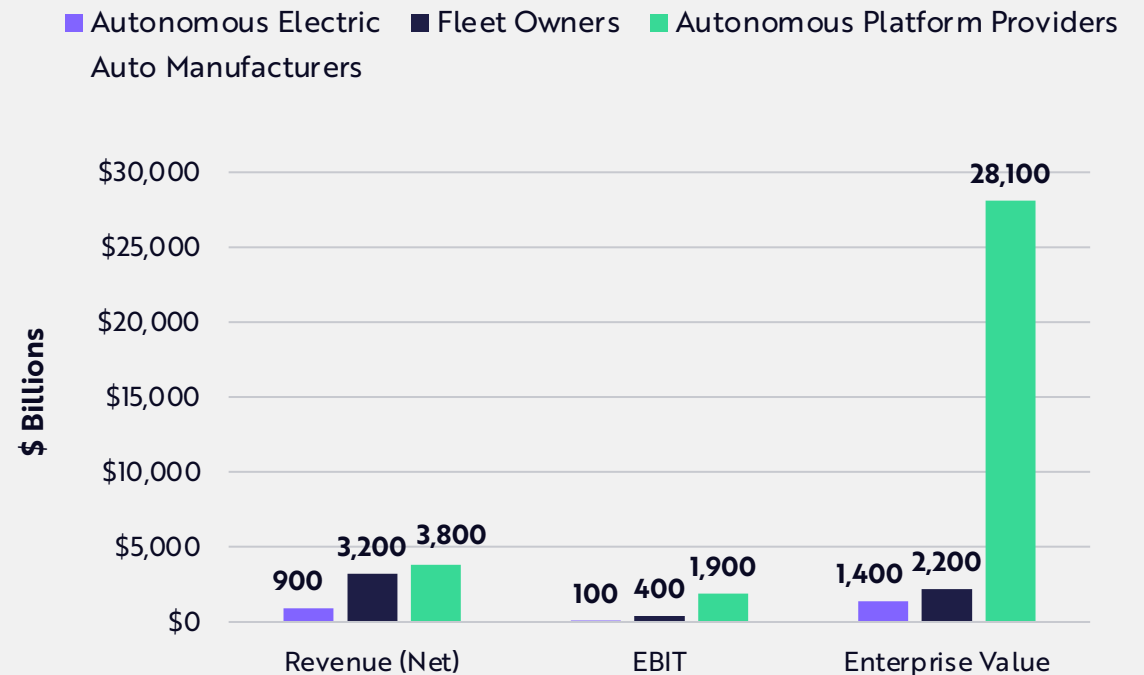
Autonomous Platform Providers Could Create ~$28 Trillion In Enterprise Value In 2030

At 15x EBIT in 2030, autonomous platform providers could scale to $28 trillion in enterprise value, or ~9x that of all auto manufactures in 2023.

Revenue, Earnings, And Enterprise Value
2023 Actual Auto Manufacturers

$ Billions

- Revenue: **$2,750**
- EBIT: **$200**
- Enterprise Value: **$3,100**
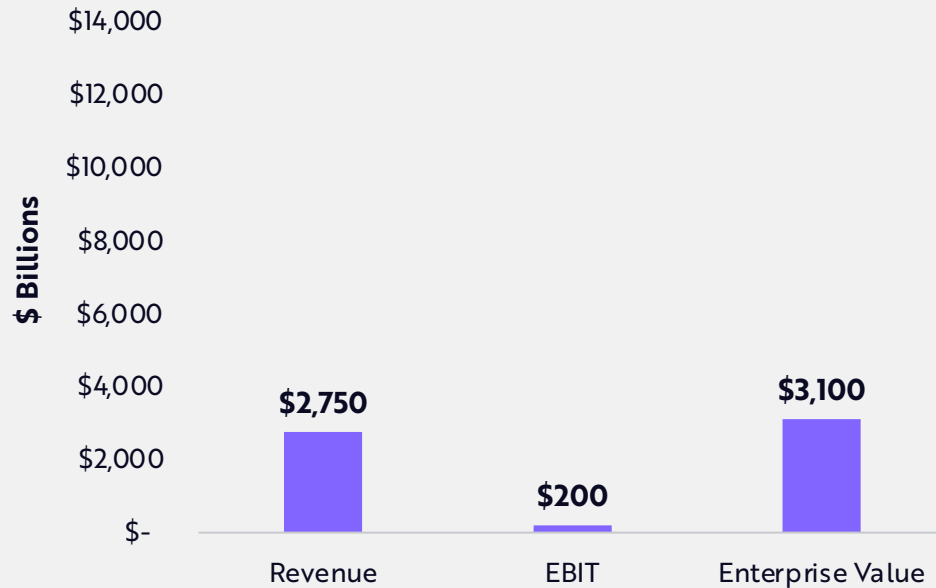
Revenue, Earnings And Enterprise Value
2030 ARK Estimates

■ Autonomous Electric Auto Manufacturers ■ Fleet Owners ■ Autonomous Platform Providers

$ Billions

- Revenue (Net): 900, 3,200, 3,800
- EBIT: 100, 400, 1,900
- Enterprise Value: 1,400, 2,200, 28,100

Numbers are rounded. EBIT = Earnings Before Interest and Taxes. Autonomous Platform Operators = Autonomous Ride-hail Companies, such as Waymo or Tesla. The chart on the left includes all publicly listed automakers with available CAPIQ data on Enterprise Value, Revenue, and Operating Income. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
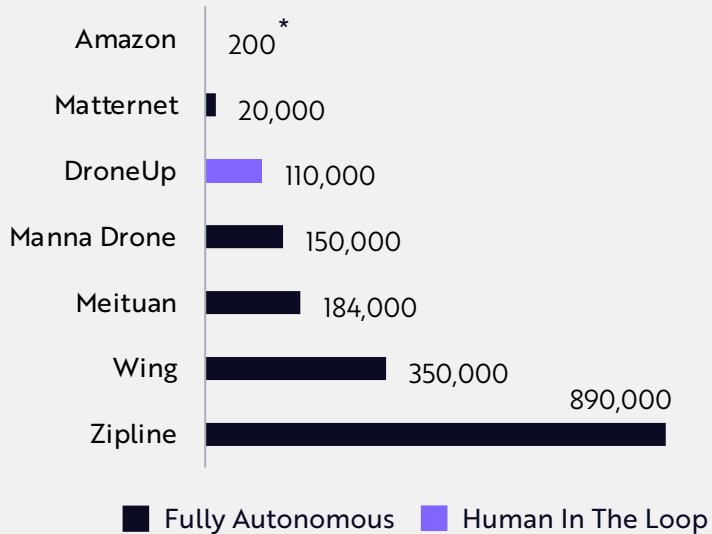
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Autonomous Logistics

Reducing Costs And
Reshaping Supply Chains

Autonomous logistics should reduce the cost of moving goods by 15-fold during the next five to ten years. Autonomous drones and robots have made millions of deliveries, while autonomous trucking companies have logged tens of millions of miles and are beginning to remove safety drivers.

AI is proving superior to human pilots and drivers, encouraging regulators to allow truly autonomous operations that will change shopping behavior.

Autonomous vehicles should impact health care by accelerating the delivery of life-saving supplies, particularly in emerging markets.

According to ARK's research, autonomous delivery revenues could scale from essentially nil today to $900 billion in 2030.

Autonomous Vehicles That Roll And Fly Could Lower Supply Chain Costs Dramatically

According to our research, autonomous vehicles should operate at higher utilization rates than human-in-the-loop systems, creating more cost-effective last-mile delivery systems.

AUTONOMOUS LOGISTICS

**Truckload Delivery Cost
(Per Ton-Mile)**

**Local Batch Delivery Cost
(Per Trip)**

**Local Small Item Delivery Cost
(Per Trip)**

$0.07 — Human-Driven Diesel Truck
−57%
$0.03 — Autonomous Electric Truck

$2.40 — Human-Driven Vehicle
−83%
$0.40 — Robot Delivery

$5.40 — Human-Driven App Delivery
−94%
$0.35 — Drone Delivery
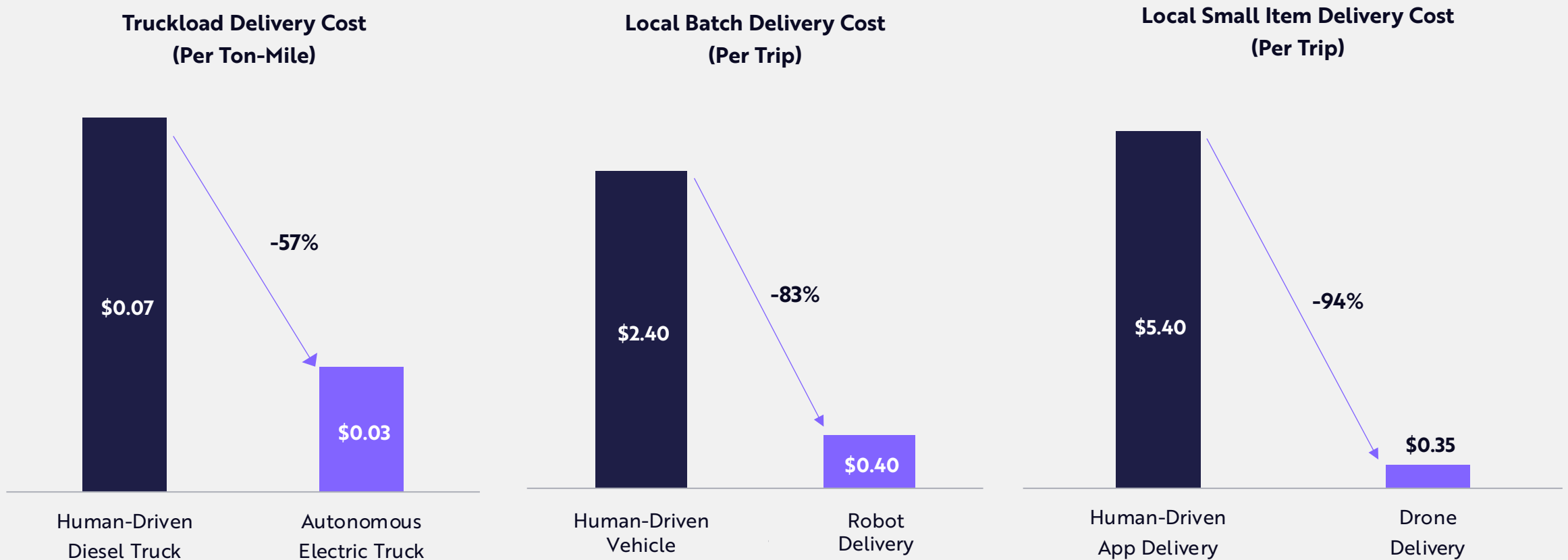
Note: Drone price per mile has been updated with our latest assumptions for replacement costs, launching and charging infrastructure, insurance, and labor costs. Fees for drone and robot delivery are shown net of infrastructure costs (outside of charging and launch/land), which we believe could either be born by the drone or robot delivery operators or shared with logistics or retail partners. ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources as of December 7, 2023, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
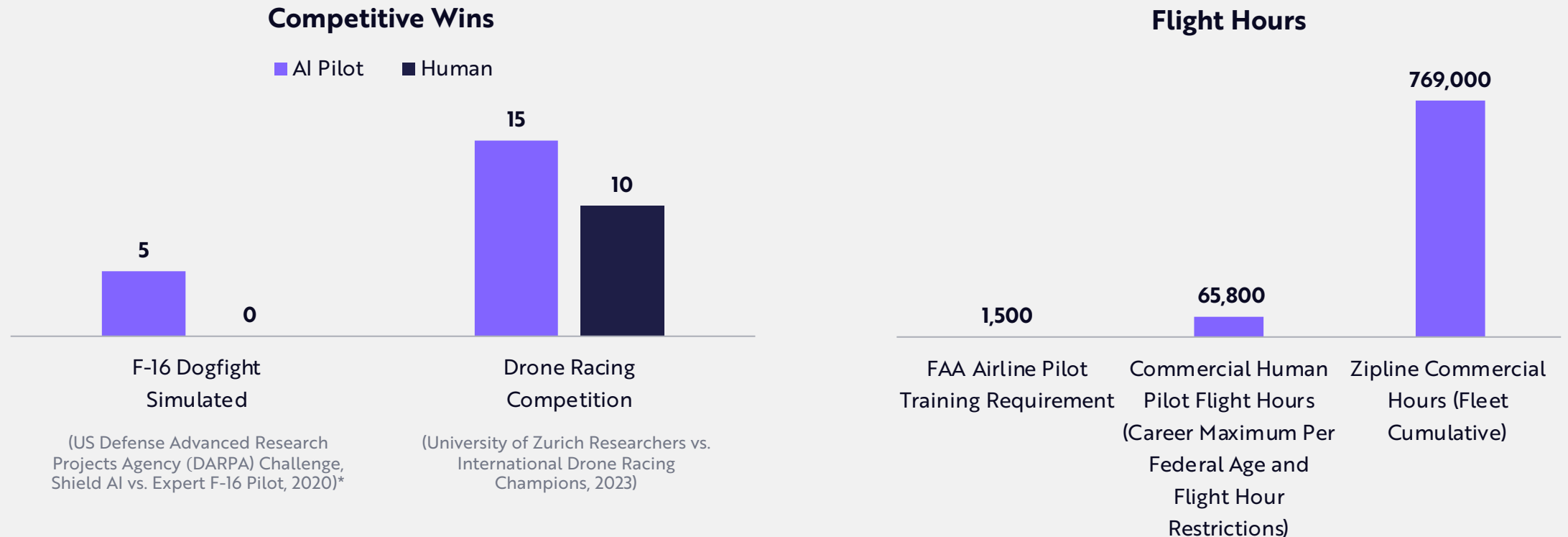
Proprietary Data Is Likely To Determine Commercial Success In Autonomous Logistics

Companies with more real-world data should have a competitive advantage. Verticalization and manufacturing partnerships also will be critical to success.

AUTONOMOUS LOGISTICS

Drones

Autonomous Trucks

Rolling Robots

Cumulative Number Of Commercial Flights

Company	Value
Amazon	200 *
Matternet	20,000
DroneUp	110,000
Manna Drone	150,000
Meituan	184,000
Wing	350,000
Zipline	890,000

■ Fully Autonomous ■ Human In The Loop

Cumulative Miles Traveled

Company	Value
Aurora	895,000
Embark	1,500,000
Gatik	1,500,000 *
Pony.ai	1,900,000
Kodiak	2,500,000

■ Fully Autonomous ■ Human In The Loop

Cumulative Number of Deliveries

Company	Value
Nuro	20,000 *
Serve Robotics	70,000
Kiwibot	300,000
Starship	5,000,000
Alibaba	29,000,000

■ Fully Autonomous ■ Human In The Loop
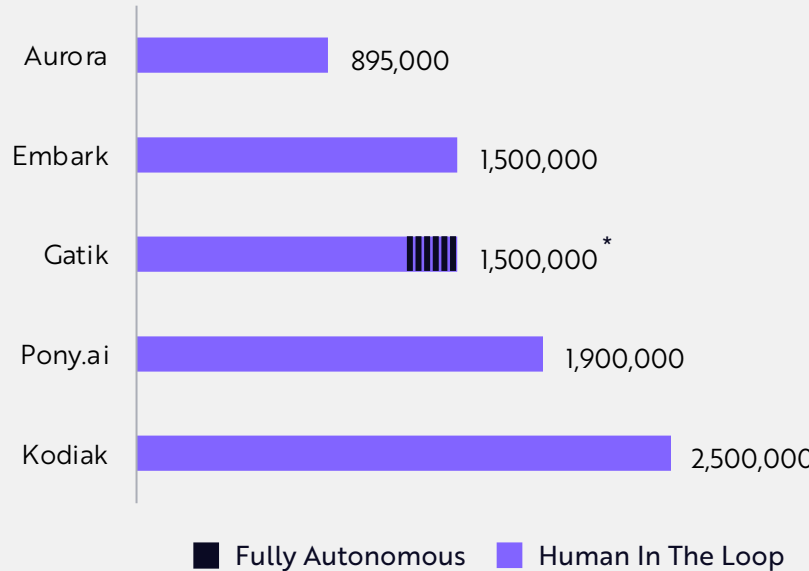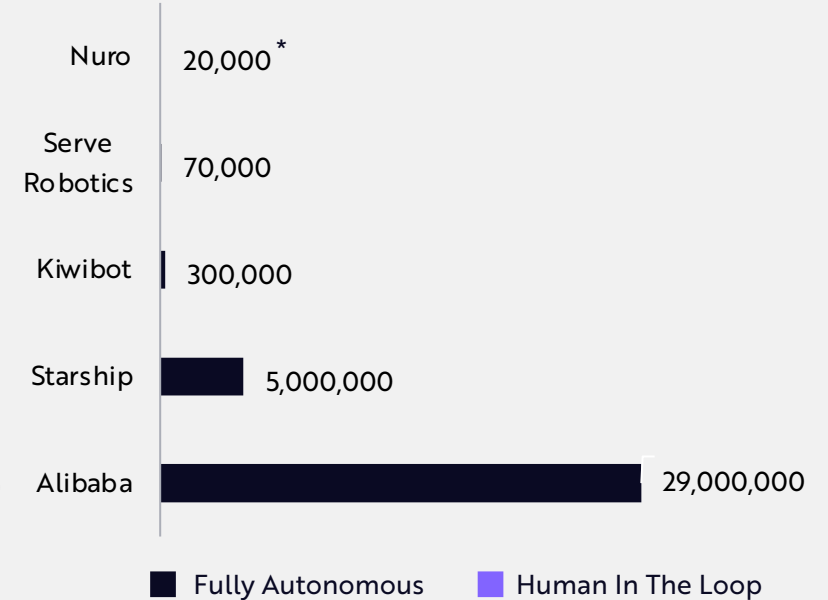
Note: All truck miles traveled are latest available real-world reported miles; Gatik Class 6 trucks have operated commercially without a safety driver in some instances and the dashed navy lines are a representation of this. *Figures estimated based on available data. Robot delivery companies have different package capacities per robot, so some can make more deliveries per run tha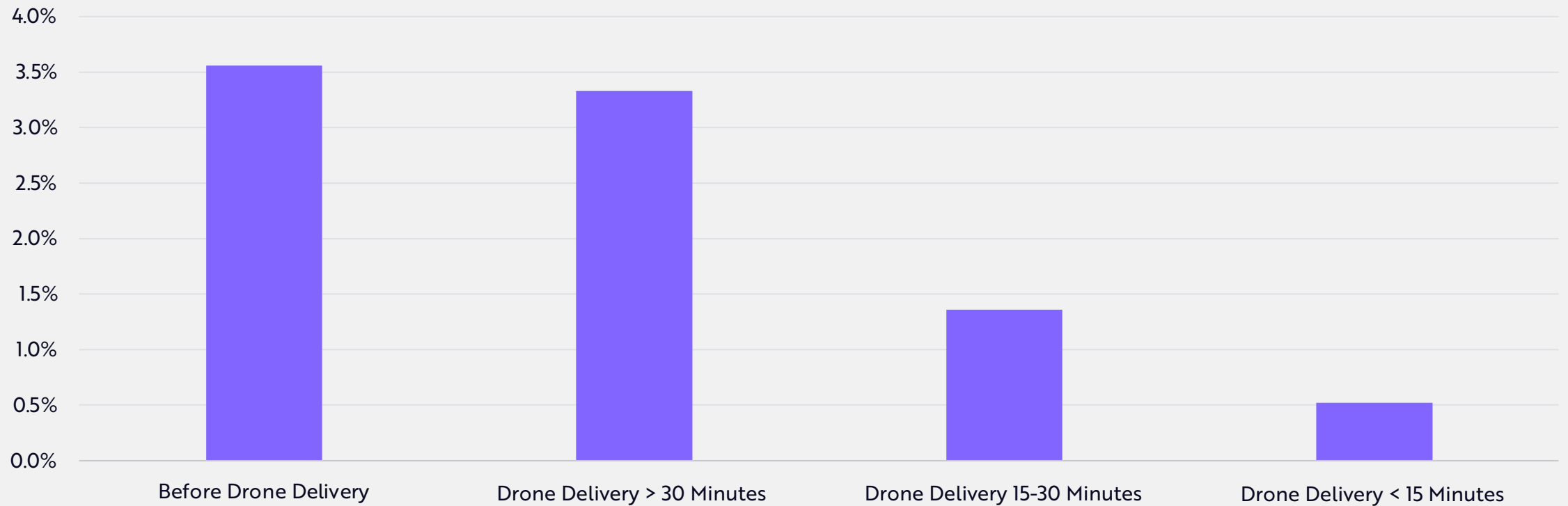n others. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources as of January 11, 2024, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

AI Pilot Performance Seems Superior To That Of Human Pilots

AI pilots have immense data advantages over humans. Zipline drones have logged more commercial flight miles than would have been possible by humans.

In head-to-head simulated F-16 dogfights with a human expert fighter pilot, Shield AI won 5-0.*

In drone races, AI trained by deep reinforcement learning outperformed professional human pilots 15 out of 25 times, with lap times ~10% faster.

AUTONOMOUS LOGISTICS

Competitive Wins

■ AI Pilot   ■ Human

15

10

5

0

F-16 Dogfight Simulated

(US Defense Advanced Research Projects Agency (DARPA) Challenge, Shield AI vs. Expert F-16 Pilot, 2020)*

Drone Racing Competition

(University of Zurich Researchers vs. International Drone Racing Champions, 2023)

Flight Hours

769,000

65,800

1,500

FAA Airline Pilot Training Requirement

Commercial Human Pilot Flight Hours (Career Maximum Per Federal Age and Flight Hour Restrictions)

Zipline Commercial Hours (Fleet Cumulative)

AUTONOMOUS LOGISTICS

Autonomous Drones Should Reduce Food Delivery Costs, Thanks To Regulatory Approvals

Boosted during and after COVID, food delivery fees have doubled the average cost of baseline menu orders.

Beyond line-of-sight drones without visual observers should reduce food delivery costs dramatically, thanks to recent FAA approvals.
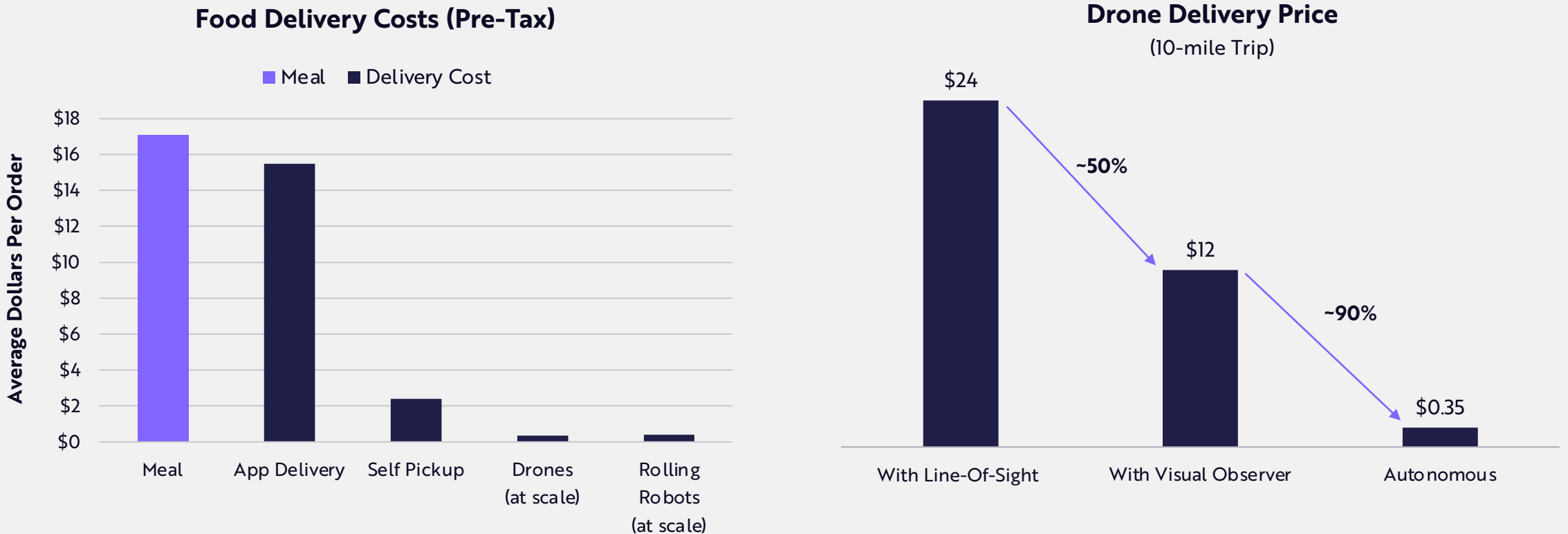
Food Delivery Costs (Pre-Tax)

■ Meal   ■ Delivery Cost

Drone Delivery Price
(10-mile Trip)

Drones Are Saving Lives

In geographies without road infrastructure, Zipline drones can deliver blood in fewer than 15 minutes, improving the mortality associated with post-partum hemorrhages by 80%.

AUTONOMOUS LOGISTICS

Postpartum Hemorrhage Mortality Rate
Before And After Drone Delivery Of Blood Transfusions In Rwanda

Autonomous Food And Parcel Delivery Could Create A $1-2 Trillion Addressable Market

AUTONOMOUS LOGISTICS

Addressable Market For Last Mile Autonomous Food and Parcel Delivery*
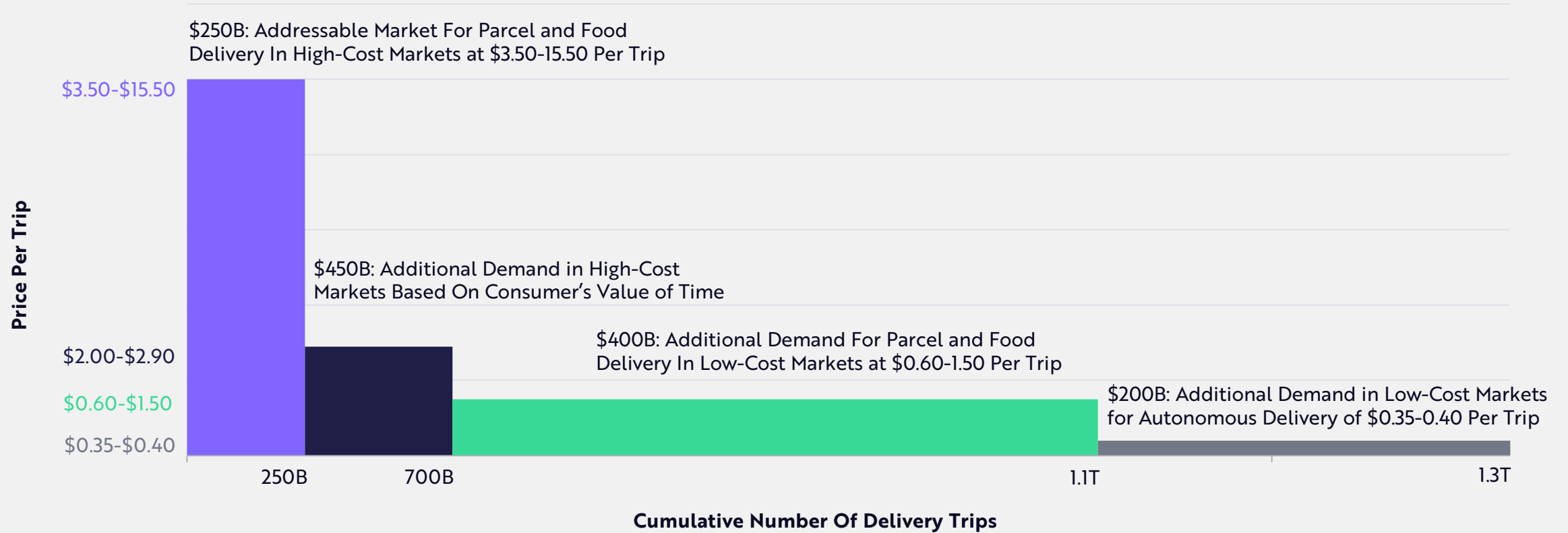
$250B: Addressable Market For Parcel and Food Delivery In High-Cost Markets at $3.50-15.50 Per Trip

$450B: Additional Demand in High-Cost Markets Based On Consumer's Value of Time

$400B: Additional Demand For Parcel and Food Delivery In Low-Cost Markets at $0.60-1.50 Per Trip

$200B: Additional Demand in Low-Cost Markets for Autonomous Delivery of $0.35-0.40 Per Trip

Price Per Trip

$3.50-$15.50

$2.00-$2.90

$0.60-$1.50

$0.35-$0.40

250B   700B   1.1T   1.3T

Cumulative Number Of Delivery Trips

Global Autonomous Delivery Revenue Could Reach $900 Billion by 2030

Robot and drone food and parcel delivery fees could reach $450 billion in 2030, as affordable technology-enabled delivery reshapes consumer habits. Meanwhile, autonomous trucking revenues could reach $450 billion in 2030, as autonomous trucks coupled with drones and robotics transform the way that businesses transport goods cost effectively and quickly.
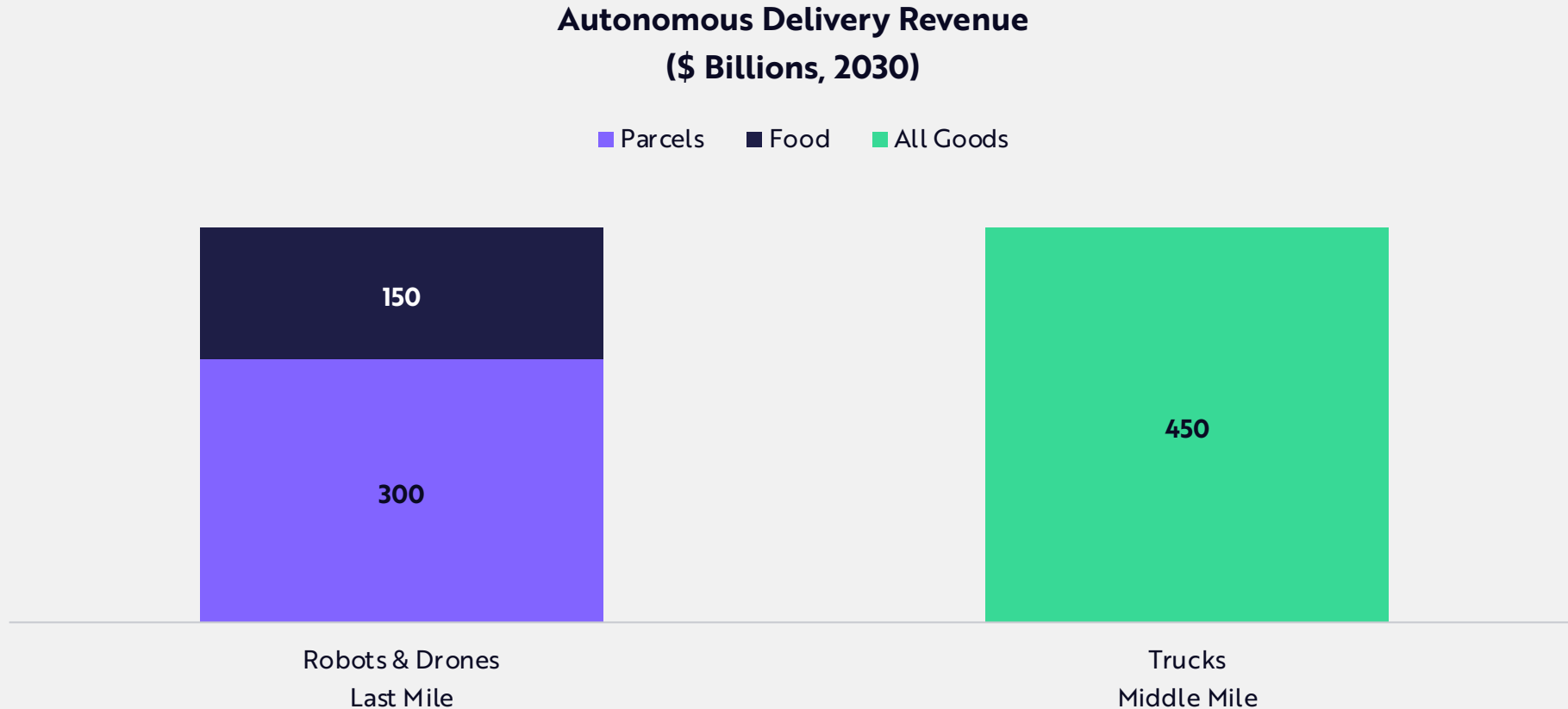
AUTONOMOUS LOGISTICS

Autonomous Delivery Revenue
($ Billions, 2030)

■ Parcels ■ Food ■ All Goods

150	450
300	

Robots & Drones
Last Mile

Trucks
Middle Mile

Autonomous Logistics Could Double The Enterprise Value Of Precision Agriculture

Thanks to continued automation and yield improvements enabled by breeding, transgenics, and agricultural biologics, the operating cost per bushel produced—a metric incorporating both cost and yield—could decline by ~30% across major US crops.*

Agricultural companies with per-acre business models could generate autonomous platform fees on the cost savings from the technology, achieving software-like margins. As a result, their collective enterprise value could roughly double to ~$600 billion at scale.**

US Farm Operating Cost Per Bushel for Major Crops*

■ Farm Operating Costs Per Bushel
■ Autonomous Platform Fee Per Bushel
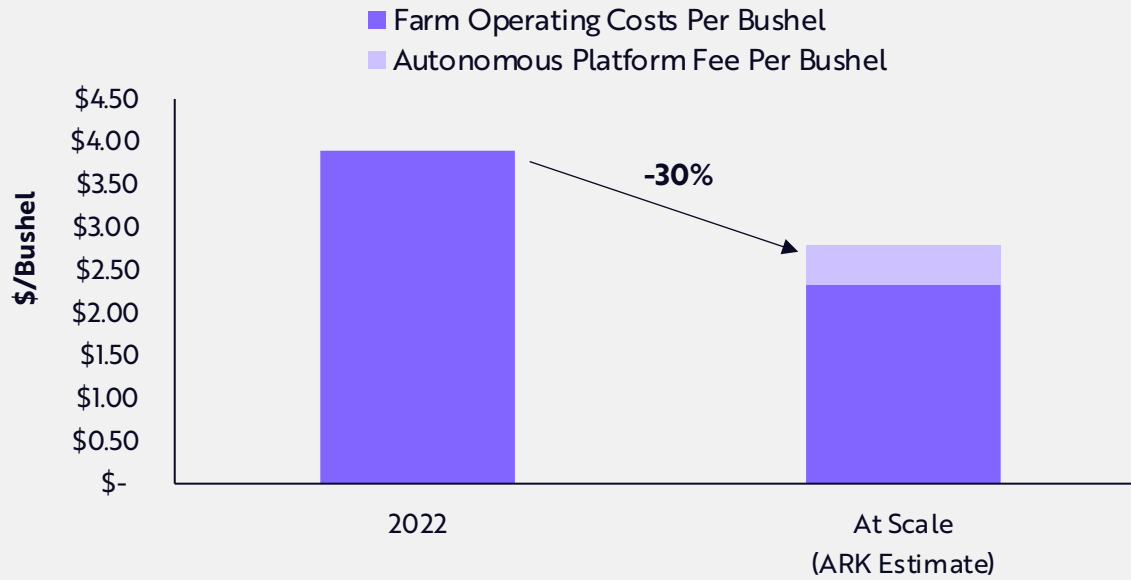
Global Agricultural And Farm Machinery Enterprise Value
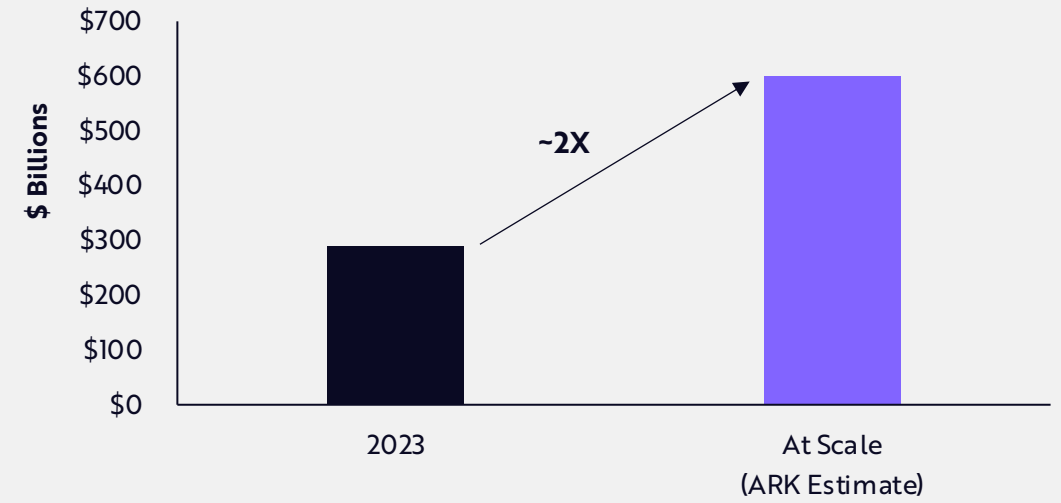
*This analysis focuses on "Major Crops"—Corn, Soybean, and Wheat—which ARK defines as the top three crops in the US based on bushel production. Numbers are rounded. **When accounting for different cost compositions and adoption rates globally. This assumes a 50% autonomous platform fee and a 19X EV/EBITDA multiple on autonomous service earnings. Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, using the latest available data as of January 4, 2024, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

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Reusable Rockets

Opening Outer Space For Business

Reusable rockets are lowering launch costs dramatically, opening outer space for business and creating new services like direct-to-device satellite connectivity. According to ARK's research, satellite connectivity revenues could reach $130 billion in 2030, still just a fraction of the roughly $2 trillion in telecommunications revenue.

Longer term, hypersonic flight point-to-point could generate revenues of ~$35 billion in 2030, and potentially reach $350 billion at scale.

Reusable Rockets Should Lower Launch Costs By An Order Of Magnitude...Or Two!

SpaceX's reusable rocket, Falcon 9, put an end to soaring launch costs. By reusing one Falcon 9 booster 19 times, SpaceX increased its annual launch cadence nearly 60% to 96 in 2023.

Rocket Launch Costs
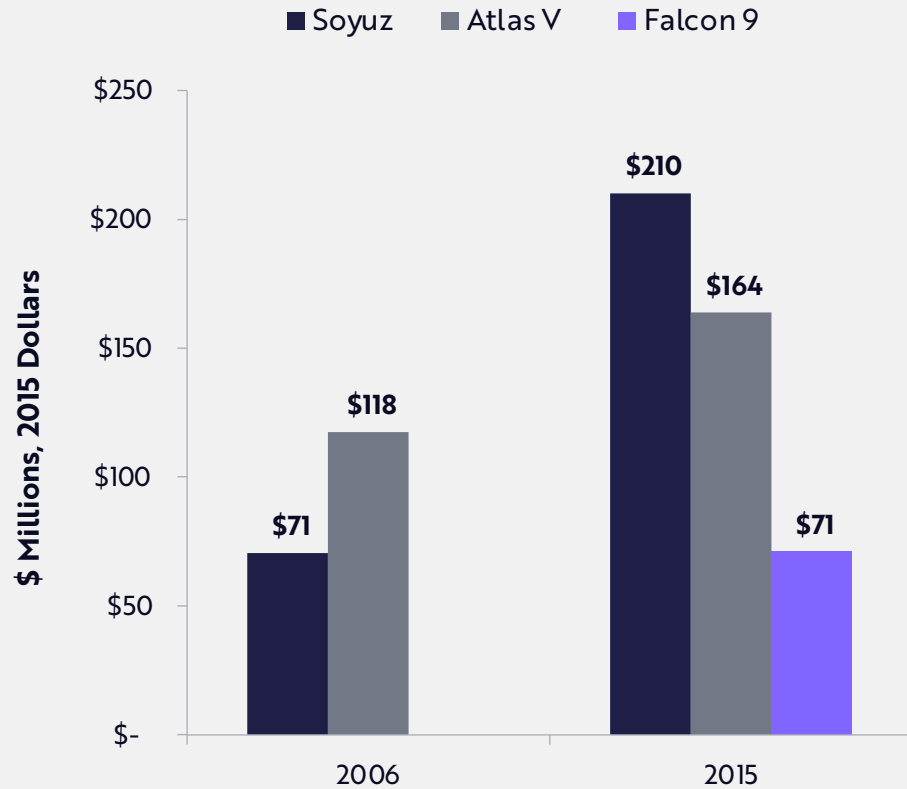
■ Soyuz ■ Atlas V ■ Falcon 9

SpaceX Launch Costs*
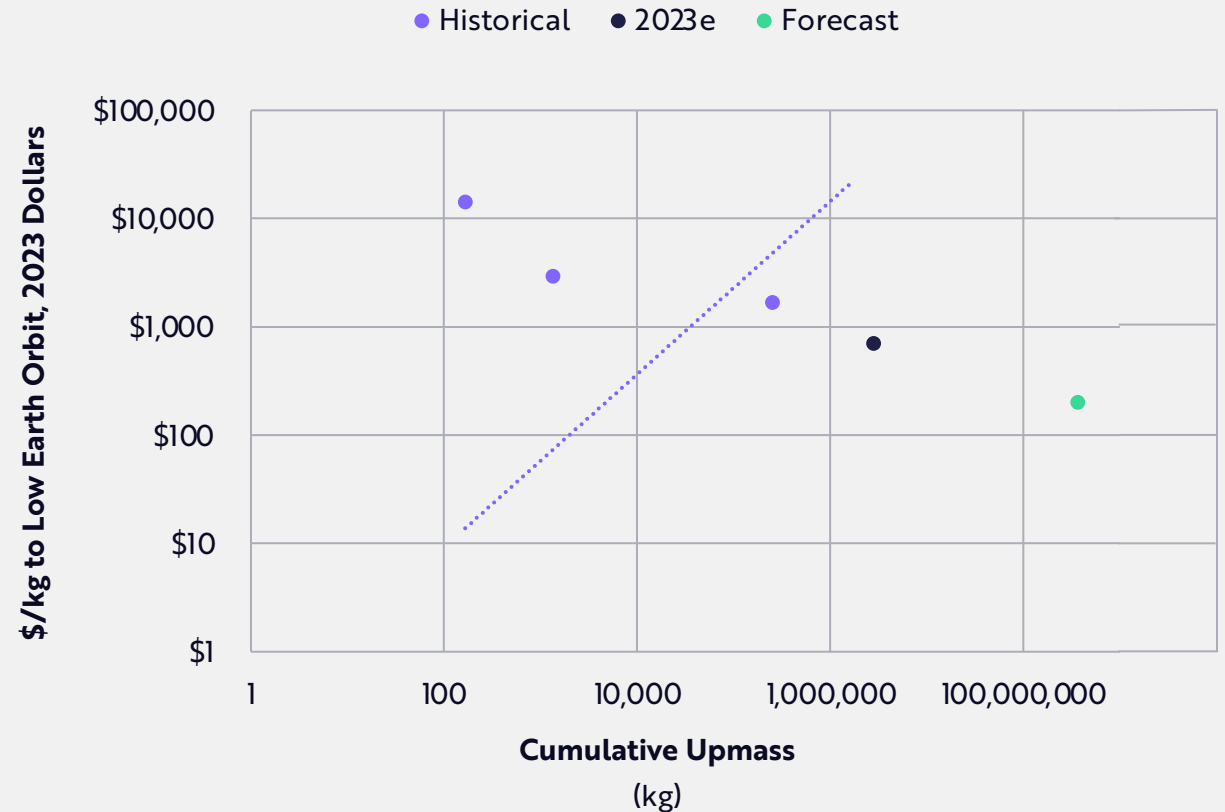
● Historical ● 2023e ● Forecast

REUSABLE ROCKETS

SpaceX Is Refurbishing Rockets In Record Time

When the Space Shuttle cost ~$1.5 billion per launch, industry experts assumed that a reusable rocket would be impossible economically. SpaceX then flipped the script.

According to ARK's research, the first stage of the Falcon 9 cost <$1 million to refurbish. Now, rocket turnaround time should be proportional to the cost required to refurbish a rocket booster, the key metric in tracking launch cost declines.
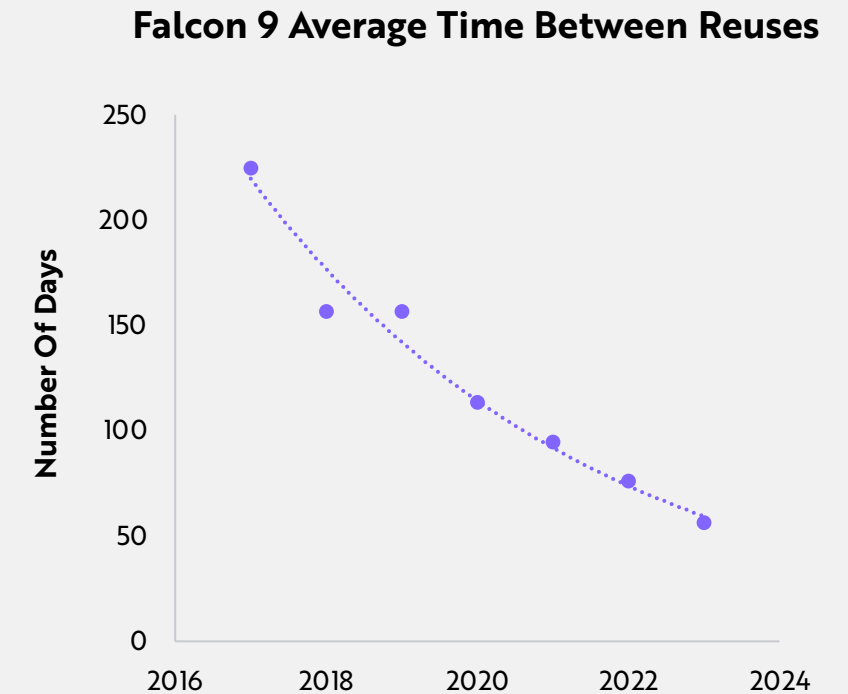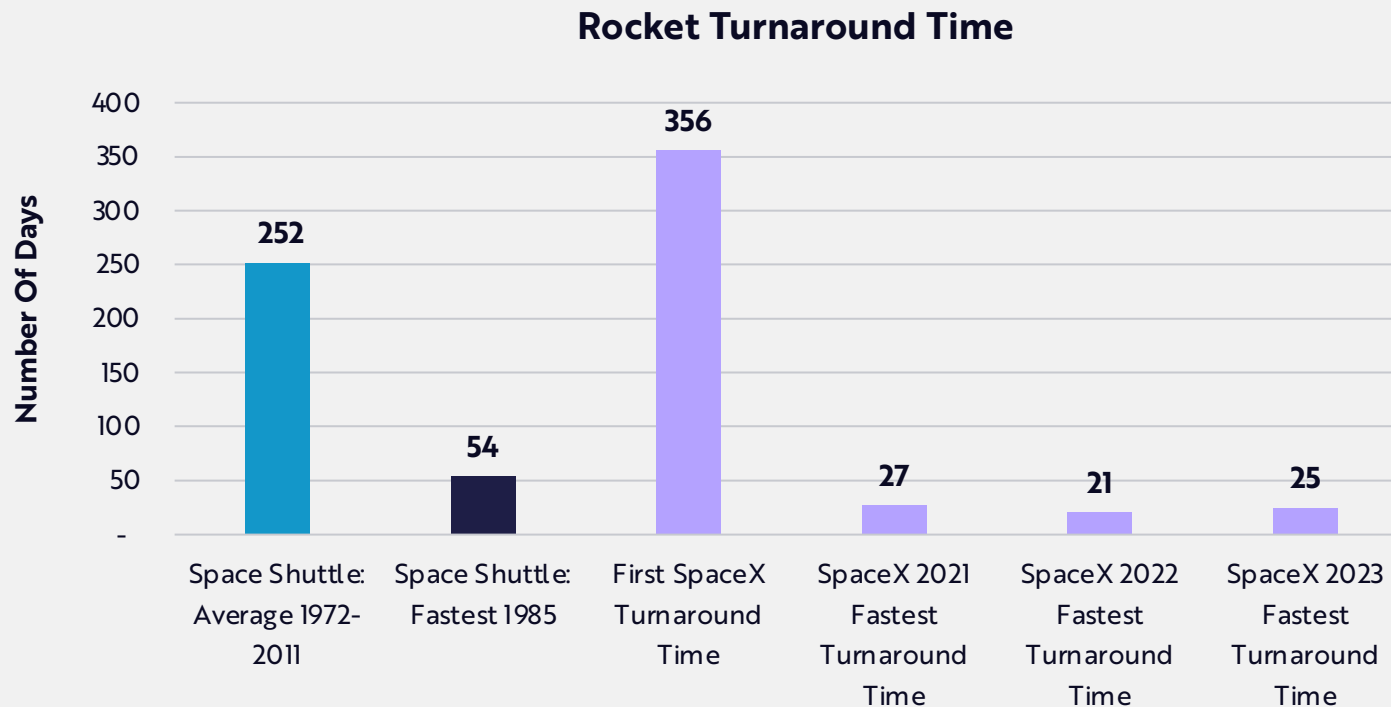
Rocket Turnaround Time

**Falcon 9 Average Time Between Reuses**

Lower Satellite Launch Costs Should Enable Continuous Global Coverage With Low Latency

While latency precluded geostationary orbit (GEO) satellites from offering a compelling broadband internet solution, now thousands of low-cost, low earth orbit (LEO) satellites can provide service with low latency, continuous global coverage, and direct-to-mobile device connectivity.

REUSABLE ROCKETS

LEO
~300 miles
<40 ms latency

Debris will fall back to earth within ~5 years
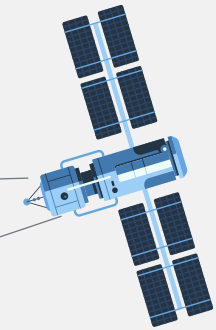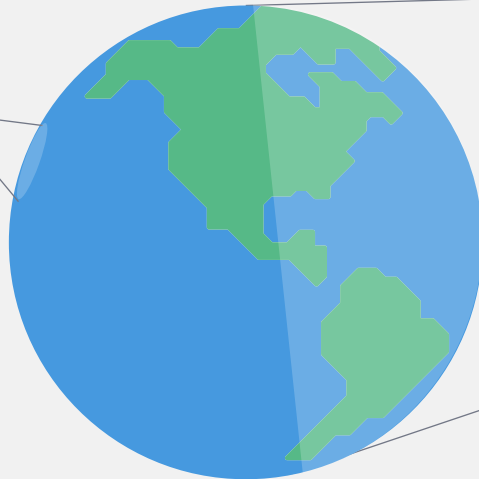
GEO
~22,000 miles
700 ms latency

Debris will fall back to earth within 1,000+ years

REUSABLE ROCKETS

Starship Will Help The Starlink Constellation Achieve Its Potential

Starship's payload capacity to LEO is ~5x that of the Falcon 9. While impressive, given the five-year life of its satellites, Starship still will have to fly every 3.5 days to maintain its target constellation of 42,000 Starlink satellites. As of January 2024, SpaceX has a constellation of ~5,400 satellites.
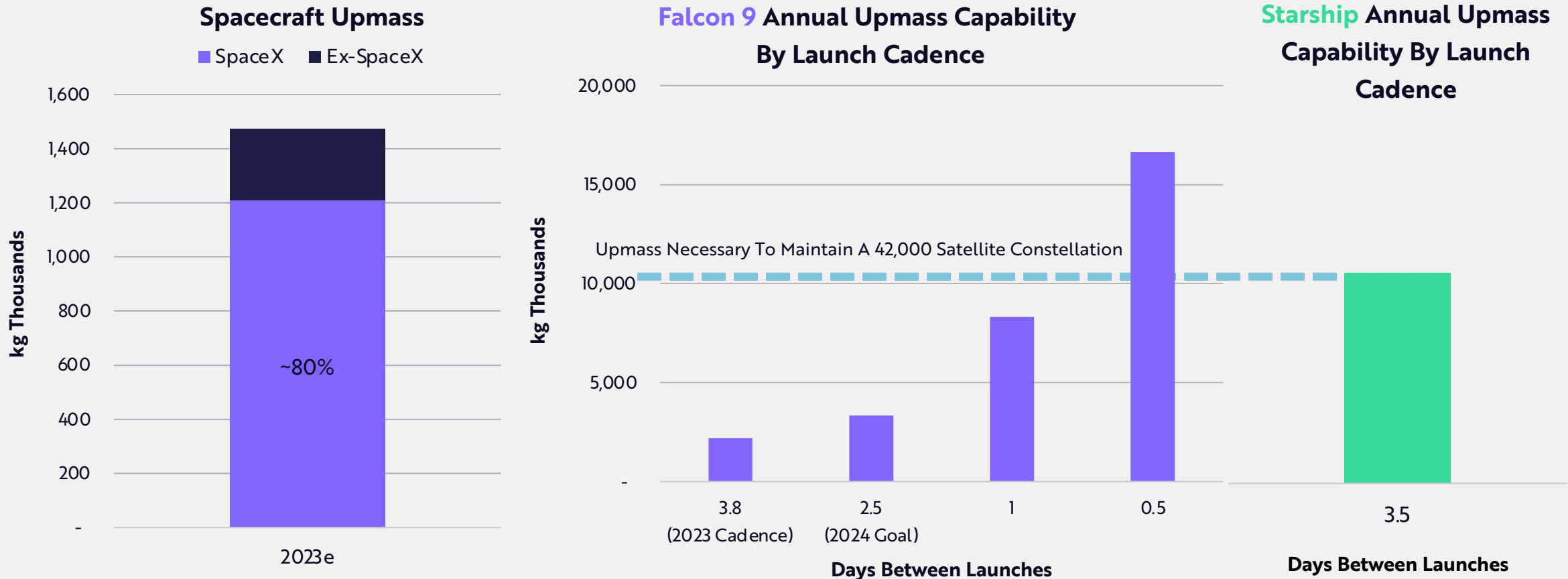
Spacecraft Upmass
■ SpaceX ■ Ex-SpaceX

kg Thousands

~80%

2023e

Falcon 9 Annual Upmass Capability By Launch Cadence

kg Thousands

Upmass Necessary To Maintain A 42,000 Satellite Constellation

3.8 (2023 Cadence) 2.5 (2024 Goal) 1 0.5

Days Between Launches

Starship Annual Upmass Capability By Launch Cadence

3.5

Days Between Launches

Sources: ARK Investment Management LLC, 2024. This ARK analysis is based on a range of underlying data from external sources, including Brycetech 2023a, 2023b, 2023c, and McDowell 2024 as of January 23, 2024, which may be provided upon request. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.

REUSABLE ROCKETS

Small Launch Providers Proliferated But May Not Be The Winners In Space

After capital spending booms, industries tend to consolidate. In the space industry, while launch capability is critical, the larger opportunity could be in the services enabled by low launch costs. Today, only 16 of the 186 small launch providers created since 1996 are operational.

New Small Launch Providers Founded
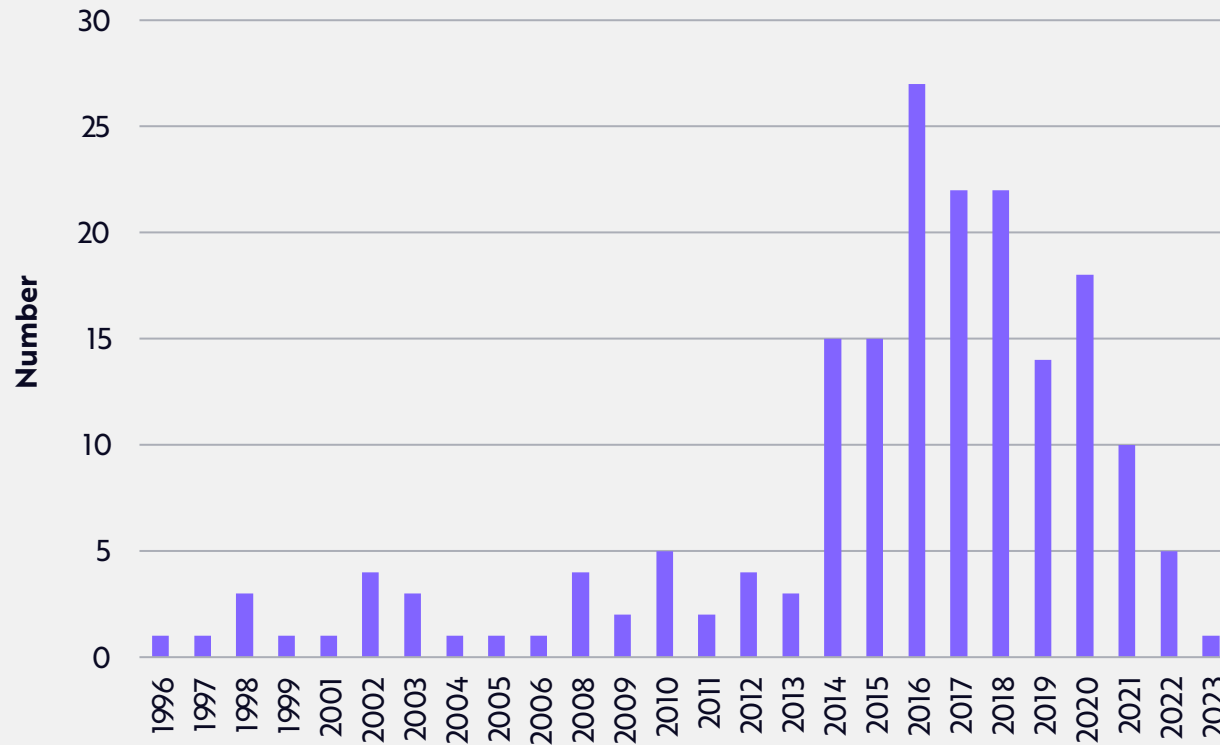
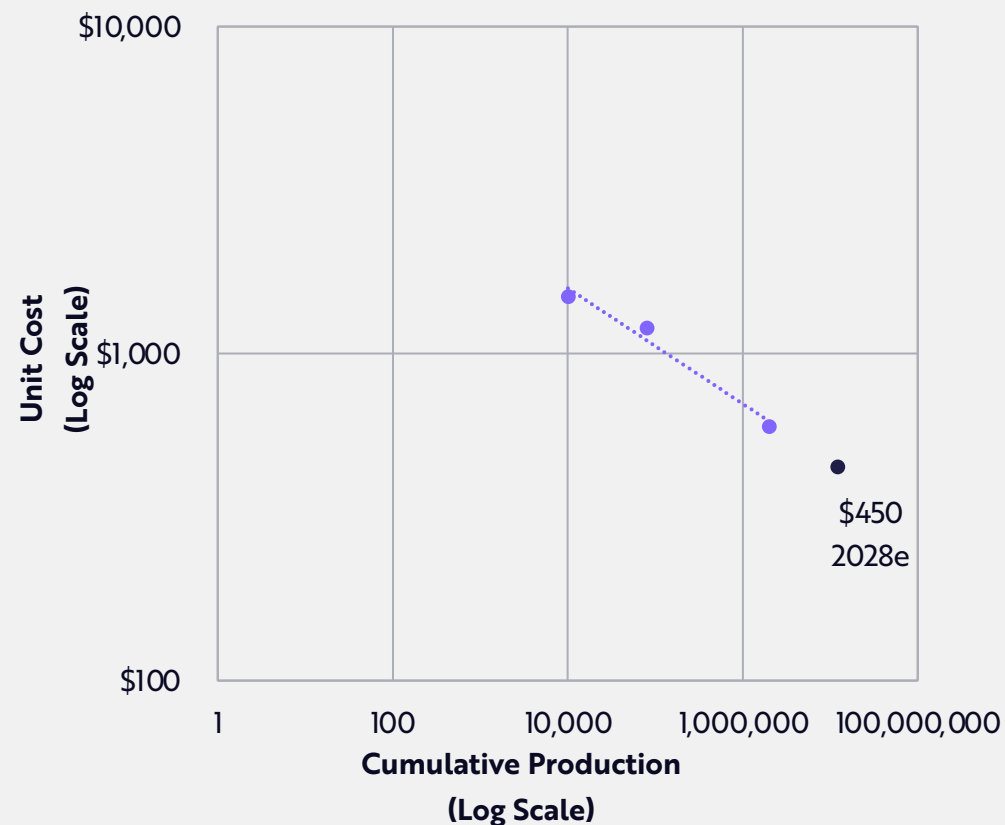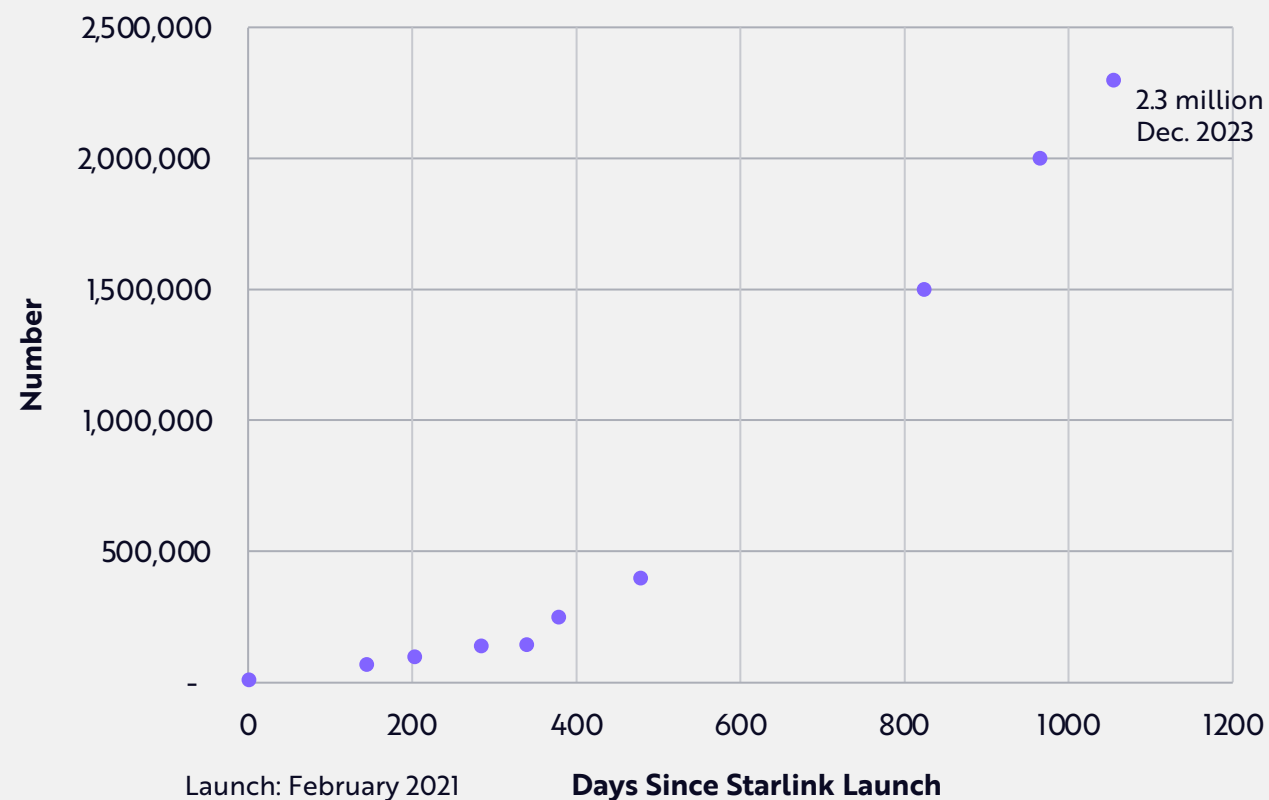### Stage Of Small Launch Providers Created Since 1996
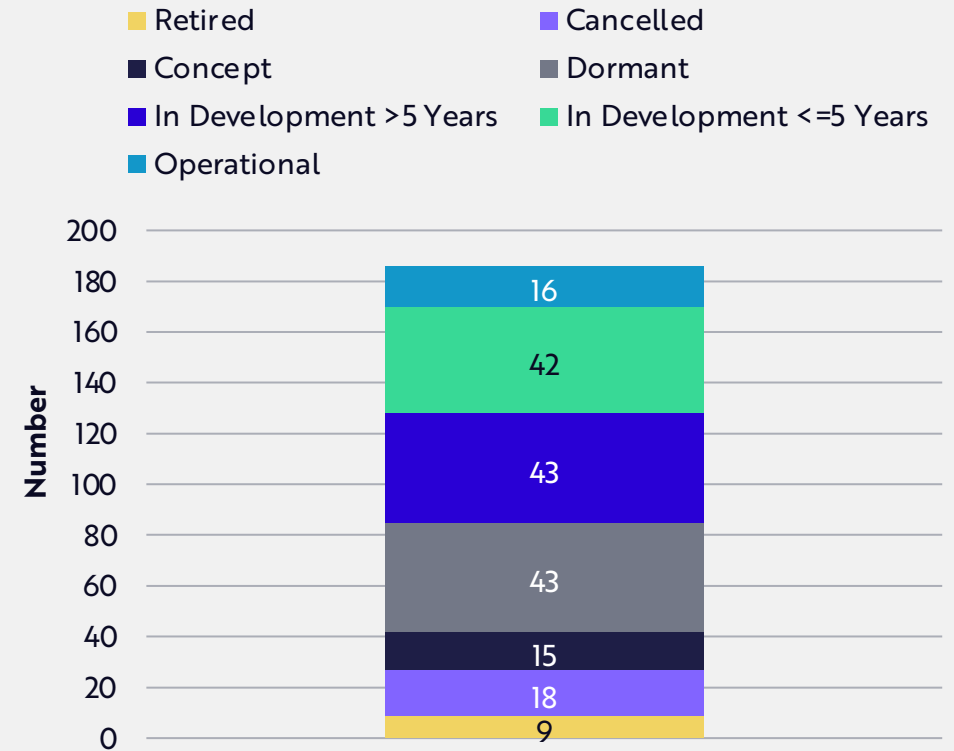
Antenna Costs Continue To Decline

SpaceX currently produces user terminals for less than the $599 it charges customers. Lower antenna costs should enable SpaceX to scale Starlink profitably.

REUSABLE ROCKETS

Starlink Antenna Costs

Unit Cost (Log Scale)

$10,000

$1,000

$100

$450
2028e

Cumulative Production (Log Scale)

1   100   10,000   1,000,000   100,000,000

Starlink Subscribers

Number

2,500,000

2,000,000

1,500,000

1,000,000

500,000

-

2.3 million
Dec. 2023

0   200   400   600   800   1000   1200

Launch: February 2021

Days Since Starlink Launch
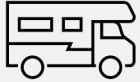
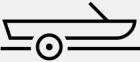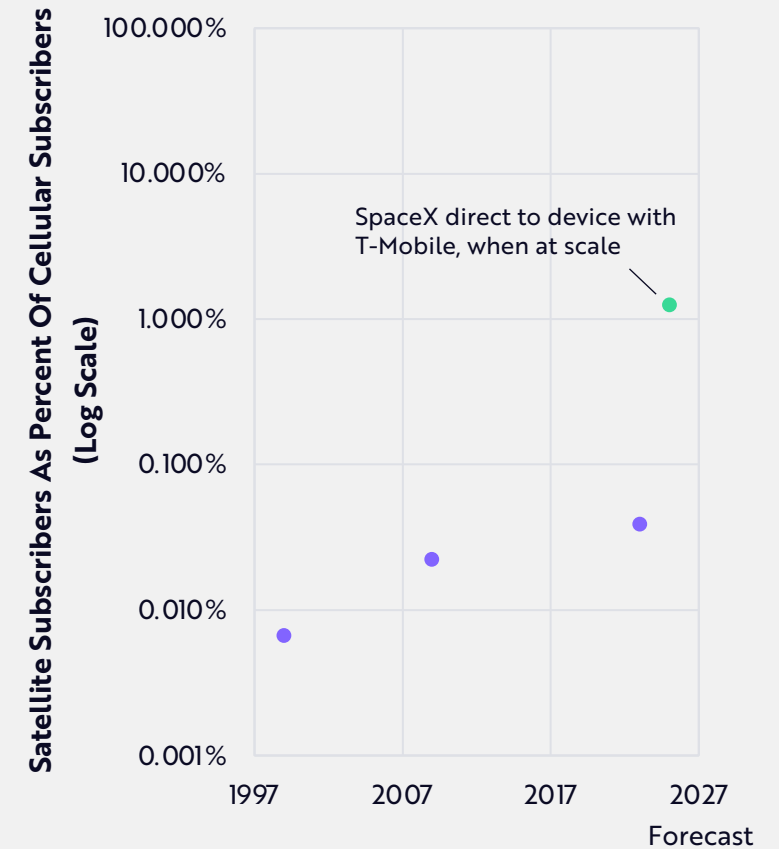# Satellite Connectivity Revenues Could Exceed $130 Billion Per Year

ARK believes direct to device capability will be adopted by all telecom operators over time.

REUSABLE ROCKETS

		Addressable Subscribers*		Annual Revenue*		Annual Addressable Market*
Direct to Device		8 billion	✖	$6	=	~$48 Billion
Global Households Without Access To Broadband		600 Million	✖	$60	=	~$40 Billion
RVs		11 Million	✖	$1,620	=	~$18 Billion
Recreational Boats		8.5 million	✖	$1,620	=	~$14 Billion
Commercial Aircraft Fleet		25 Thousand	✖	$225,000	=	~$6 Billion
Cruise Ships, Warships, Commercial Ships		100 Thousand	✖	$60,000	=	~$6 Billion

Total: ~$132 Billion

Satellite Subscribers As Percent Of Cellular Subscribers

Satellite Subscribers As Percent Of Cellular Subscribers (Log Scale)

SpaceX direct to device with T-Mobile, when at scale

1997   2007   2017   2027 Forecast

REUSABLE ROCKETS

By 2030, Hypersonic Flight Could Be A ~$35 Billion Market, Ready To Scale To ~$350 Billion Longer Term

According to the US Department of Transportation, leisure travelers are willing to spend 60%-90% of their estimated hourly household income to save one hour.*
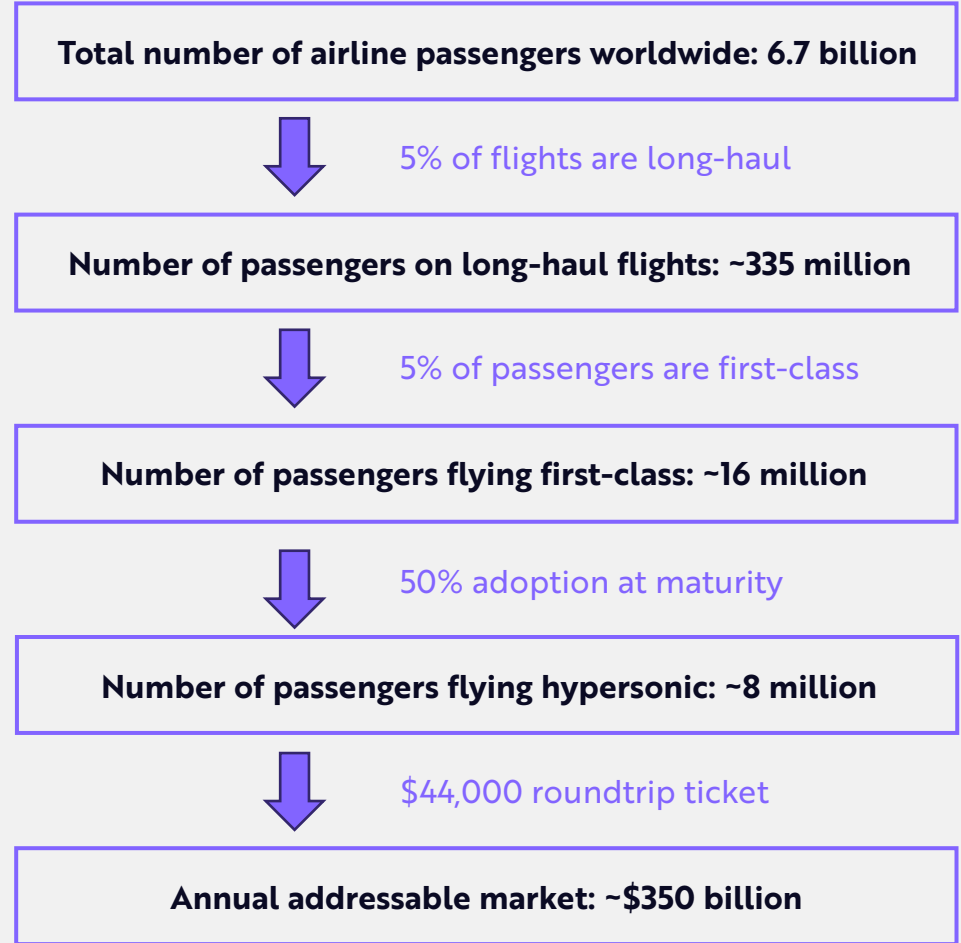
Compared to conventional flights that can take 28 hours roundtrip, ARK estimates that hypersonic flights could take just 6 hours, saving each traveler ~22 hours.

Given the typical cost and potential time savings, ARK's research suggests that a first-class passenger should be willing to spend $44,000 roundtrip for a hypersonic flight.

If launch costs decline in line with ARK's expectations, early adopters of hypersonic flight could generate $35 billion revenue by 2030.

	Starship		Roundtrip		Price
110kg	✕	$200/kg to LEO	✕	2	=	$44,000

Building Blocks Of Addressable Market Forecast

Total number of airline passengers worldwide: 6.7 billion

↓ 5% of flights are long-haul

Number of passengers on long-haul flights: ~335 million

↓ 5% of passengers are first-class

Number of passengers flying first-class: ~16 million

↓ 50% adoption at maturity

Number of passengers flying hypersonic: ~8 million

↓ $44,000 roundtrip ticket

Annual addressable market: ~$350 billion

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Research Associate

BIG IDEAS 2024

3D Printing

Reshaping Manufacturing

In automotive manufacturing, 3D printing has lowered both the part count and the product development timeline dramatically. As a result, automakers can carry less inventory and save on tooling costs.

In healthcare, 3D printing is making novel surgeries possible with customized guides, tools, and implants.

3D printing also should provide positive environmental benefits relative to traditional manufacturing.

Thus far, companies using 3D printing have benefited more than the 3D printing equipment manufacturers. In the future, data feedback loops could change that dynamic.
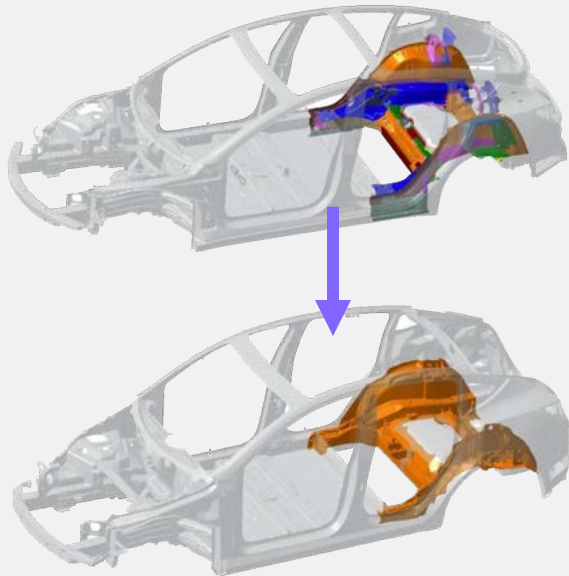
According to ARK's research, 3D printing revenues could scale ~40% at an annual rate during the next seven years, from ~$18 billion today to ~$180 billion in 2030.

Thanks To 3D Printing, Automotive Production Has Entered Unchartered Territory

Reportedly, Tesla is experimenting with 3D printed sand molds to cast auto underbodies that could substitute one part for 400 parts, lowering automotive development timelines and mold design validation costs by 50% and 97%, respectively. 3D printing could play a role in the production of every car.

3D PRINTING

400 parts → 1 casting

Vehicle Development Time

3-4 Years (Historical Average) → **-50%** → 18-24 Months (Average With 3D Printing)

Design Validation Cost

$ Millions

Metal Mold → **-97%** → 3D Printed Sand Mold
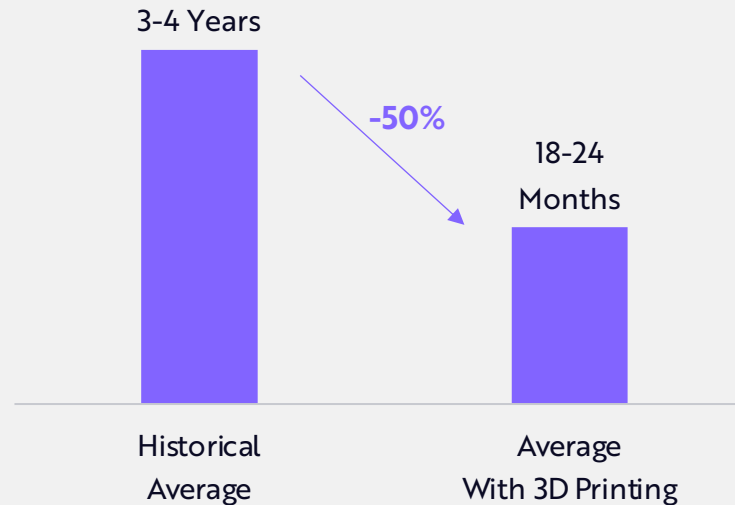
3D Printing Has Played A Role In Medical Breakthroughs

In fewer than 24 hours after identifying the donor, Materialise 3D printed pivotal surgical tools and guides used in the world's first eye transplant. Speed to operation is critical to preserving donor tissue deprived of blood supply.
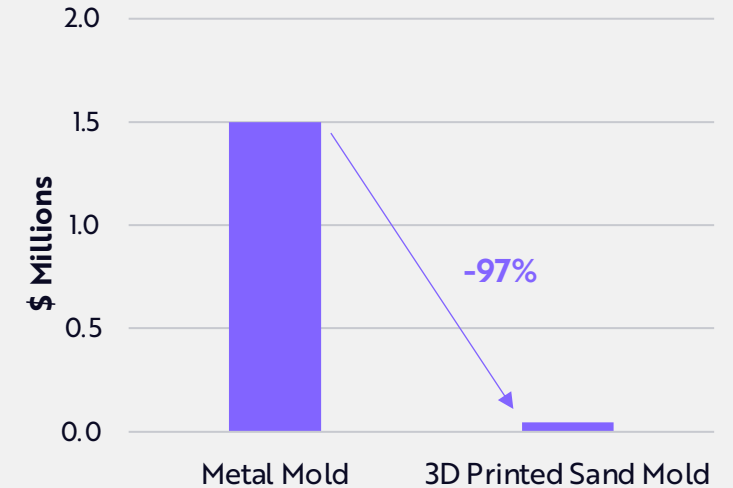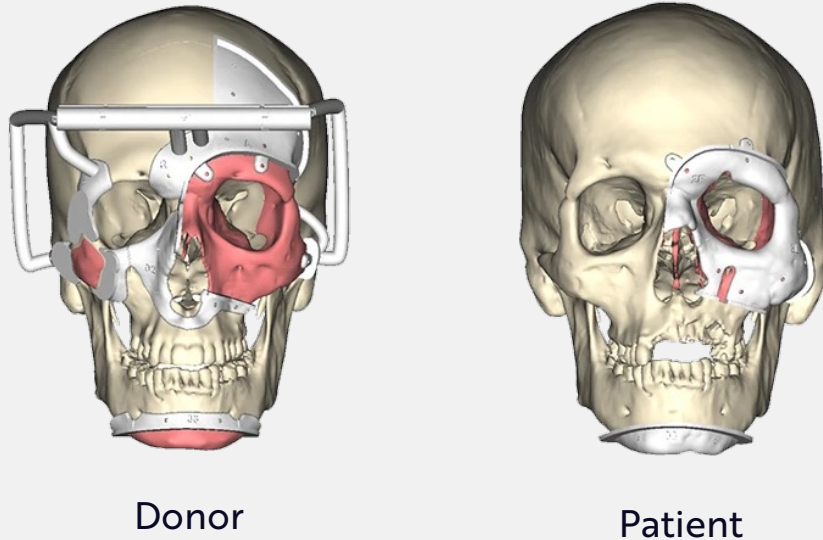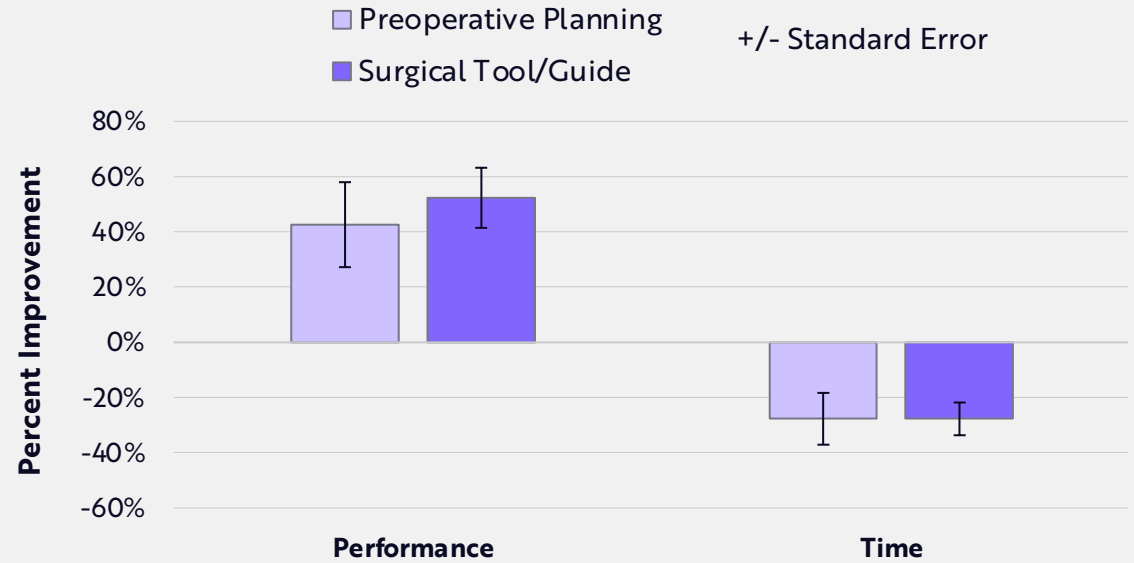
Across a range of surgeries, 3D printed tools, guides, and models increased performance, as measured by surgical accuracy and results, by ~40-50% and reduced operating time on average by ~30%.

During Surgeries, 3D Printed Tools, Guides, and Models Shorten Time And Improve Accuracy

Donor

Patient

Note: Time Savings and Accuracy Improvements Provided by 3D Printed Surgical Guides and Preoperative Planning Aides: bars represent the average percent improvement in time or performance as described in Bergmann et al. 2017 and Woodard et al. 2019, N=6-9 for each sample group. Error bars represent +/- standard error. The above analysis was conducted across medical fields; however, oral maxillofacial surgery and musculoskeletal studies were the most prevalent.

Thus Far, 3D Printing Has Benefited Users More Than Suppliers

SpaceX uses 3D printing every day to make parts for Starship's Raptor engines. Today, the operating margins of SpaceX's launch and satellite business are superior to those of any 3D printing supplier. Industrial companies benefiting from 3D printing could vertically integrate to sustain their competitive advantages.

Velo3D And SpaceX
2023 Estimates In Thousands

■ Velo3D   ■ SpaceX

$180,000

$108

$103 $9,000

-$71 $3,000

Enterprise Value   Revenue   EBIT
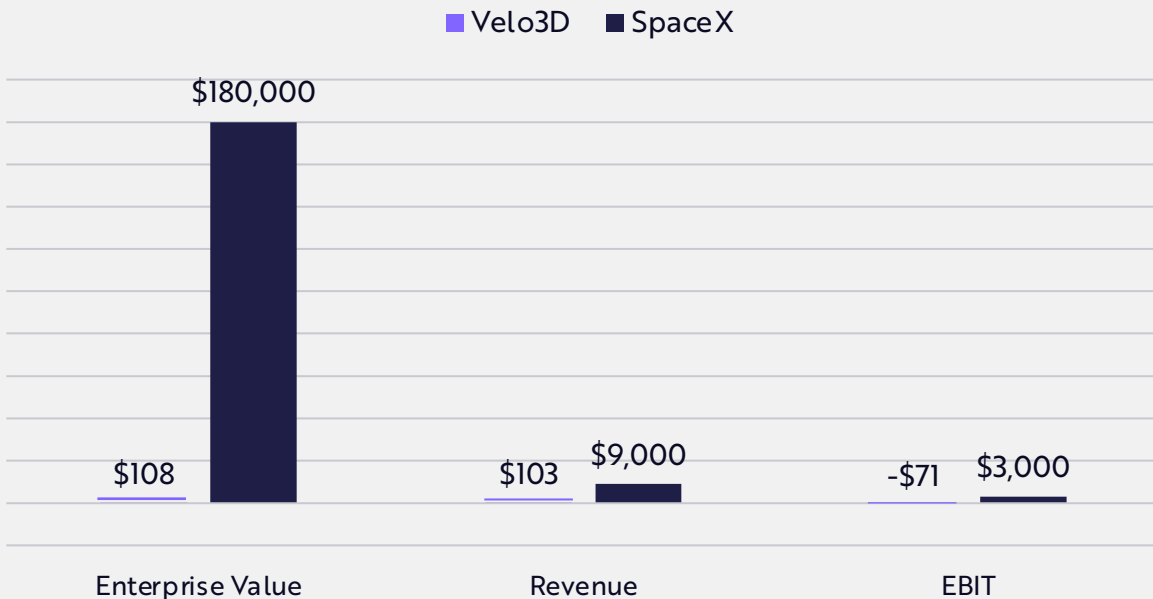
A SpaceX Super Heavy Booster With 33 Raptor Engines:

@ErcXspace / Twitter

Velo3D is a 3D-printer manufacturer specializing in support-free powder bed fusion. Sources: ARK Investment Management LLC, 2024, based on data from S&P Capital IQ, 2024. SpaceX Heavy Booster Illustration sourced from Ali 2021. Forecasts are inherently limited and cannot be relied upon. For informational purposes only and should not be considered investment advice or a recommendation to buy, sell, or hold any particular security. Past performance is not indicative of future results.
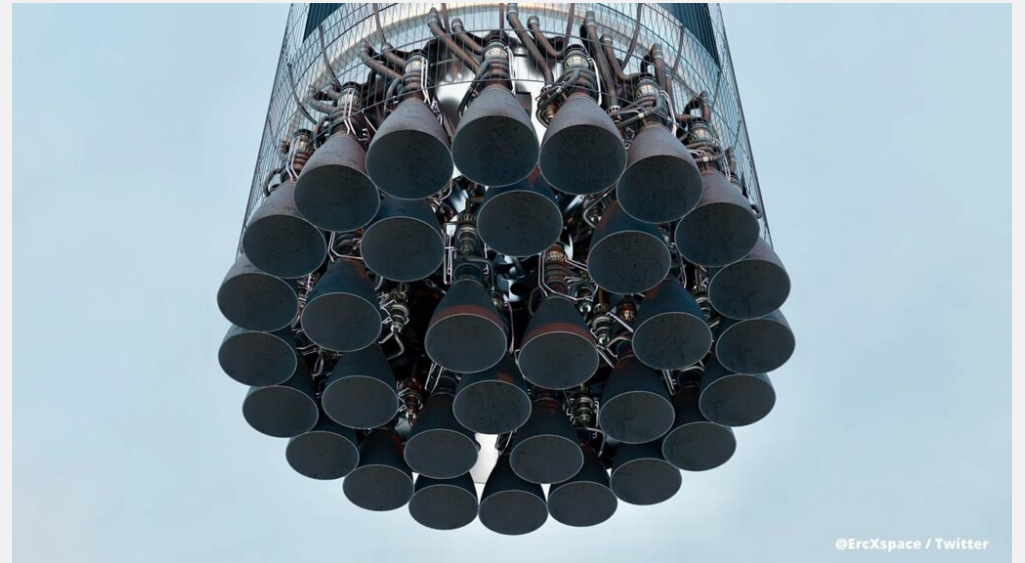
Software-Defined 3D Printers Could Shift Some Economics Back To Printer Manufacturers

With sensor-equipped 3D printers, 3D printing equipment manufacturers can collect data from customer print jobs and improve their fleets of printers in the field with over-the-air software updates. This data feedback loop could help 3D printing companies capture more economics than they do today.

While companies may be reluctant to share data, AI-enabled manufacturing solutions should create better outcomes for 3D printing equipment companies and their customers

Real Time Printing Data From Sensors on Customer Printers:
Geometry
Temperature
Moisture

Sent To 3D Printer Manufacturer

Over-The-Air Updates Improve Each Print
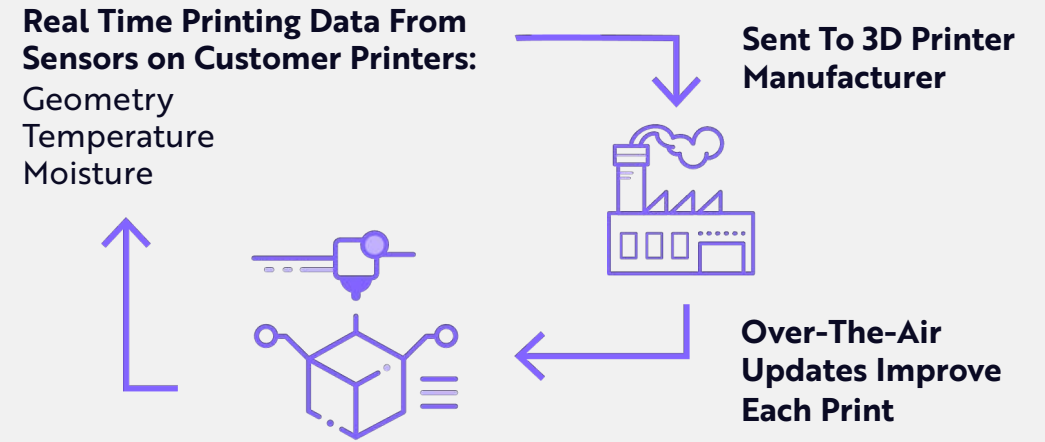
**Margin Structure
3D Printing Manufacturers Vs. Mature Tools Company**

■ Gross Margin ■ EBITDA Margin

Average of 3D Printer Manufacturers (Latest 12 Months)

Illinois Tool Works (Latest 12 Months)

3D Printing Revenues Could Grow ~40% At An Annual Rate To $180 Billion By 2030

3D PRINTING

3D Printing Revenue Forecast

$ Billions
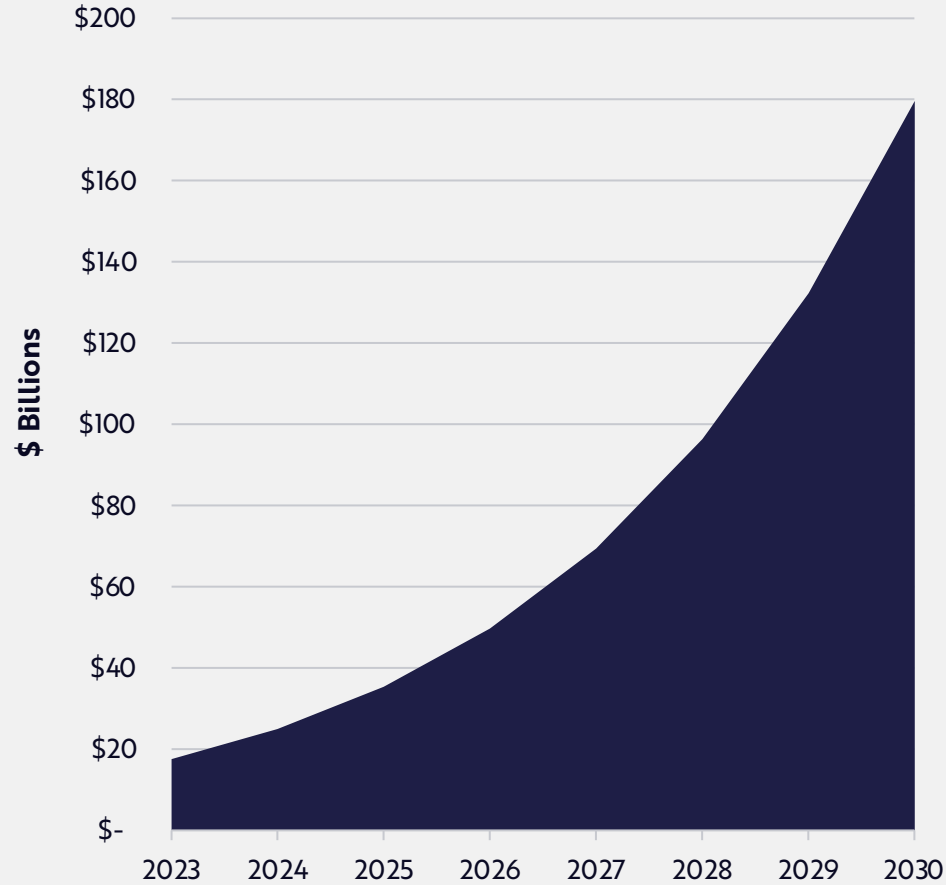
Revenue By Industry
Select Industries Using 3D Printing
(Latest 12 Months As of 1/18/24)

$ Trillions
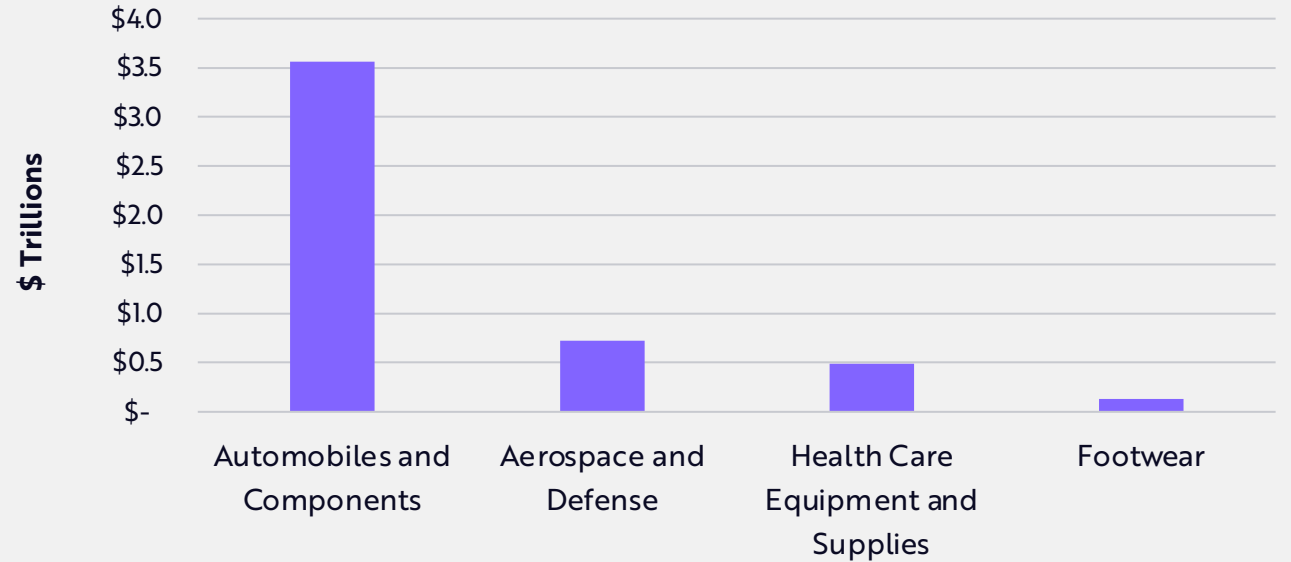
Company Examples:	Automobiles and Components	Aerospace and Defense	Health Care Equipment and Supplies	Footwear
	Tesla Volkswagen Ford General Motors BMW	SpaceX Lockheed Martin	Stryker Align	Nike Adidas

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DISCLOSURE

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