Thematic Investing

To the Moon(shots)! - Future Tech Primer

Thematic Investing

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Eureka! The 14 technologies of the future you must know

6G could have a download speed of 1Tb/s, the OceanTech economy could be as big as Germany's GDP, and thanks to Emotional AI our personal devices will know more about our feelings than our families. If we don't appear at meetings via Holograms, we will get there by eVTOL flying cars and, by the end of the decade, we will spend more time in the Metaverse than 'real life'. These are just a few of the 14 moonshots in this report, i.e., radical technologies that could change our lives and accelerate the impact of global megatrends. And we argue they are not as far into the future as you might think.

Tomorrow may be too late; pace of change to accelerate

Failure to identify future tech today could mean missing out on the next big revolution. The pace at which themes are transforming businesses is blistering, but the adoption of many technologies – like smartphones or renewable energy – have surpassed experts' forecasts by decades, because we often think linearly but progress occurs exponentially. And we haven't seen anything yet: a paradigm shift in the explosion of data (we are generating 2.5 quintillion bytes of data every day which is doubling every 2-3Y), faster processing power (>1 trillion-fold increase since Apollo 11), and the rise of AI (already same IQ as a 6 year old) would bring about the fastest rollout of disruptive tech in history.

Imagine investing in the Internet before dot.com boom

Leftfield technologies will be needed to tackle immense global challenges. Could 5G be unable to handle the exponential growth in data by the end of the decade? Then 6G will need to be rapidly deployed in just 5-6Y. Could scarce natural resources and increasing emissions hold back the planet from decarbonizing and tackling climate change? Then carbon capture storage, nextgen batteries and green mining could be the solution to decrease emissions by 70% and enable access to 3x more rare earth metals. Is health the new wealth post-COVID? Then bionic humans, brain-computer interfaces and synthetic biology could all take us a step further towards the holy grail of 'immortality'.

Disruption always wins: 1.5% generated 100% of net wealth

In the past 30Y, just 1.5% of companies generated all the net wealth on the global stock market, meaning that actually only a handful of disruptors ('superstar firms') really influence long-term financial markets growth. Furthermore, accelerating innovation places incumbents at greater risk of displacement. In 1958, the average company lasted 61 years on the S&P 500; by 2016 this was 24 years and is forecast to be just 12 years by 2027.

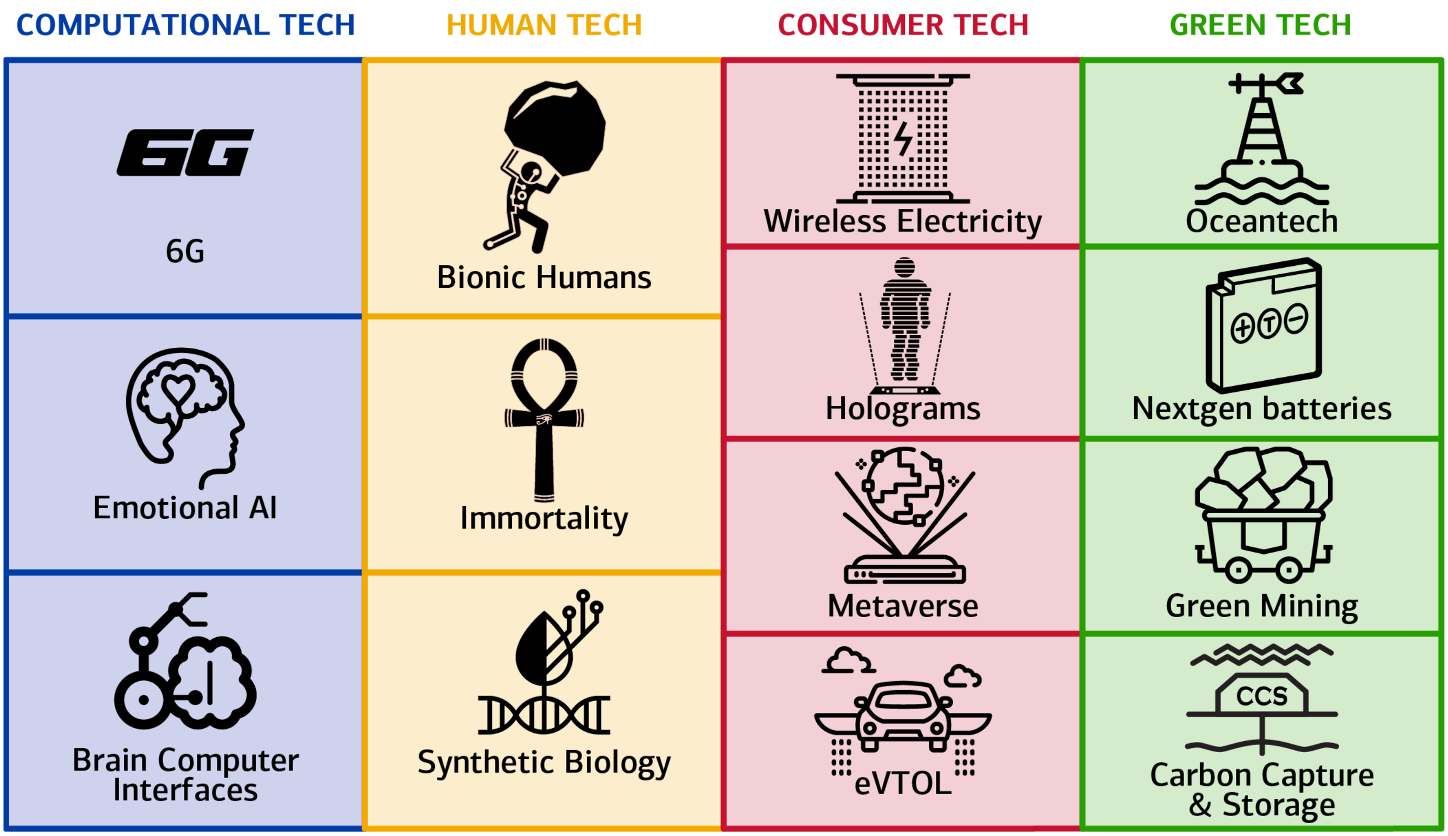
US$330bn mkt today; possibly US$6tn+ by the next decade

The 14 technologies we highlight in this report represent a US$330bn market size today (2019-21) growing at an average CAGR of 36% to potentially US$6.4tn by the 2030s. These moonshots could transform and disrupt multiple industries, contributing to the next big cycle of technology-driven growth.

Contents

14 Moonshots: what you need to know

Exhibit 1: What are the next future technologies?
14 disruptive moonshot technologies



Source: BofA Global Research

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Exhibit 2: Moonshots 101
Overview table of the 14 future technologies

Moonshot	Description	Milestones
6G	The next generation of telecom networks that is faster than 5G with 1TBps download speeds	2028: data volumes reach capacity of 5G networks
BCI	Connecting brains with computers to augment humanity cognition / thoughts	2021: human trials in progress
Emotional AI	Affective/Cognitive Computing capturing, analysing and responding to human emotions with AI	2020s: increasingly pervasive in everyday life
Synthetic Biology	Harnessing nature by redesigning organisms through genetic engineering to have new applications	2030: most people will have eaten, worn, or used synbio
Immortality	Breakthroughs in health/ biotech, anti-ageing drugs for radical life extension that 'disrupts death'	2029: humans could become 'immortal' and live forever
Bionic Humans	Technology that augments physical human capabilities e.g. exoskeletons, biohacking, implants	2021: world's first artificial cornea implanted
eVTOL	Electrical vertical take-off and landing vehicles that provides alternative mobility to road transport	2023: three eVTOL certified for commercial launch
Wireless Electricity	The use of magnetic fields or radio waves to transmit electricity wirelessly without cables	2025: 10 connected devices per person that needs charging
Holograms	Light imagery projections without headsets for digital interactions not requiring physical presence	2021: world's first hologram dining experience
Metaverse	Virtual worlds universe that interoperate with each other superseding the internet/physical world	2030s: spending more time in virtual world than real world
Nextgen Batteries	Next EV technologies after lithium-ion batteries such as solid state, sodium ion, vanadium flow etc	2020: one million mile battery pack breakthrough
Oceantech	Blue Economy where technology is deployed in the sea (ocean energy, precision fishing etc)	2030: global ocean economy equivalent to 2010 German GDP
Green Mining	Climate change is metals intensive requiring sustainable mining (sea, agro, wastewater, asteroid)	2024: commercial deep-sea mining set to start
CCS	Negative emissions technologies that captures and stores CO2 before release into the atmosphere	2040/50: $1 trillion in cumulative capex investments in CCS

Source: BofA Global Research

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Did eUreka Know?

- **6G**: At current average global mobile speeds it will take c.181mn years to download all the data from the internet … 838,000 years on 5G and "only" 17,000 years on 6G (source Statista, Unicorn Insight, IDC, BofA Global Research)
- **6G**: At a speed of 1Tb/s, you can download 142 one hour 4K movies in 1 second…or the entire NY Library in approximately 20 seconds (source: IDC, BofA Global Research)
- **Brain Computer Interface (BCI):** Early human clinical trials of minimally-invasive BCIs have allowed patients with ALS to text, bank, shop and email online (source: Synchron, 2021)
- **Brain Computer Interfaces (BCI):** A brain-to-brain interface has already allowed one human to control another's hands through their thoughts alone (source: University of Washington)
- **Emotional AI**: By 2022, your personal device will know more about your emotions than your family (source: Gartner)
- **Emotional AI**: An average person is exposed to 5,000 branded messages a day. 12 will be remembered, 90% of decision-making regarding those will be emotional (source: Captivate Group, Harvard)
- **Synthetic Biology**: By 2030 scientists believe most people will have eaten, worn, used or been treated by something created through synthetic biology (source: Nature, Visual Capitalist)
- **Synthetic Biology**: The TAM of synbio is estimated to be worth over US$1tn covering anything from agriculture, electronics, consumer care to pharma drug manufacturing (source: Zymergen)
- **Immortality**: By 2029, humans could become virtually 'immortal' by extending their lives considerably/indefinitely/ forever (source: Ray Kurzweil)
- **Immortality**: In 2018 the WHO recognized ageing as a disease, updating its classifications for the first time in 35 years (source: WHO)
- **Bionic Humans:** in 2013 the world's first walking, talking bionic man ('FRANK') with artificial limbs & beating heart unveiled (source: Live Science)
- **Bionic Humans:** in 2021, Israeli surgeons implanted the world's first artificial cornea into a bilaterally blind 78-year-old man (source: press article)
- **eVTOL:** Safety levels for eVTOL are expected to match that of commercial airlines, i.e. 1 in a billion chance of catastrophic failure (source: EASA)
- **eVTOL:** 3 passenger eVTOL aircraft are expected to be certified for commercial launch by 2023 (source: EASA)
- **Wireless Electricity:** By 2025 there will be 10 connected devices per person that will need to be charged (source: IHS Markit, McKinsey, Gartner)

- **Wireless Electricity:** 5G could act as a source of energy to store the exponentially growing volume of connected devices (source Eid et al, 2021)
- **Holograms:** Swedish pop band ABBA plan to release their first album in 40 years with a hologram tour (source: press articles)
- **Holograms:** 6G will be required because a hologram display over a mobile device (one micro meter pixel size on a 6.7 inch display form-factor requires at least 0.58 Tbps (source: Samsung)
- **Metaverse:** By the 2030s virtual reality will be totally realistic and compelling, meaning we'll be spending more time in the virtual world than real world (source: Ray Kurzweil)
- **Metaverse:** Ariana Grande, Marshmello and Travis Scott have performed 'video game concerts' in Fortnite showing what the future of gigs could look like in the metaverse (source: Epic Games)
- **Nextgen Batteries:** In 2020, CATL announced that it had developed a power pack that lasts 2mn kilometers (1.24mn miles) and more than 6 years (source: BNEF).
- **Nextgen Batteries:** In 2021, for the first time, the proposed Tesla 4680 cylindrical cell EV battery technology can now be fully charged in 10 minutes (source: Storedot)
- **Oceantech:** By 2030 the global ocean economy could reach a gross value of around US$3tn roughly equivalent to the size of the German economy in 2010 (source: OECD)
- **Oceantech:** Ocean energy can provide 10% of Europe's current electricity needs by 2050, which is enough to power 94mn households per year (source: Ocean Energy Europe)
- **Green Mining:** Europe has over 10,000km2 of land with low fertility and productivity that are rich with metals that could be put to the alternative use of agromining (source: LIFE-AGROMINE)
- **Green Mining:** Deep sea mining could produce metals with 70% less CO2 emissions (source: DeepGreen, The Metals Company)
- **Carbon Capture Storage (CCS):** All paths towards net zero and 1.5C of warming *requires* CCS / negative emissions technologies (source: IPCC)
- **Carbon Capture Storage (CCS):** by 2030 annual capex for CCS could reach ~US$25bn or equivalent of US$100bn of cumulative investments. By 2040 / 2050 there could be US$1tn in cumulative investments (source: BofA Global Research)

Sectors and Industries impacted – tailwinds / headwinds

Exhibit 3: Industries impacted by Future Tech
Beneficiaries are Technology, Healthcare vs Challenged are Autos, Commercial Real Estate

Sector	Beneficiaries/Challenged	Future Tech Comments
Communication Services		
Telcos	Beneficiary	6G should benefit telco equipment providers with denser networks, telco service providers will have to cope with sooner than expected 5G to 6G migration
New Media & Entertainment	Beneficiary	Gen Z will drive shift towards Metaverse and Holograms, greater content creation for virtual worlds, more leisure time in the very long term could benefit sector
Big Tech Platforms	Beneficiary	Leading pioneers in multiple moonshot technologies (Emotional AI, Brain Computer Interfaces, Bionic Humans, Immortality, Holograms, Metaverse)
Consumer Discretionary		
Autos	Mixed	eVTOL could be disruptor for road passenger vehicles, Nextgen Batteries and Green Mining is an opportunity and risk for shift towards EVs
eCommerce / Retailing	Beneficiary	Metaverse could drive the next retailing wave like eCommerce with the rise of Social Commerce and virtual worlds shopping
Energy		
Oil & Gas – Majors & Refining	Mixed	CCS the last 'earthshot' technology for fossil sector to remain relevant, otherwise increased stranded assets risks from EV reducing oil demand, growth of renewables & energy storage
Real Estate		
Data Center, Telco Tower	Beneficiary	Sector benefits from 6G creation which will accelerate demand for even more data intensive services like holograms, metaverse, emotional AI, brain computer interfaces, eVTOL
Offices	Challenged	Hologram technology could accelerate the WFH trend even more with people interacting more in virtual offices in the Metaverse
Commercial/Malls/Residential/Lodging	Challenged	Metaverse could be the next big thing on par with eCommerce disruption with consumers shopping more and more in virtual worlds
Health Care		
Biopharma & Biotech	Beneficiary	Immortality breakthroughs' sector could drive next big cycle of healthcare innovation eg. anti-ageing drugs, senolytics, geroscience, life extension medicine
Life Sciences Tools/Diagnostics	Beneficiary	Synthetic Biology could be as big as CRISPR as we enter the next stage of genomic engineering with biofacturing, LST sector will be a key beneficiary as the enablers of the SynBio revolution
MedTech / HealthTech	Beneficiary	Bionic Humans exoskeleton will drive growth in robotic surgery, implants, wearables etc that benefits the sector, other human tech like immortality and synthetic biology could also provide tailwinds
Industrials		
Capital Goods	Beneficiary	Collaboration between humans and robots (cobots) will be a key driver of Bionic Humans, sector however could be disrupted if Wireless Electricity theme mainstreams and put pressure on cabling / voltage companies
Commercial Aerospace / Transport	Mixed	eVTOL innovation being driven by incumbent A&D companies, however with Holograms and Metaverse there is a risks of long term decline in demand for commercial aviation via corporate / business travel as people WFH
Materials		
Metals & Mining	Beneficiary	Green Mining, Nextgen Batteries, Oceantech benefits sector, climate change decarbonization is positive for metals eg. EV demand for lithium, cobalt, nickel, gold, copper
Chemicals	Beneficiary	Synthetic Biology could unleash wave of new materials/chemicals innovation and Nextgen Batteries likely to benefit sector as enabler of EV materials
Information Technology		
Semiconductors	Beneficiary	Among the biggest beneficiaries in Future Tech with Moore's Law as the key enabler of 6G, Brain Computer Interfaces, Emotional AI etc
Tech Software / Cloud	Beneficiary	Another big beneficary of future tech that will power Holograms, Metaverse in the future supported by tech hardware
Tech Hardware / Cybersecurity	Beneficiary	World of future tech will need strong cyber privacy solutions to protect businesses from the next global black swan
Utilities		
Renewables / Integrated Utilities / IPPs	Beneficiary	Green Tech beneficiary from innovation in Wireless Electricity, Oceantech, Nextgen Batteries, Green Mining and CCS along with existing tailwinds in solar, wind, EV charging, energy storage etc

Source: BofA Global Research

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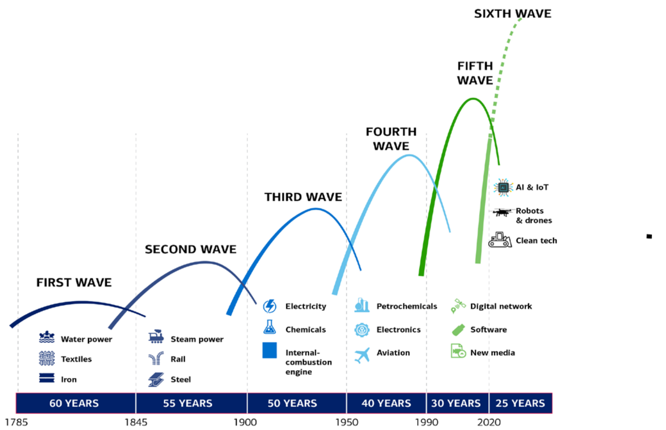
Success requires focus on new disruptors

The pace of transformation in many fields is the fastest in human history. And the impact of this change is more tangible than ever before, whether via climate change, demographics, or technological innovation.

Exhibit 4: Innovation waves are speeding up

The waves of innovation have increased from 60+ years to 25 years today



Source: Visual Capitalist, Edison Institute

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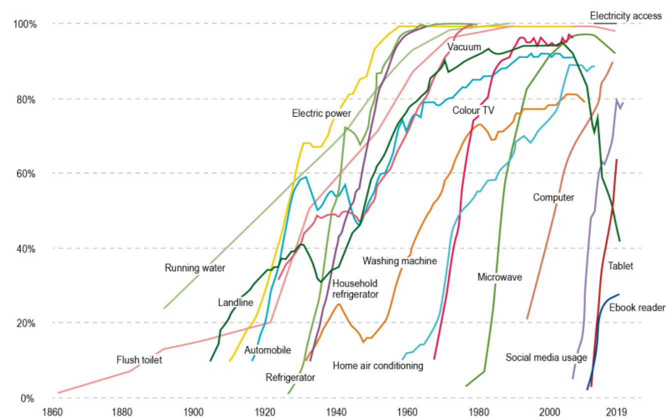
Exhibit 5: Technological consumption is spreading faster today than ever before

The pace of penetration of technologies to the mainstream has increased over time



Source: Comin & Hobijn, Horace Dediu, Our World in Data

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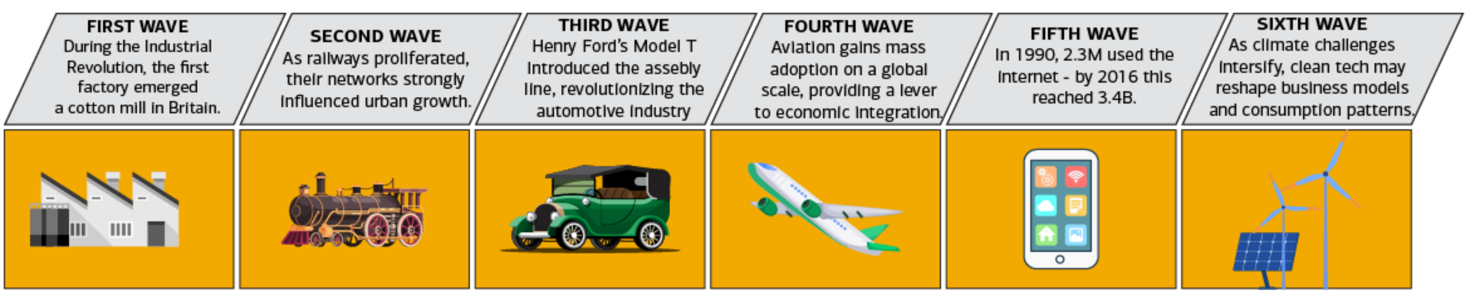
Consequently, 'long-term' trends that seemed far off previously are drawing ever closer. In this primer, we look at some of the future tech out there – the inventions/discoveries that could innovate and disrupt industries and produce social and economic growth in a sustainable way.

Exhibit 6: Key breakthroughs from the six waves of innovation

Cleantech comes to the forefront in the sixth wave with increasingly pressing climate concerns



Source: Visual Capitalist, World Bank, OECD, Nacima Baron, HAL

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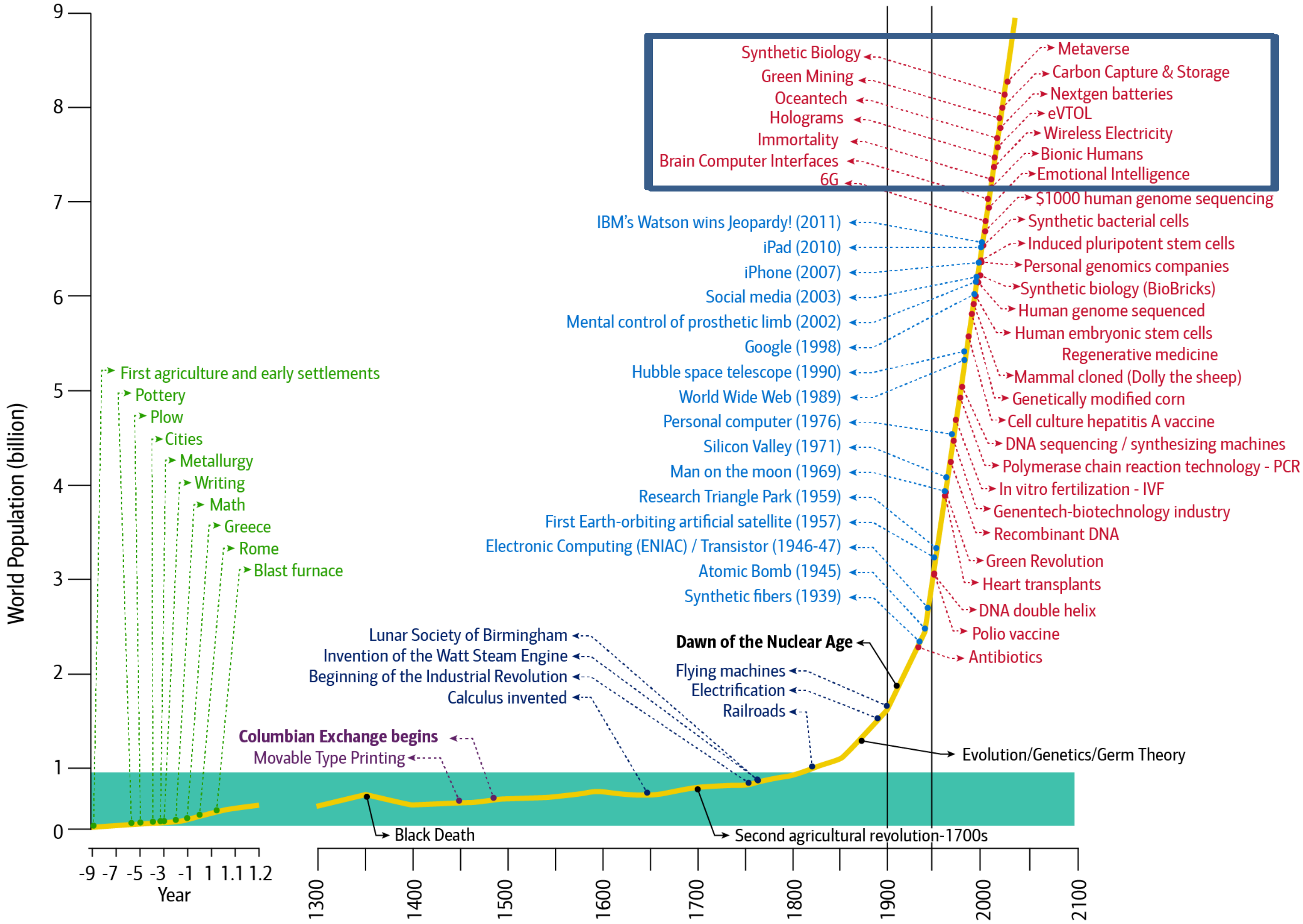
Exhibit 7: Innovation fuels population growth. How will the Next Technologies drive growth and quality of life?
Technology developments over time vs population growth



Source: Robert Fogel, BofA Global Research

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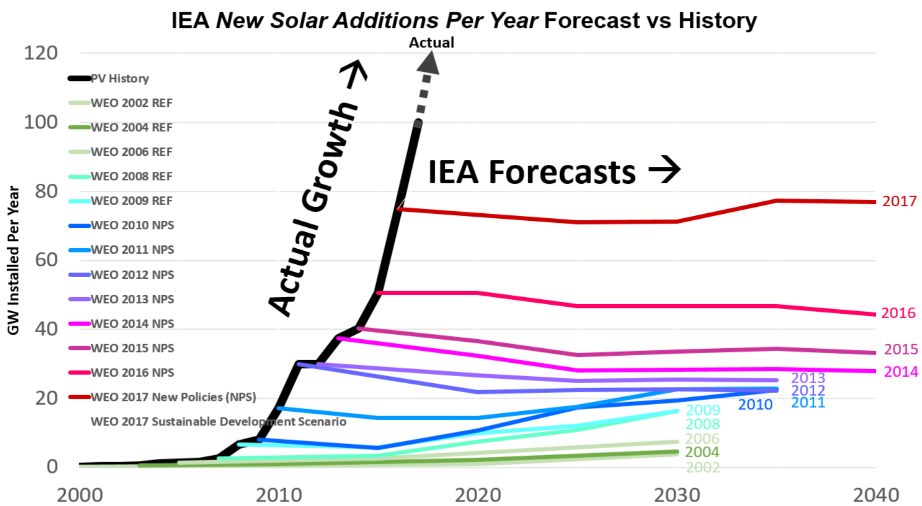
New tech is consistently underestimated

The pace of transformation continues to accelerate, meaning that long-term, distant technologies are approaching ever faster. However, humans continue to underestimate this acceleration, failing to accurately assess the near-term potential of new technologies and their disruptive impact on society. In this report, we highlight 14 new technologies that could prove disruptive and yet have barely been considered by investors and wider society.

Exhibit 8: Humans and even expert forecasters are prone to underestimate exponential growth
IEA each year has forecast linear growth of solar additions/year while actual growth of new solar GW installed per year has been exponential



Source: Visual Capitalist, IEA

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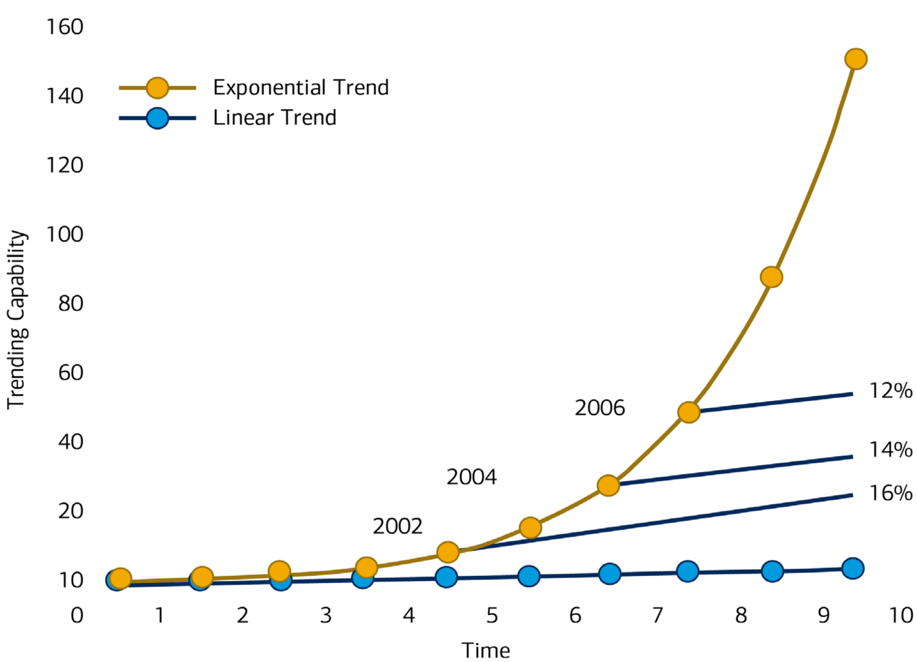
Exhibit 9: History doesn't always repeat itself.... but it rhymes...
Trends that seem linear often surprise to the upside and grow exponentially



Source: Ramez Naam

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Why do we keep underestimating tech? Exponential development

At our New York 2021 (Virtual) Transforming World Conference, futurist Ramez Naam highlighted 6 key steps that define and characterize the exponential development of technologies. Beyond digitization of a product, he notes that we tend to be deceived by the rate of development of tech. Having seen slower development to begin with or even disappointment, individuals can underestimate the rate of development of various technologies.

Exhibit 10: How does exponential technology change the world?
The 6D's framework: digitised, deceptive, disruptive, dematerialised, demonetised, democratised

Source: Ramez Naam

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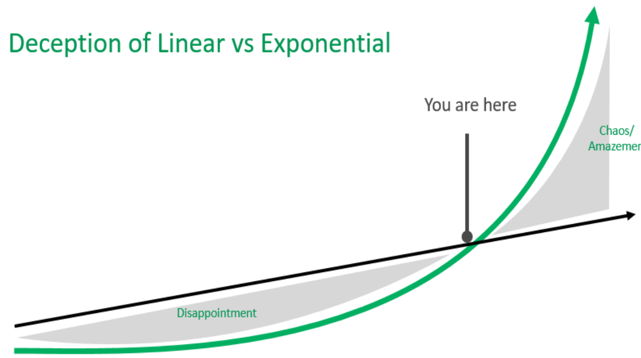
Exhibit 11: Why is exponential growth often mistaken for linear?
Initial disappointment of exponential tech leads to linear belief and chaos/amazement as growth exceeds expectations



Source: Ramez Naam

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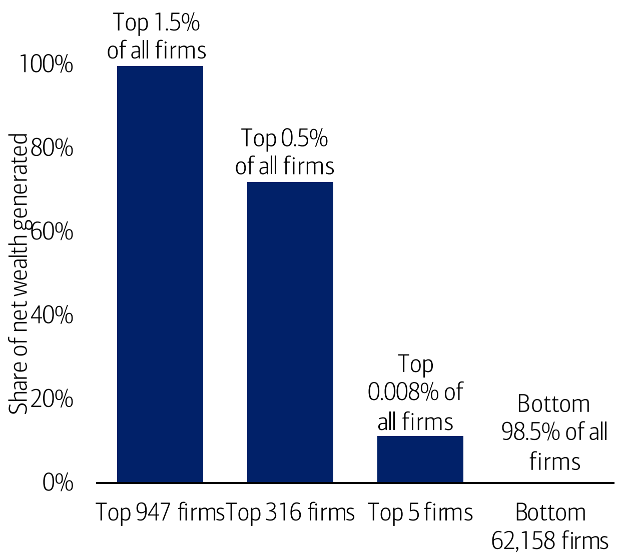
This underestimation can be seen in multiple technologies from mobile phones and clean energy to biotech. Forecasts, at each point in time, have assumed linear growth into the future similar to the growth at the time. Instead, realised growth has continued exponentially, exceeding all forecasts. In the case of solar, for instance, the exponential decline in cost has meant that today's solar prices are ahead of IEA forecasts from 2010 by 50-100 years.

Why does understanding tech properly matter? Just 1.5% of companies create all wealth

Consequently, understanding technologies that may arrive much sooner than expected and distinguishing which will become disruptive is key for a financial industry. Especially given that the financial industry is driven predominantly by the returns of a very small share of disruptive companies. In fact, between 1990 and mid-2020, the global stock market generated US$56.2tn. However, just 1.5% of companies accounted for all of that wealth creation. The majority (56.6% of US stocks and 61.3% of non-US stocks) underperformed one-month US Treasury bills (source: H Bessembinder, Arizona State University, 2020). Globally excluding the US, the picture is even starker, less than 1% of firms actually accounted for US$20.1tn of the net wealth creation. This trend of concentrated wealth creation by a small number of companies is actually accelerating in 2016-19, just 5 companies accounted for 22% of net wealth concentration.

Exhibit 12: Just 1.5% of all stocks have generated net wealth in the global markets since 1990
Share of net wealth* generated by stocks between 1990 & mid-2020



Source: H Bessembinder, Arizona State University 2020, *net wealth accounts for wealth generated above the performance from one-month Treasury bills

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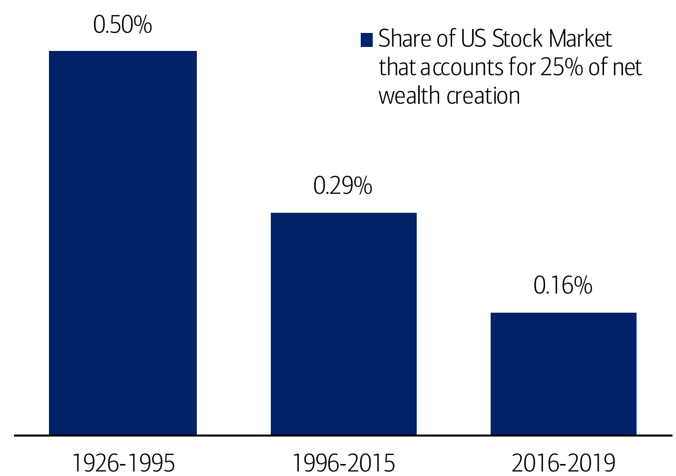
Exhibit 13: What share of the US stock market has accounted for 25% of net wealth concentration over time?
Share of US stock market that has accounted for 25% of net wealth concentration in each 3 year period since 1926 has declined and accelerated recently



Source: H Bessembinder Arizona, State University, 2020

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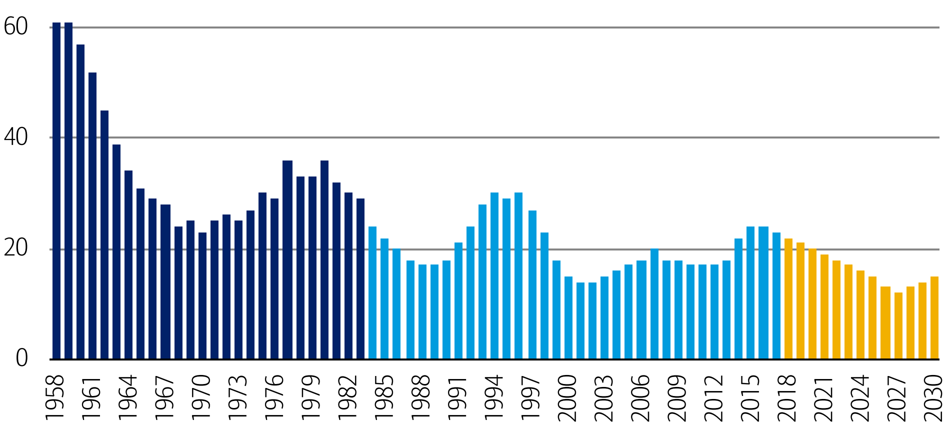
Life expectancy of incumbents keeps falling

What's more, the displacement of incumbents is only growing. In 1958, the average 7-year rolling lifespan of a company on the S&P 500 was 61 years; by the 1980s it had dropped to 30 years and by 2016, it was just 24 years. In 2017, 26 companies dropped out of the S&P 500. If we continue on this road, by 2027, companies could last just 12 years as they become increasingly disrupted (source: Innosight, S&P 500) – see Chart 1.

Chart 1: Incumbents are getting disrupted quicker
Average company lifespan on S&P 500 Index (year, rolling 7 year average)



Source: Innosight

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How does Next Tech succeed? Economics, adoption, regulation

From cryptocurrencies to meme stocks, trends can be susceptible to hype and over-exaggeration as excitement takes hold. To pick out the meaningful technologies that that result in disruptive success, three key elements are needed:

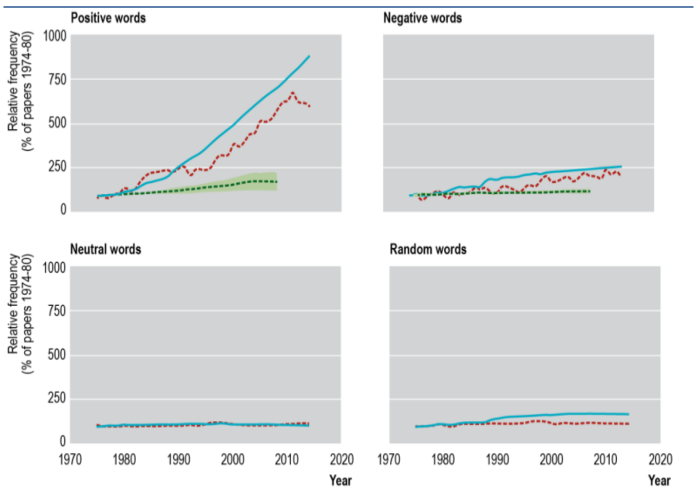
1. **Technology** – the innovations enabling the Next Tech must have the potential to be economical and cost-competitive (e.g. 99.999% fall in the cost of genome sequencing, smartphones enabled by exponential progress in computing power).

2. **Mass adoption** – new products must address a gap in the market, such as more convenience, solve a key problem such as climate change or improve quality of life (smartphones providing convenience by combining a phone, internet and camera).

3. **Governmental support** – regulation providing a favorable environment (subsidies enabling renewables to reach cost effectiveness, EVs gaining from autos emissions regulations in the EU).

Exhibit 14: Hype in science is growing

Relative frequency different types of word in PubMed science abstracts 1974-2014



Source: Vinkers et al, BMJ, 2015

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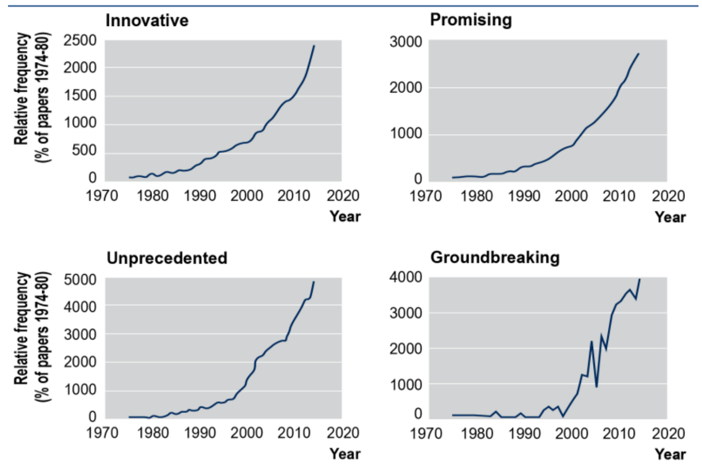
Exhibit 15: Science is getting excited, 'unprecedented', 'ground-breaking'...

Relative frequency of specific positive word in PubMed science abstracts 1974-2014



Source: Vinkers et al, BMJ, 2015

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So what *are* these new technologies?

We examine the moonshots, comparing risks, market sizes, CAGRs, catalysts and timelines, to give a comprehensive overview and assessment of what technologies could take hold next – either transforming the computational world of data, changing humans and their capabilities, affecting the new consumer or solving the problem of climate change.

- **6G:** The next generation of telecom networks will be needed in less than a decade as data continues to grow exponentially and 5G reaches its upper limit capacity.

- **Brain Computer Interfaces:** As we reach a point where humans are unable to keep up with computers and AI, brain computer interfaces could help 'level up' humans with computers. Shorter term, brain computer interfaces hold solutions for paralyzed individuals and promise a new wave of innovation in gaming.

- **Emotional Artificial Intelligence:** Emotional AI (EAI), also known to as "Affective Computing" and "Cognitive Computing" is designed to capture, analyze and respond to human emotions and simulate human thoughts. EAI can potentially collect, analyze and respond to completely new varieties of data and situations and predict or simulate human thought, leading people to take action.

- **Synthetic Biology**: This is a field of science that combines features of molecular biology, genomics, chemistry, engineering, machine learning, and computer science. At its core, "synbio", as the field is commonly referred to, takes advantage of the vast diversity of nature to make biomolecules that traditional chemistry cannot

- **Immortality:** Breakthroughs in healthtech, biotech and anti-aging drugs could result in radical life extension that 'disrupts death'. Traditionally, aging has not been viewed as a disease that can be treated but this is changing. Actors in this space are increasingly looking to tackle the hallmark of aging via pathways such as 'genomic instability, telomere attrition, mitochondrial dysfunction, and cellular senescence' among others.

- **Bionic Humans:** Augmentation technology that seeks to extend and expand (physical) human capabilities. This could be invasive (e.g. implants) or non-invasive (e.g. exoskeleton). Biohacking is also an associated field which is essentially applying DIY biology to boost oneself e.g. RFID chip in hand for contactless payments

- **eVTOL:** Electrical vertical take-off and landing vehicles that could provide an alternative mobility transportation solution to outdated infrastructure and overly stressed roads in urban settings.

- **Wireless Electricity:** As the IoT takes off, automating and creating near continuous charging solutions could provide convenience for consumers, while solving charging problems for the rollout of EVs and secure electricity supplies for remote communities.

- **Holograms:** A technology capable of creating a simulated environment through light imagery projections that will allow everyone to come together in one virtual room, without having to leave their physical location. Unlike virtual / augmented reality, it does not require users to wear glasses or head mounted devices (HMDs).

- **Metaverse:** describes the concept of a future iteration of the Internet, made up of persistent, shared, 3D-shared spaces linked into a virtual universe. It could comprise countless persistent virtual worlds that interoperate with one another, as well as the physical world and transforming markets such as gaming, retail, entertainment etc

- **Nextgen Batteries:** Whilst lithium batteries are the major EV technology, this does not necessarily need to stay true with alternatives such as solid state, vanadium flow, sodium ion etc provide promising additional attributes, such as faster charging, greater energy densities and better reusability.

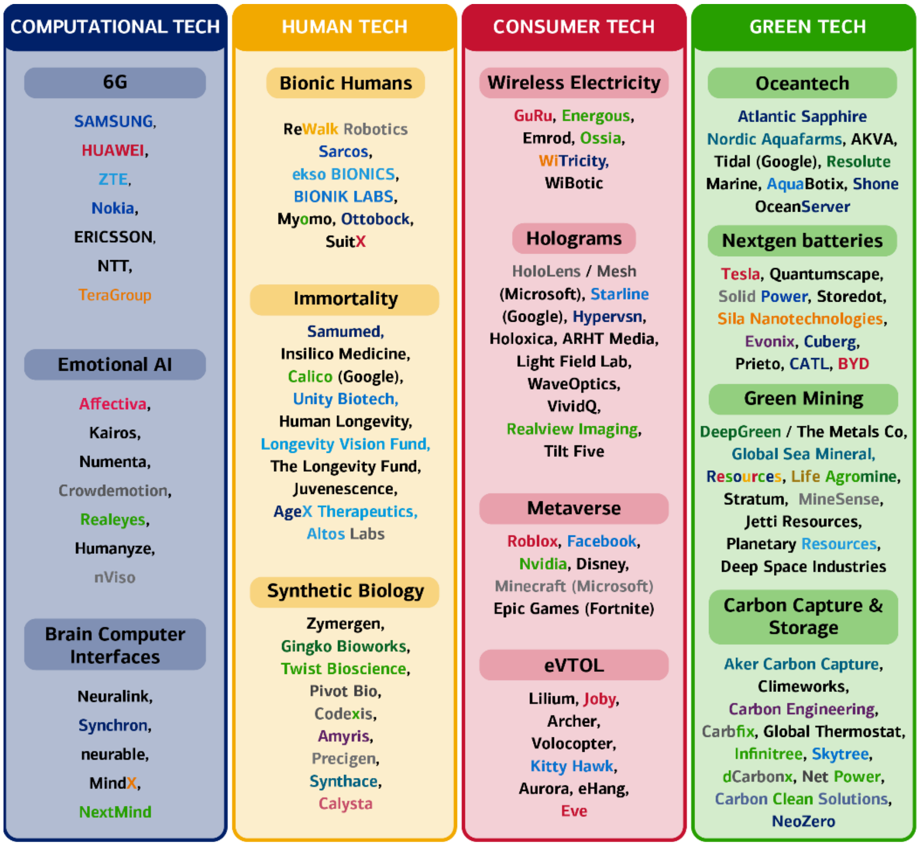
- **OceanTech:** aka Blue Economy is the advanced technology industry focused on products that work in or use the ocean. It seeks to answer: 'How do we increase sustainability of the ocean economy while harnessing its benefits?' Solutions could include ocean energy, land based aquaculture, and precision fishing using AI, etc.

- **Green Mining:** Transitioning away from a carbon-intensive economy will mean moving to a metal-intensive one. Green mining solutions like deep-sea mining, agromining, mining of wastewater and asteroid mining could provide less polluting and destructive solutions as the green economy's thirst for metals grows.

- **Carbon Capture & Storage (CCS):** All current zero-carbon pathways require some form of CO2 removal. CCS, alongside other geoengineering solutions, could act as part of the solution with long-term permanent removal of CO2 vs afforestation.

Exhibit 16: Enablers of Eureka! Future Tech

Moonshot enablers spanning computational / human / consumer / green tech



Source: BofA Global Research, company reports

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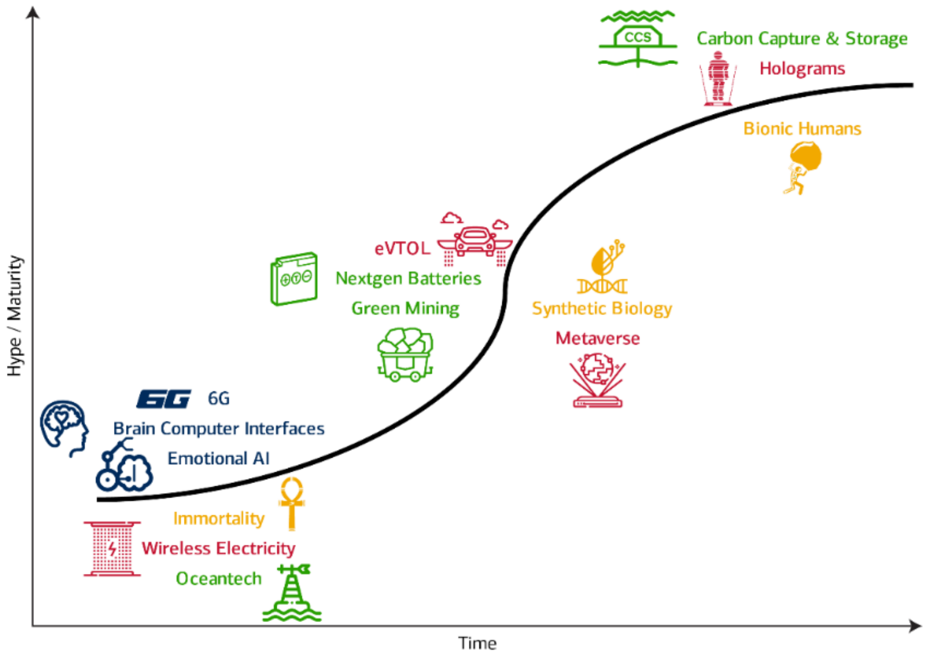
Emerging tech: addressable market vs. industry adoption

The next disruptive technology's importance depends on the potential total addressable market (TAM) size, where it currently fits in the technological hype cycle as well as its ability to penetrate the space and achieve wide market adoption (e.g. partnerships, customer licensing deals).

Exhibit 17: Moonshot Future Tech S-Curve Adoption Trajectory

6G, BCI still in the early stages, eVTOL, Nextgen Batteries reaching the inflection point, CCS late stage



Source: BofA Global Research

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Market Size: US$330bn today, 36% CAGR towards 2030s

While moonshots start at a low market size, their disruptive nature means there is the potential for high growth. Overall, using third-party projections of potential market sizes, the moonshots we evaluate are worth US$330bn today (2019-21) growing at an average CAGR of 36% towards the 2030s. In particular 6G, eVTOL, CCS and Immortality have the highest CAGRs (source: BofA Global Research, various third-party market size estimates).

Exhibit 18: Market Sizes of Future Tech

6G set to have the largest TAM by 2035

Moonshot	2010 (US$bn)	2019 (US$bn)	2020 (US$bn)	2021 (US$bn)	2024 (US$bn)	2025 (US$bn)	2026 (US$bn)	2028 (US$bn)	2030 (US$bn)	2035 (US$bn)	CAGR	Source
6G									8.76	1773.09	133.89%	BIS Research
Brain Computer Interfaces			1.488						5.463		13.90%	Allied Market Research
Emotional AI			28.7					284			32.50%	Emergen Research
Synthetic Biology		7.54					34.51				21.90%	Bradessence Research
Immortality		1.6				20					52.34%	UFX / Inc.com
Bionic Humans		70.9			206.9						23.90%	Markets and Markets
eVTOL			1.1			1.5				240	66.12%	Pitchbook / Oliver Wyman
Wireless Electricity			5.71						35.23		21.30%	Allied Market Research
Holograms			1.13						11.65		29.10%	Allied Market Research
Metaverse				180		390					17.00%	ARK Invest
Nextgen Batteries			21						354		32.64%	BofA Research
Oceantech	1500								3000		4.73%	OECD
Green Mining		9			12.9						7.50%	Markets and Markets, Bloomberg
Carbon Capture & Storage				1		8			25		50.00%	BofA Research

Source: BofA Global Research based on various sources. Beige shaded columns current market sizes. Blue shaded columns forecasted market sizes

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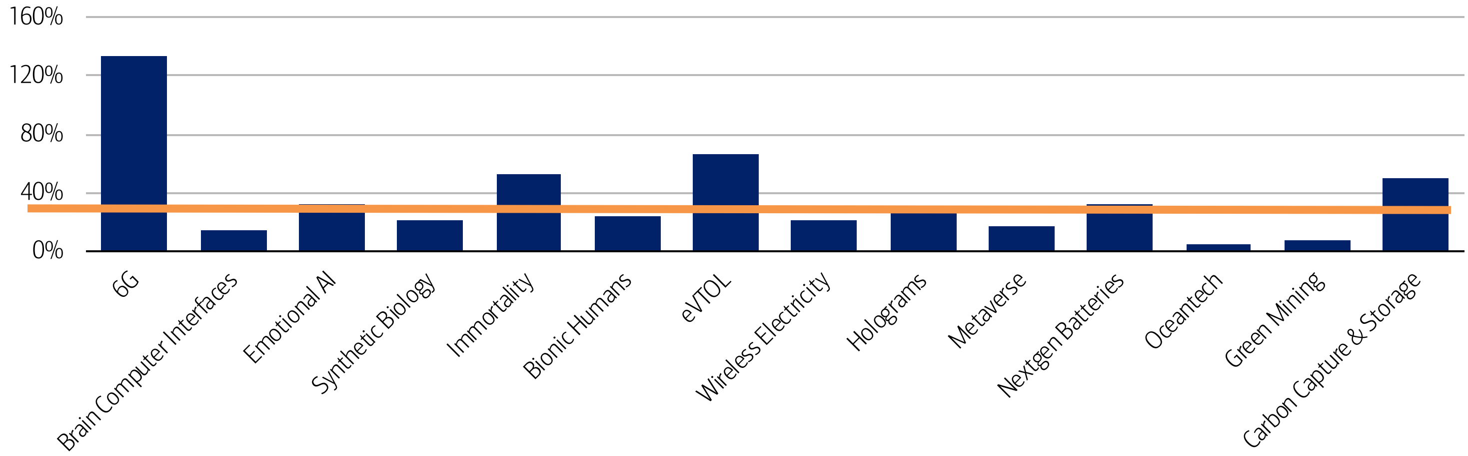
Exhibit 19: CAGR average of 36% across Future Tech (Orange Line)

6G is the fastest growing whilst Oceantech is the slowest



Source: BofA Global Research based on various sources

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Catalysts: what could bring these moonshots to market more quickly?

We highlight the wide variety of timeframes for these disruptive technologies and the catalysts that could drive earlier adoption and transition of moonshots to established technologies.

Exhibit 20: Key moonshot catalysts / milestones

What are the important milestone events for future tech?

Year(s)	Moonshot	Catalysts / Milestones
2020	Nextgen Batteries	One million mile battery pack breakthrough
2020s	Emotional AI	Increasingly pervasive in everyday life
2021	Bionic Humans	World's first artificial cornea implanted
2021	Brain Computer Interfaces	Start of human trials in progress
2021	Holograms	World's first hologram dining experience
2023	eVTOL	3 eVTOL potentially certified for commercial launch
2024	Green Mining	Commercial deep-sea mining set to start
2025	Wireless Electricity	10 connected devices per person that needs charging
2028	6G	Data volumes reach capacity of 5G networks
2029	Immortality	Humans could become 'immortal' and live forever
2030	Synthetic Biology	Most people will have eaten, worn, or used synbio products
2030	Oceantech	Global ocean economy will be equivalent to 2010 German GDP
2030s	Metaverse	We might be spending more time in virtual worlds than the real world
2040/50	Carbon Capture & Storage	$1 trillion in cumulative capex investments in CCS

Source: BofA Global Research , Company reports

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Risks: what could go wrong?

We see 3 key risks that could slow or stop adoption of the next technologies: 1) slow or limited technological/scientific development, meaning that the tech IP is not as useful or commercially scalable, preventing use in industry; 2) prohibitive costs outweigh the benefits and prevent the expansion of the technology to the mainstream; and 3) regulation limiting the applicability of a technology.

Exhibit 21: Risks for Future Technologies

Moonshot risks can be divided into: 1) Tech/Scientific 2) Cost-Benefit Adoption and 3) Regulation

Moonshot	Technological/Scientific Risk	Cost-Benefit Adoption Risk	Regulation Risk
6G	6G parameters remains undefined as a technology	Not needed yet, 5G sufficient for the time being, denser network required, microwave health concerns	US vs China splinternet could bifurcate use of Huawei vs Western telco equipment
Brain Computer Interfaces	Early limited use cases, not at telekinesis 'mind control' levels yet	Normal computing via smartphone still the most cost effective method	Invasive brain procedure on humans = health regulation
Emotional AI	AI still in infancy of fully understanding human emotions and needs	Costly to install multiple cameras & sensors for potentially limited use	Privacy concerns around facial recognition technology
Synthetic Biology	Early stage tech, without scalable proven use cases yet	Existing materials and chemicals still cheaper to mass produce	Concerns on introduction of genetically engineered products
Immortality	Limitations remain on the human body, still no 'step change' on longevity, reversing ageing still in trial phase	Inequitable health investments - rich live longer by only few years vs. poor life expectancy lags from insufficient basic medicines access	Ethical / health regulation on extending lifespans
Bionic Humans	Concept has been around for a while and use cases remain quite niche and not scalable	Expensive upgrades for individual humans that are personalised and can't be mass produced	Unregulated bionic implants and cybersecurity risks from bio- hacking
eVTOL	Travel distance still quite short per flight, battery weight still quite heavy	Mostly still cheaper to use ground transport e.g. taxis, trains	Urban air traffic regulation above cities for safety
Wireless Electricity	Slower charging compared to wired connection	Wired/Fibre/Cabled electricity still cheaper to install and adopt	Safety/Overheating debate on unproven wireless connections
Holograms	Tech concept has been around for a while but never taken off with killer app	Very data intensive and current WFH tech is more cost effective	Privacy and health concerns around prolonged use of tech
Metaverse	Virtual/Augmented reality tech not mature enough to power virtual worlds	Requires high capex requirements on data centers, processing powers, VR headsets etc	Open/Decentralized vs Closed/Centralized debate on who controls virtual world
Nextgen Batteries	Lithium-ion remains the dominant technology currently	Alternatives remain more expensive than li-ion which benefits from economies of scale	Climate wars could create global bottlenecks in securing supply chain of raw materials
Oceantech	Majority of ocean(tech) remains unexplored	More cost effective with current land technologies	ESG pushback against overexploitation of seas
Green Mining	Technology still in development with varying tech hurdles	Currently still cheaper to mine on land	Environmental concerns over recycling of metals
Carbon Capture & Storage	Tech has been around for a while but yet to efficiently scale	EVs, Renewable Energy, Hydrogen etc more cost effective right now as climate solutions	Carbon taxes/credits and pollution permits regulations to increase on fossil sector

Source: BofA Global Research, Company reports.

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1) COMPUTATIONAL TECH
6G: one technology to connect it all

What is it? The next generation of mobile technology with download speeds estimated around 400Gbps - 1Tbps

The answer to: 'what if 5G is not enough in the next decade?'

Did you know: we are creating 2.5 quintillion bytes of data, every day, and this is doubling every 2-3 years

In the 2020s: 6G might need to replace 5G in six to seven years at current data generation rates

Market size: US$1.77 trillion by 2035

Beneficiary Sectors/Industries: Telecom equipment, healthcare, cloud, Industrials, technology, gaming, automotive.

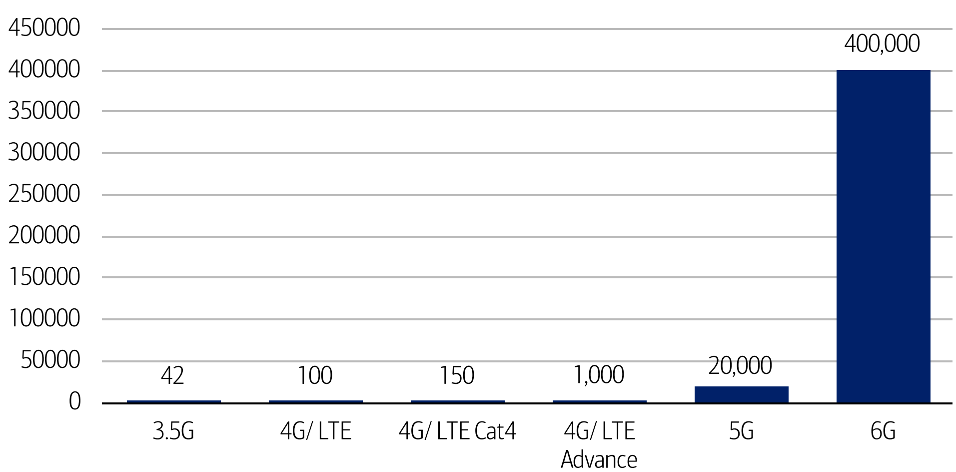
In November 2020, China sent its first 6G satellite into orbit, kicking off what we believe could be the next tech war between the superpowers – the 6th generation of mobile technology, or 6G. Although the satellite was aimed more at testing terahertz radio waves – the frequency 6G will be based on – rather than 6G technology per se, it sparked a debate around the mobile technology, which could herald one of the biggest wireless communication revolutions.

The technology that will change how we look at data

6G will be the successor to 5G mobile technology in the transmission of mobile data and is estimated to be commercially available before the end of this decade. 6G will offer 10-50x higher speeds and bandwidth compared with 5G, with a much better latency ratio (up to 1/1000). According to different estimates, 6G download speeds could reach 400-500Gbps (Samsung, Ericsson, Cisco) or even up to 1Tbps (Bremen University), with close to zero latency, and be able to handle 10x more data capacity than 5G. While the technology and protocols are still in development, 6G will use the higher bands of the spectrum like the Terahertz radio waves (Terahertz = 1,000 Gigahertz). These bands have greater capacity and are more stable, but will cover shorter distances.

Exhibit 22: Theoretical speeds (Mbps)

While 6G can offer up to 20x faster speeds than 5G, it's more than the speed. Some estimates are projecting 1Tbps speeds (1,000,000Mbps)



Source: GSMA Intelligence, Ericsson, BofA Global Research

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The speed is just a bonus

As stated above, 6G can offer 10-50x faster speeds than 5G. However, looking at speed alone is misleading. Most of us use regular applications that do not require 1Tbps download speed. We need to look at 6G instead as the technology that could have the capacity for all the data we are creating, could connect the digital world to the physical one, and could handle complex data. To do so, 6G will be the first mobile technology to have AI capabilities embedded in it. What other technology could support the connectivity of all autonomous driving, Industry 4.0, one trillion connectable devices, smart city holograms, and the world of gaming, etc? Plus, more importantly, what other technology will allow all applications to “talk” to each other, so creating even more data than the sum of each application as a standalone (complex data). We are living in a world that 1) is creating more and more data and 2) needs a way for all applications to connect and “talk” to each other. Whereas with 5G speeds we can download Netflix movies in seconds, with 6G all the applications could connect and synchronize seamlessly. Furthermore, with so many devices online that need to communicate with each other, 6G technology could be the platform to allow AI-based smart connectivity.

Why do we need 6G? Because nothing is linear when it comes to technology…

The idea behind 6G is to create a technology that will connect everything. This was also the bedrock of 5G, but new applications and the speed of data creation placed a question mark over its ability to support the “connected world” over time:

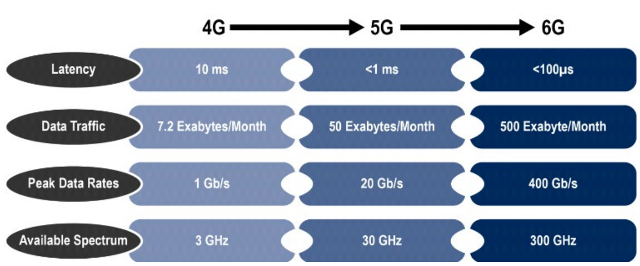
1. The data we are creating is increasing exponentially and will clog up 5G network capacity sooner than expected.

2. New applications are being developed all the time that require more data. In this report, holograms, metaverse, brain computer interfaces, EVTOL etc are just some of the tech we explore that will be very data-heavy and have yet to be launched. Not to mention quantum computing, which could immediately leapfrog the total data creation once commercially available. In short, data is going to grow far faster than initially expected in coming years, well beyond the exponential growth we are currently seeing on mobile networks.

3. All these and other technologies will have to “talk” to each other and connect seamlessly with zero latency. This will place even more pressure on the network.

Exhibit 23: 6G capabilities vs. 5G

Higher speeds, bandwidth, capacity and close to zero latency



Source: BofA Global Research, Ericsson

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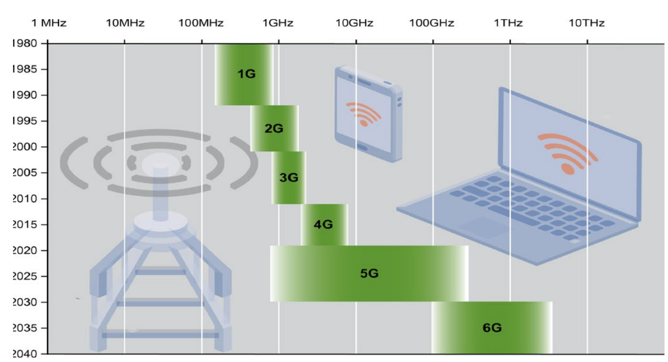
Exhibit 24: Spectrum allocation

6G will be the first mobile technology to use Terahertz spectrum to transmit more data.



Source: BofA Global Research, futuretimeline.net

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The first mobile generation with AI-embedded technology

It is too early to assess what the network architecture and technology will look like and who will control it, but we highlight the following:

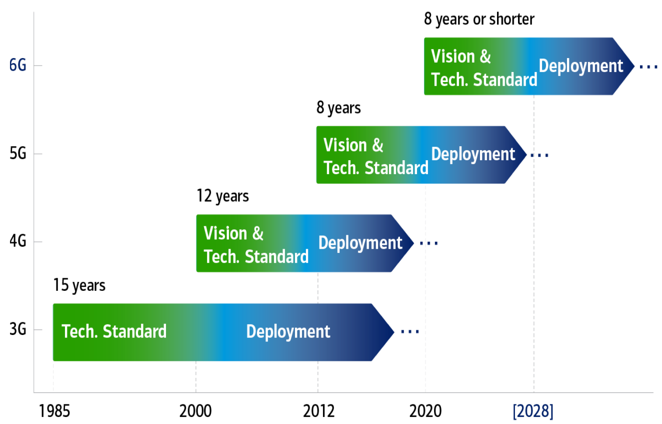
- As the first network that will handle complex data independently, 6G will be the first network to adopt AI-embedded machine learning algorithms to channel data and maximise network traffic. These capabilities are still being tested but their mass adoption could increase 6G rollout prices. However, efficiency gains on maximising network capabilities should pay for the extra cost in the long term.
- Spectrum unification at the high end of the band (300GHz- > 1THz) should require a denser network. Some of the high-end bands are not in use now, except for academic research purposes, which might reduce rollout costs.

When? Soon! Data growth waits for no-one

> We are creating 2.5 quintillion (million trillion) bytes of data, every day! *(Domo, WEF)* and global data is doubling every 2-3 years *(IDC)*

Some might think it's too early to talk about 6G, when 5G is still being deployed and should become fully operational in most countries no sooner than 2022. 5G was regarded as the ultimate solution to our current world needs, but we think these will change significantly this decade.

Exhibit 25: 6G timeline
While most researchers believe that 6G won't be deployed this decade, Samsung believes it could happen by 2028. Perhaps even sooner?



Source: BofA securities global research, Samsung

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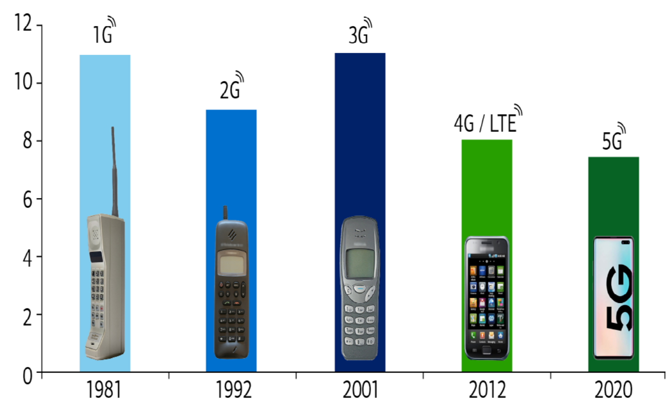
Exhibit 26: Could 5G be the shortest live mobile technology?
The timeline for a mobile technology is usually c.10 years, but the explosion of data creation and complexity might push out 5G before that.



Source: BofA securities global research

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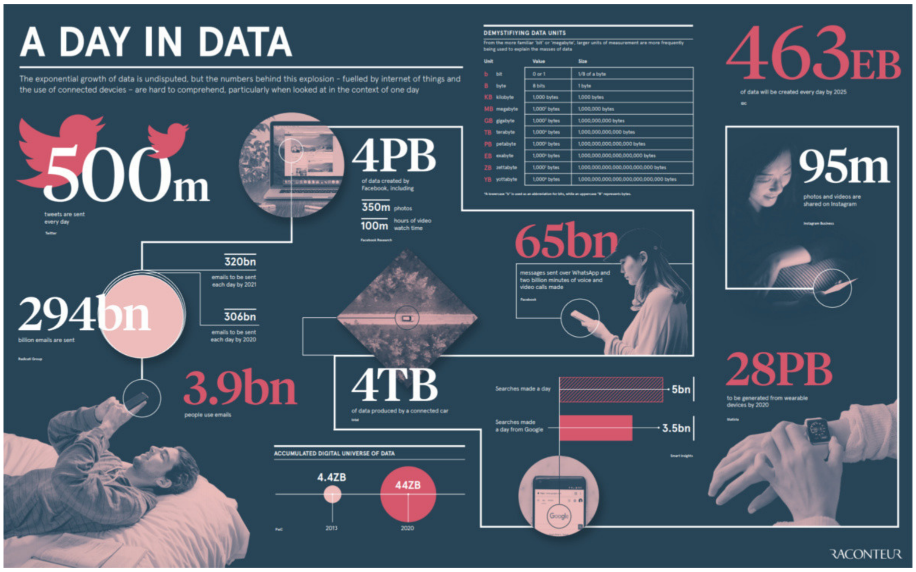
Currently, we are storing and transmitting only 1% of global data (IDC). Therefore, if we take into consideration 1) the exponential growth of data creation, 2) that the amount of global data stored and analysed could swell given that 37% of data could be useful if analysed (vs 1% actually analysed today), 3) that more people will be online globally, especially post the COVID crisis, and 4) the higher penetration of data-heavy and yet to be launched applications (holograms, quantum computing etc), then there is likely to be a 10-year limit, or even less, on 5G network capacity.

Exhibit 27: World of data

In 2020, every person generated 1.7MB... every second! (source: IBM)



Source: WEF, Visual Capitalist

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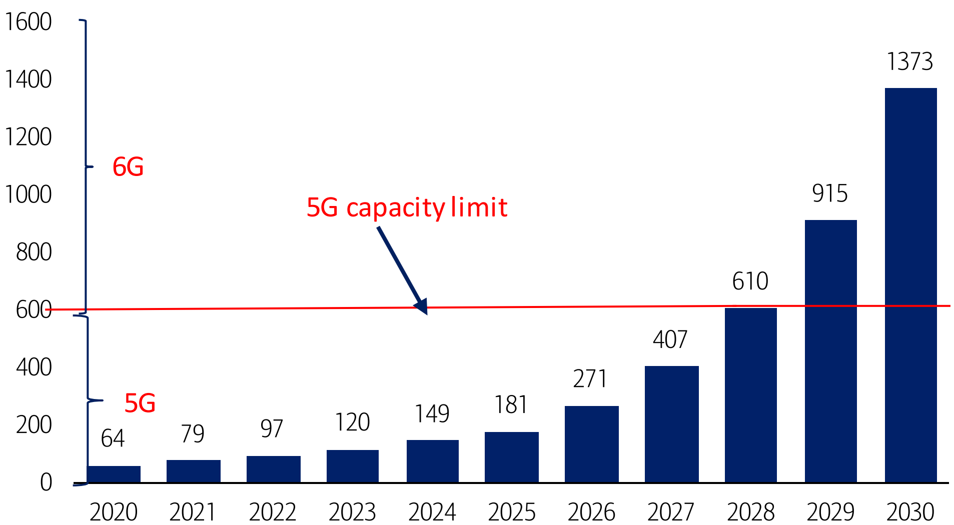
The digital universe has reached the level of the Yottabyte, with 90% of the world's data having been created in the past two years (source: IBM). As of 1H21, there are around 6bn mobile phone users worldwide, of which about half use smartphones. According to IDC, the amount of data created is projected to double every 2-3 years, and according to Statista, in 2020 we created c. 64ZB of data, projected to grow to 181ZB by 2025E.

5G networks can handle total data traffic of 50Zb/month (Ericsson) or 600Zb/year. Global mobile data generation reached 64ZB in 2020. Assuming global data doubles every 2-3 years, by around 2028, global data capacity will be beyond current 5G capabilities (see below). Assuming 5G will be enhanced like generations before it, the inflection point will be around 2030E, when we enter the Yottabyte era.

Exhibit 28: Global data generation (Zettabytes/year)

At the current rate of data creation, 5G will hit full capacity as soon as 2028. However with new applications penetrations like XR, Holograms, Autonomous vehicles etc – could it happen sooner?



Source: BofA securities global research, Statista, Ericsson

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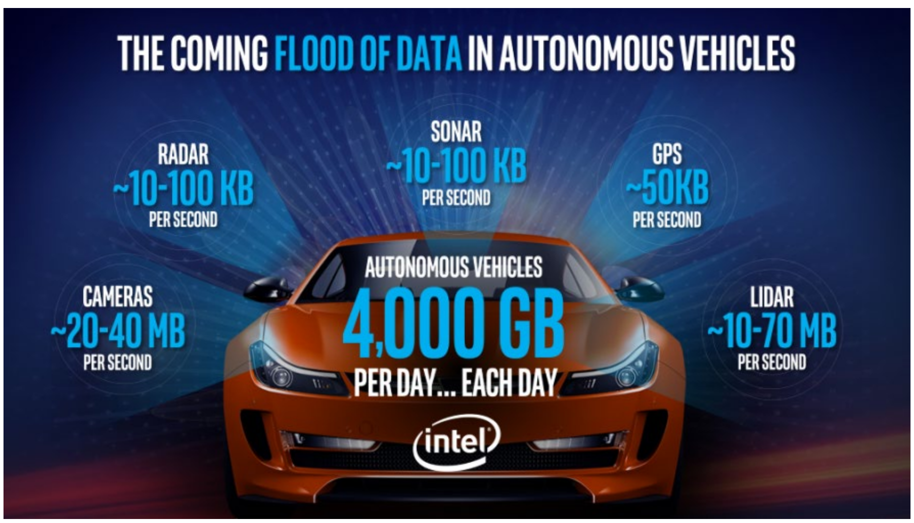
Saying that, as explained before, new applications and technologies might boost data creation much faster than expected, and the "connectivity of things" might be underestimated relative to the amount of data creation.

Did you know?

At current average global mobile speeds it will take a person c.181 million years to download all the data from the internet …but it will take 838,000 years on a 5G network and "only" 17,000 years on 6G.
Yet….data is doubling every 2-3 years….
(Statista, Unicorn Insight, IDC, BofA Global Research)

It's not just about data generation, or traffic. It's about data complexity. 6G should be able to handle big data complexity problems, for example, connectivity of autonomous vehicles (AV). Intel believes one autonomous vehicle (L-5 level) will generate 4TB of data every day. One connected AV will generate the same amount of data as 3,000 internet users (Intel), However, two cars will generate data closer to that of 8,000-9,000 users, as not only will they generate data, but they will also need to communicate between themselves, and so on. The growth of data just from AVs will be exponential. On this calculation 1,000 cars will generate more data than the entire planet.

Exhibit 29: Autonomous car data creation
Every car will generate 4TB of data every day … excluding the data from all these cars communicating



Source: Intel

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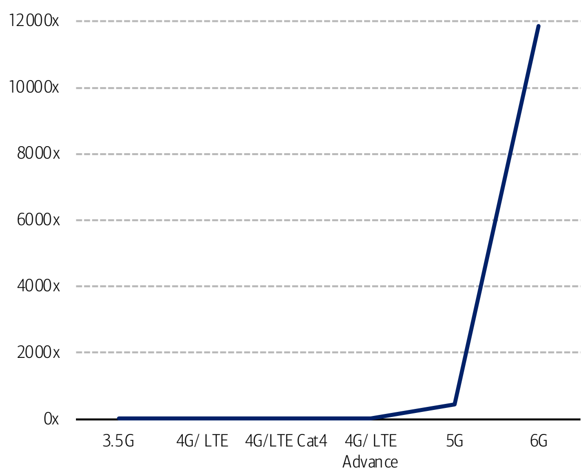
Connected car data volumes are already staggering. Wejo estimated 95 petabytes of data generated globally in 2019 from connected cars. And this is the tip of the iceberg. Petrolus estimates that by 2030, 88% of cars sold worldwide will be pre-connected to networks via embedded devices and almost 100% of vehicles in the EU and US will be connected. According to a McKinsey study, >60% of cars will also have low-level autonomy by 2025.

And this is just one small example of the complex data we are creating. Smart cities with populations of 1 million people will generate 200EB of data every day (200 million GB), which will need to be connected, transmitted and analysed with different agents. The issue is not just how much data, but the complexity of this data that needs to be processed and transmitted in real time. Thus, smart algorithms collaborating on a large scale will generate data complexity problems that current technologies will eventually not be able to cope with. And this will affect every aspect of our lives, as the number of connectable devices, sensors and machines is expected to grow to >200bn by 2025.

Challenges: complexity, prices, Moore's law, emission…

- Moore's Law won't catch up with 6G and data? The total data we are creating is doubling every 2-3 years or in other words at c50-60% CAGR, which is greater than the increases in CPU processing power. Now that we are entering to the era of complex data, the problem could even intensify. 6G data transmission rate is 12,000x faster than 3.5G and 50-100x faster than 5G. Meaning in few years' time CPU processing power will have to match the growth of transmission of data and according to the current projections, we are not there. Actually we might get to the limit of Moore's law this decade. Could quantum computing and 6G would be the ultimate match then that will change it all? (see Exhibits 31 and 32)

Exhibit 30: wireless generations download speeds compare to 3.5G
6G download speed will be c. 12,000x higher and while global data growth continues to jump…



Source: BofA Global Research

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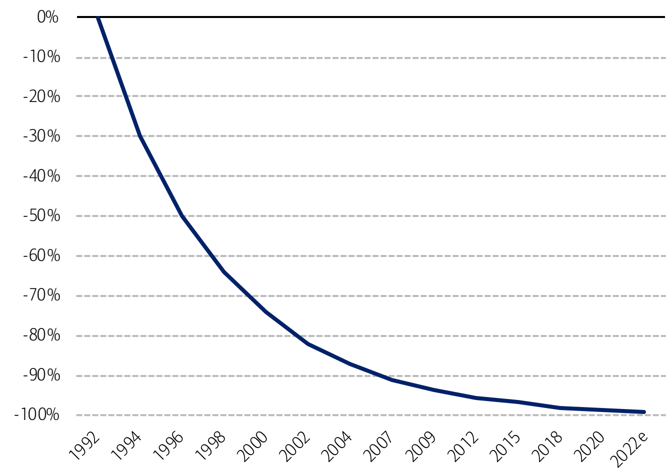
Exhibit 31: change transistors gate nanometer length (1992 base year)
…but at the same time we are reaching to the limit of the Moore's law. and processing speed growth in moderating reaching its limit in 2020s



Source: BofA Global Research

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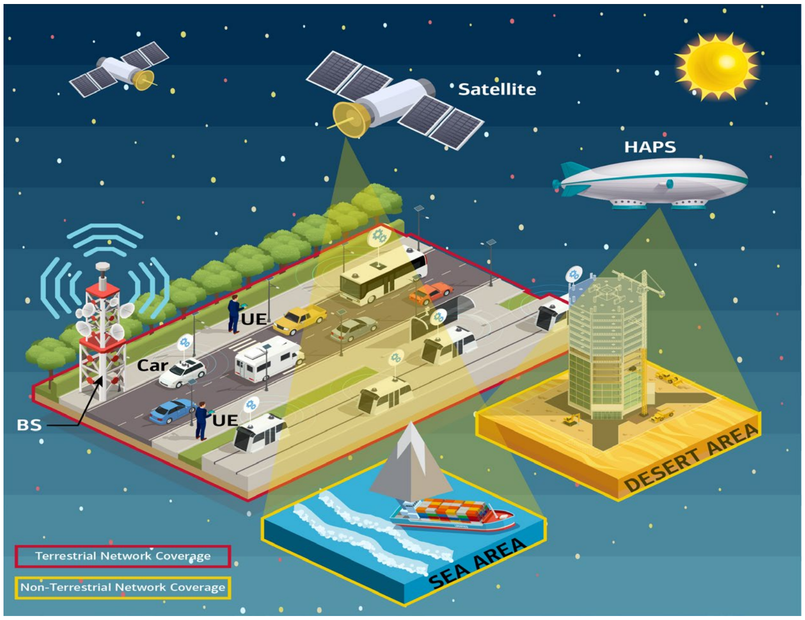
- More sites mean higher radiation due to denser networks creating potential health risks. This issue has not been fully explored even in relation to 5G and will likely be in the spotlight the closer we get to 6G. 5G case studies will be crucial for the implementation of 6G.

- 6G will operate on a higher spectrum than 5G. The higher we go on the spectrum, the more data that can be carried. The downside is that the distance we can carry the data is shorter. Currently, in lab conditions, the Tera waves range is about only 10 metres. As with the deployment of 5G, the density of the network will continue to increase, the higher we go up the generation. Bottom-line, we will need more sites. How many? It's not yet clear. Some estimates suggest 10x more sites, towers or micro-sites. Samsung is exploring the idea that personal mobile phones will work as transmitters that will amplify the signal. Other solutions Samsung's whitepaper explored are using satellite signals to cover more areas, splitting spectrum etc

- Could 6G increase global emissions? It will eventually be a very dense network that will require a lot of power, so it could. Part of the network will be based on the current 5G network and will replace some of the existing power generation, but this will still be only a partial solution.

Exhibit 32: Suggested solutions for 6G network architecture
Sites, microsites, towers, satellites are some of the solutions needed to increase network signal



Source: BofA Securities global research, Samsung, Ericsson

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US$1.8 trillion market by 2035

The global 6G market is projected to reach $1773.09 billion by 2035. The market is set to witness a CAGR of 133.89% between 2028 and 2035. However the market is assumed to be negligible where the industry for of 6G is yet to start as companies like NTT Docomo etc have only announced 2030 as the launch year for 6G (source: BIS Research)

Brain Computer Interfaces (BCI): human mind control

What is it? Brain waves of humans and animals directly interacting with the external world and vice versa

The answer to: 'How do we level up humanity to compete with AI?'

Did you know? A brain-to-brain interface has already allowed one human to control another's hands through their thoughts alone

In 2021: Humans are already trialling brain computer interfaces that can enable them to text, shop, bank and email online with their brains

Market size: US$5.46bn by 2030E

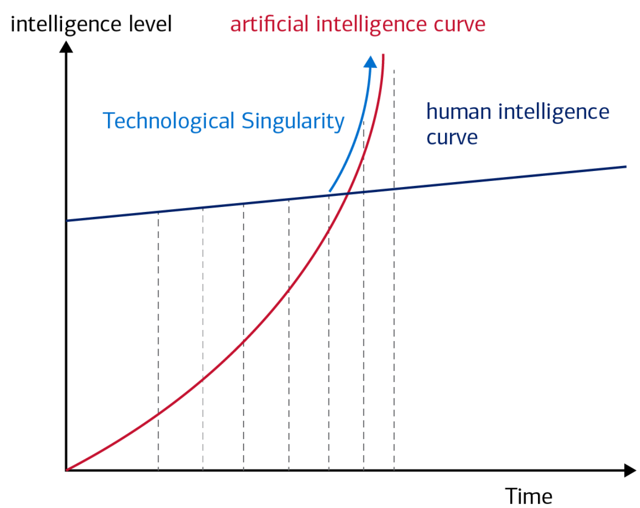
Sectors affected: Gaming, humans, collaboration and military

How does humanity keep up with AI as we approach technological singularity?

"Humans, who are limited by slow biological evolution, couldn't compete and would be superseded." *Stephen Hawking, BBC, 2014*

Artificial intelligence is growing in power and capability, increasingly overtaking human ability in various actions. Forecasts estimate that we may reach technological singularity, – the point at which technological innovation accelerates beyond the point that human intelligence can keep up – as soon as 2045 (source: Ray Kurzweil). To keep up and maintain effectiveness vs this new competitor, one solution includes integrating humans with AI through brain-computer interfaces. Beyond, physical implants, strides are being made in developing technology that reads brain waves with applications in video games and beyond.

Exhibit 33: If AI continues to improve exponentially, unaided humans will fall behind
AI intelligence curve vs human intelligence curve over time



Source: Liu et al, University of Chinese Academy of Sciences 2017

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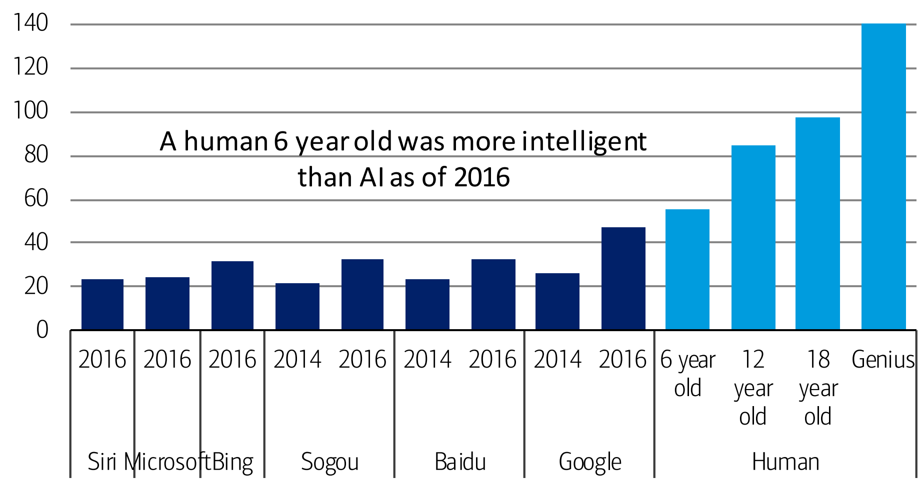
Just how smart is AI?

> "AI is a fundamental risk to the existence of human civilization in a way that car accidents, airplane crashes, faulty drugs or bad food were not — they were harmful to a set of individuals within society, of course, but they were not harmful to society as a whole." – *Elon Musk, 2017* (source: CNBC)

AI has some way to go even to reach child-like IQ levels. Google's AI, which scientists in Beijing and Nebraska found to have the highest IQ, was rated 47.28 in 2016. In comparison, a 6 year old is rated 55.5 and a human is considered a genius if they have an IQ of over 140. However, this is a vast improvement from 2014 when Google AI's IQ was 20 points lower at 26.5. AI from companies such as Sogou and Baidu have also seen advancements.

Exhibit 34: The IQ of AIs is not yet at the level of a 6 year old (as of 2016)
IQ of various AIs vs human at different ages



Source: Liu et al, Chinese Academy of Sciences, 2017

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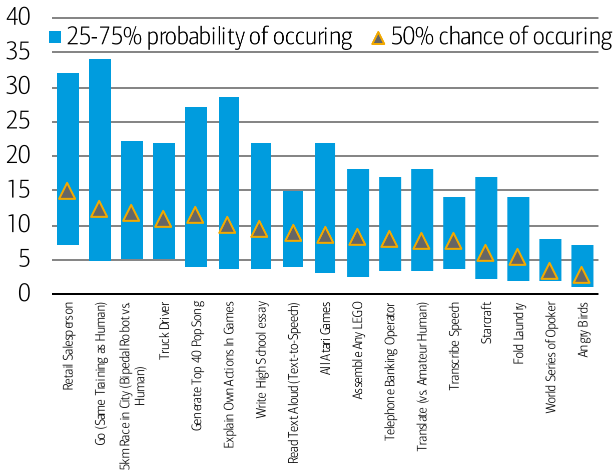
AI is already beating humans at individual tasks

> Ex-DARPA boss Regina Dugan believes we will have a skullcap able to transmit sentences out of your brain at a rate of 100 words per minute in the future (source: MIT Technology Review 2017)

Since 1997 when Deep Blue defeated world Chess champion Garry Kasparov, computing has been beating humans in various individual activities. More recently, LawGeex neural network did better than 20 experienced lawyers at finding issues in 5 standard non-disclosure agreements (NDAs) in 4 hours with a 94% accuracy rate for the algorithm vs the average of 84% for humans. Meanwhile, Microsoft's speech recognition systems reached parity with professional human transcribers in 2017. Various AI algorithms will continue to grow their abilities. In 2016, a survey of over 350 machine-learning researchers revealed that they thought there would be a 50% probability of an unaided machine beating humans in all tasks at a lower cost within 45 years and automation of all human jobs within 120 years (source: Grace et al, Journal of AI Research 2018). But before that, they had thought AI could be beating humans in translating languages by 2024E, writing a high-school level essay by 2026E, and working in retail by 2031E.

Exhibit 35: When will AI exceed human performance? Shorter term
50% probability of automation of retail salespersons within 15 years, according to 352 machine learning researchers surveyed



Source: Grace et al Journal of AI Research 2018

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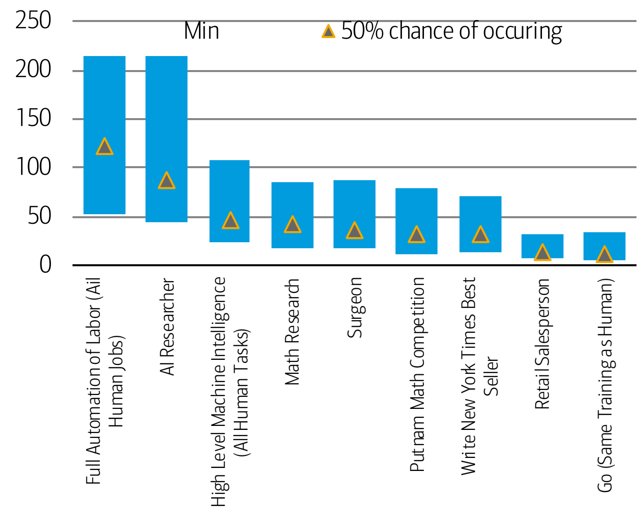
Exhibit 36: When will AI exceed human performance? Shorter term
50% probability of automation of all human jobs within 120 years, according to 352 machine learning researchers surveyed



Source: Grace et al Journal of AI Research 2018

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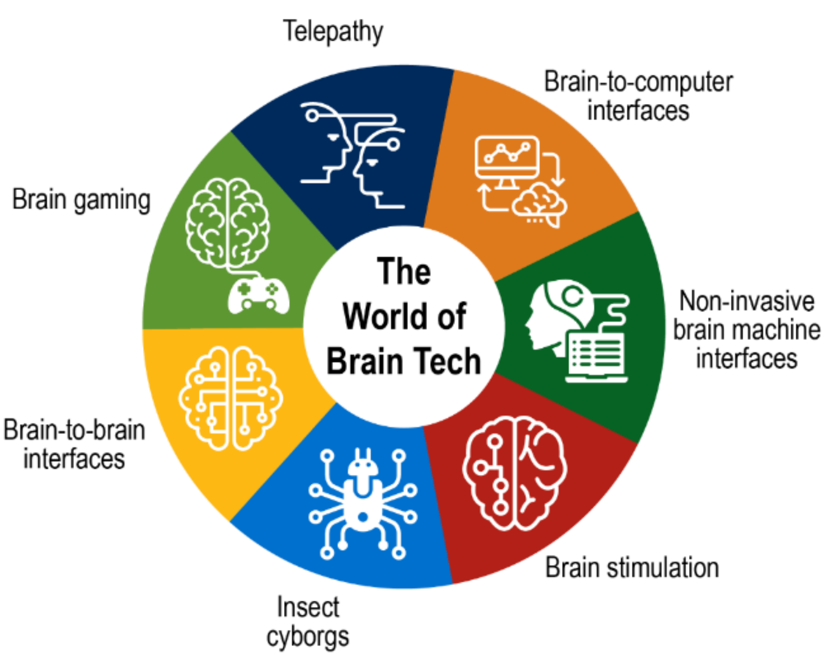
If you can't beat them, join them? Human-machine implants

If AI is set to become more intelligent than humanity, some start-ups are focusing on creating a human-machine cooperation that will prevent humans from being left behind. As a nascent technology, different approaches are being trialled with different motives. Consequently, brain computer interfaces differ in invasiveness and abilities. Start-ups like Neuralink are investigating such technology with physical implants that would allow a human to control a connected device, while others like Facebook and CTRL-Labs are looking at non-invasive technologies to read human thought. Other start-ups include Synchron, Neurable.

Exhibit 37: How is brain technology being developed?
The World of Brain Tech



Source: BofA Research

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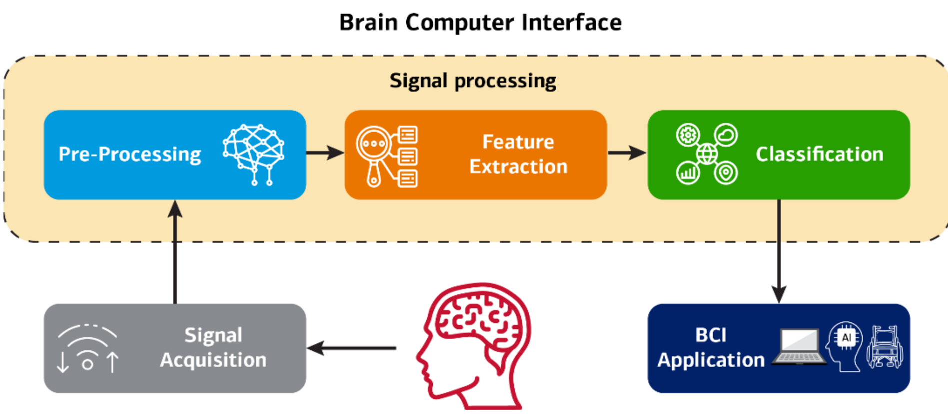
How would brain computer interfaces work?

Examples of brain implants that are already in use:

- Cochlear implants stimulate the auditory nerve to provide some form of sound for hearing-impaired individuals.
- In a research lab, BrainGate's implants have allowed individuals with spinal cord injuries and ALS to control a cursor on a computer with their thoughts. In 2021, the team managed to decode thoughts of handwriting movements and translates them into text on a screen as well as producing a wireless transmitter to transport the full spectrum of signals recorded. Note that this still requires a transmitter to sit on the person's head.

The concept of brain implants is not completely new. Academics have already completed studies of implants using a few hundred electrodes to collect brain data in animals. In addition, procedures to stimulate parts of the brain for patients with Parkinson's disease and clinical depression already occur. However, recently, businesses have increasingly taken leadership in developing the latest implants.

Exhibit 38: How do brain computer interfaces work?
The process of using human brain waves



Source: Semantics Scholar

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Early human clinical trials now in progress

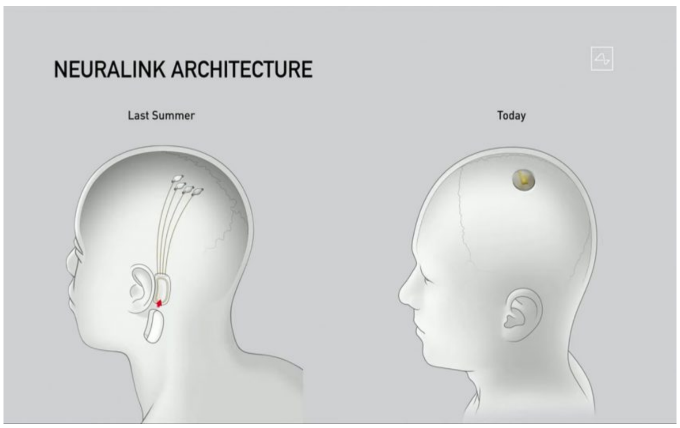
Minimally invasive implants are now being trialled in humans. Synchron, a brain interface platform company, is trialling implants with 4 patients in Australia. In its study, individuals with paralysis were able to text, bank, shop and email online. Synchron's approach involves lacing blood vessels that supply the brain with a mesh tube of sensors and electrodes from which neuron signals can be picked up. The signals are passed to an external unit that translates the signals and conveys them to a computer.

Case study: Neuralink fully integrated brain machine interface (BMI) systems

- **The tech:** Neural implants include neural threads that are inserted with a neurosurgical robot into the brain to pick up neural signals being transmitted. Neuralink's implant, the Link, is expected to contain 1,024 electrodes. These neural threads transfer data back and are directly connected to the implant. This implant processes and further transmits the neural signal to the outside world.

- **The aim:** The brain data collected by the implants would then enable individuals to control a keyboard or computer mouse, particularly ground-breaking for individuals with spinal cord injuries. Longer term the implant could help enable motor and sensory functions and even strengthen a healthy person's capabilities looking further ahead.
- **Success with animals:** Beyond safely inserting, collecting data and removing the implant in pigs, Neuralink has also showcased the implant's success in monkeys. The monkey with 2 implants placed can play online ping pong-type games solely with its mind once the neural signals are calibrated.

Exhibit 39: Original vs Updated Neuralink
Neuralink implant has switched from ear canal to apex of skull



Source: Neuralink

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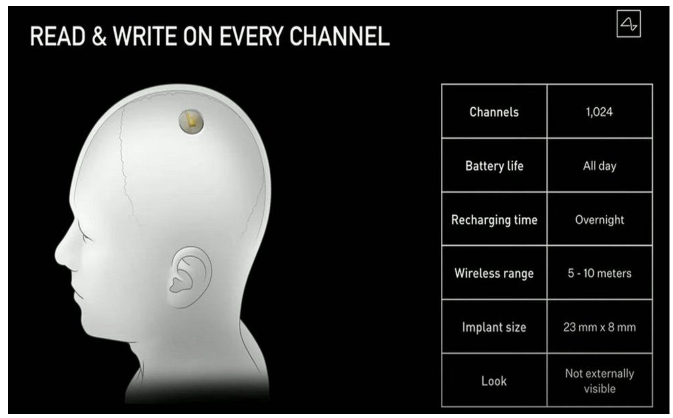
Exhibit 40: Neuralink characteristics
Battery life can last all day with overnight charging



Source: Neuralink

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Non-invasive technologies are already being used in gaming

Non-invasive techniques are also used to collect data about human brains, e.g. EEGs with neural sensing headsets. These technologies that are placed on human heads can pick up brain signals as well and have already been applied in some use cases. Specifically, NextMind's brain sensing wearable (pictured below) can enable a human to control a TV just by thinking about it, play games, or engage in AR/VR platforms without the need for handpads. Facebook, meanwhile, is working on a 'typing by brain' project with the aim to type at over 100 words per minute.

BCIs in gaming: Non-invasive brain-sensing wearables have been developed and showcased to the public. NextMind's sensor can sit attached to a cap at the back of the head accessing data from the user's virtual cortex in the brain and translating into action with computer games, VR/AR headsets and beyond.

Exhibit 41: Non-invasive brain computer interface that allows you to play games with just your mind
NextMind's brain sensing wearable at CES 2020

Source: NextMind, CES 2020, BofA Global Research

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Unlocking the brains of the animal kingdom and the world of insect cyborgs

The greatly different experiences and skills of animals – such as the sonar skills of a bat, the superior smell senses of locusts and undersea capabilities of sharks and fish – have remained largely a mystery to humans. Brain implants could open the so-far inaccessible vaults that are animal brains. Beyond research purposes, manipulation and reading of animal brain waves could have potential military applications. For instance, scientists have found that locusts can detect different forms of explosives and, by reading their brain waves, this knowledge could be utilized (source: University of Washington in St Louis, 2020). This is an example of a wider research area to manipulate insects rather than trying to create costly, small, complex robots that behave like insects.

> **Upgrading the canary in the coal mine:** Scientists have used implants to read brain waves of locusts to know when they smell explosives (source: University of Washington in St Louis, 2020)

Telepathy: not just brain-to-computer but brain-to-brain interactions too

The field of development relating to brains is still expanding. Brain-to-brain interfaces that allow the brains of two animals to communicate directly have also been investigated. For instance, a rat has been able to help a second connected rat choose the correct levers by firing a relevant neuron. Similarly, a researcher in 2013 used a non-invasive interface to send signals via the internet to a second colleague across campus to control the hand movements of that colleague (source: University of Washington). Further research has enabled 3 humans to collaborate through brain waves to play a Tetris-like game (source: Jiang et al, nature, 2019). Long term, researchers hope such connectivity could result in a brain-net or a collaborative solution for problems that need more than 1 brain.

> Brain-to-brain computer interfaces have been used to collaborate between 3 humans using just brain signals (source: Jiang et al, 2019)

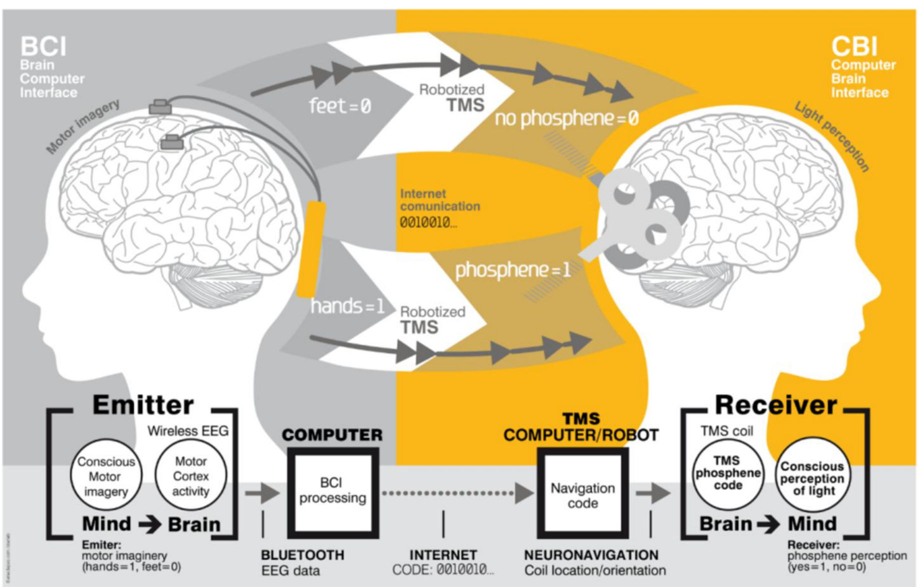
The moonshot technology of greatest ethical concern?

With access to brains comes serious ethical questions. Actions such as manipulation of brains to induce public compliance by governments, create harder-working employees or increase desire for company goods would need to be regulated, and control over which thoughts are exported out of the brain would also need to be established.

> "The brain controls pain. It controls fear. Sleep. Empathy. Hunger. Everything we associate with the heart or the soul or the nervous system is actually controlled by the brain. Everything. What if you could control it?" *Dennis Lehane*
>
> "The real question is, when will we draft an artificial intelligence bill of rights? What will that consist of? And who will get to decide that?" *Gray Scott*

Regulation of such a contentious technology will no doubt play a key part in the rollout of BCIs. The Breakthrough Devices Program by the FDA that is intended to speed up the process for developing solutions for irreversibly debilitating conditions has enabled products like Stentrode by Synchron to achieve faster permissions to be investigational objects.

Exhibit 42: Brain computer interface vs computer brain interface
How would a human brain/cloud interface work?



Source: Frontiers

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US$5.46bn market by 2030E

The global BCI market was valued at US$1.49bn in 2020, and is projected to reach US$5.46bn by 2030, increasing at a CAGR of 13.9% between 2021 and 2030. Based on application, the healthcare segment held the highest share in 2020, garnering more than half of the global market. Based on type, the non-invasive segment accounted for more than three-quarters of the total market revenue in 2020, and is expected to retain its dominance by 2030 (source: Allied Market Research).

Emotional AI: when computers are in touch with their feelings

What is it: Emotional AI (EAI) is designed to capture human feelings, respond to them and even use emotions drive to action.

The answer to: 'can robots replicate the most human of traits'?

Did you know: 90% of our decision making is emotional

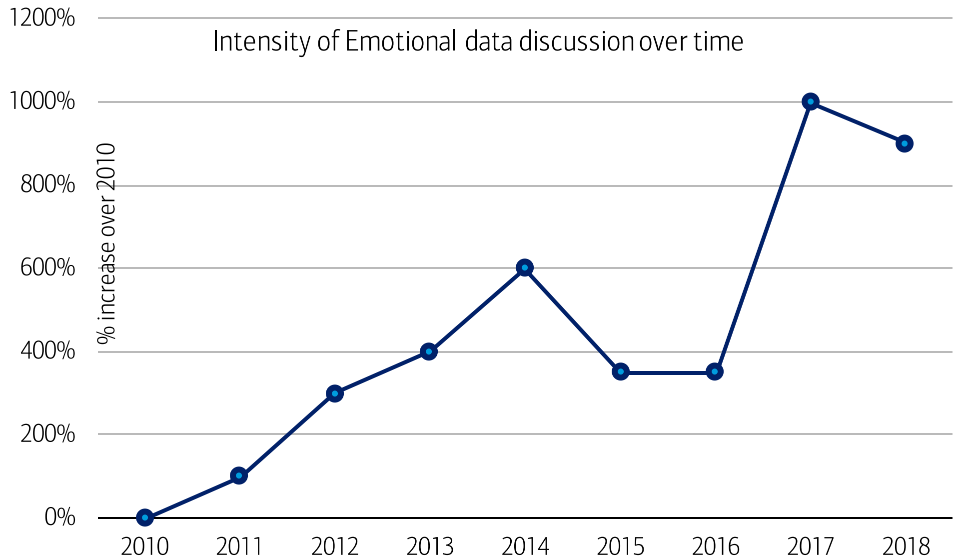
By early 2020s, emotional AI will become increasingly present in everyday objects and practices (Andrew McStay)

Market size: US$284bn by 2028

Sectors affected: Tech Hardware & Software, Industrials, Cybersecurity

We are entering the next stage of computer/human interaction: emotions...
Emotional Artificial Intelligence (EAI, also known to as "Affective Computing" and "Cognitive computing") is designed to capture, analyse and respond to human emotions and simulate human thoughts. EAI can potentially collect, analyse and respond to completely new varieties of data and situations and predict or simulate human thought, leading people to take action.

Exhibit 43: Company discussion intensity on Emotional AI technologies in Earning Release calls
Increase in intensity of Emotional AI discussion in Earnings calls to around 900% in 2018 for Communications, Technology, and Platform companies with base year 2010



Source: Accenture

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By collecting data from cameras, microphones or any other sensor that can track movements, voices vitals or other human signals, EAI could interoperate and determine a person's current emotional state. Eventually EAI will be able to analyse what drives different emotions and how these emotions translate into action. The next generation of EAI is designed to capture and interoperate third-party reactions and binary interactions and determine emotional states by the reaction of third parties.

Exhibit 44: Emotional AI cheap sheet

EAI could analyses emotions which are responsible for 90% of human decision making and could be implemented in many sectors.

Source: BofA Global Research

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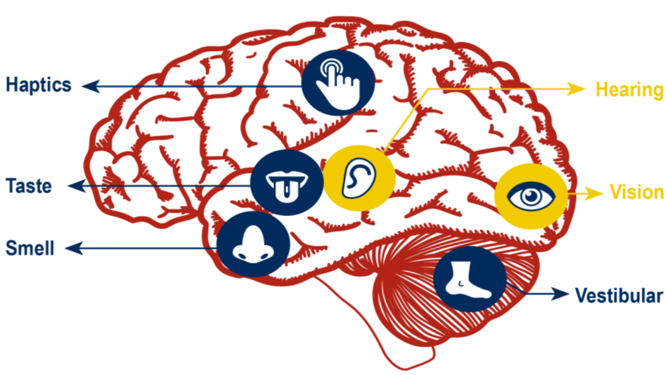
We are now entering the next stage of computer/human interaction which is the bedrock of EAI. We see this in the form of body sensors in wearables that automatically collect data. Voice control is also making rapid advances: users can already control digital assistants, such as Amazon Alexa or Google Assistant, by voice which entails far less effort than a keyboard or mouse, and reveals a lot of information about us, which is being collected and analysed. Chatbots are improving in their ability to communicate thanks to artificial intelligence and will continue to do so with EAI. Whether voice and gesture control or total reality, human-machine interaction is just at the beginning of an evolution and in future, data from different sensors such as cameras, microphones, etc will be increasingly combined to capture and control complex processes like emotions optimally.

Exhibit 45: Tricking the human senses

70% of our sensory receptors are in our eyes, and 50% of the brain is involved in visual processing



Source: Oculus 2015, BofA Global Research

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AI algorithms are action-driven and big data-based. Simply put, AI is results-driven and evolves according to the data that is created by each action. However, how about processes that are not part of final result but impact it? These processes are our emotions. EAI is taking artificial intelligence one step further and trying to increase data on what drives our emotions. A 2016 study by Harvard Professor Gerald Zaltman suggested that 95% of awareness happens in our emotional brain and more than 90% of our decisions-making is emotional (while we use logic to justify these decisions).

> 95% of awareness happens in our emotional brain, 90% of our decision-making is emotional (source: Harvard)

How does EAI work?

Sensors, processors & effectors are key

EAI is typically a machine with sensors, processors and effectors able to perceive the environment, have situational awareness, make appropriate decisions, and make decisions according to the environment.

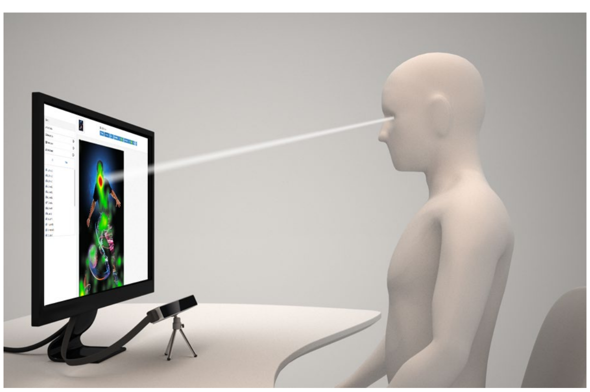
> AI has surpassed humans in both voice/speech and facial recognition since 2015 with >95% accuracy.

Example EAI can analyses emotion: eye tracking

Eye tracking monitors the motion of the eye to determine where the user is looking. In a sense, "the eyes become the mouse pointer" and can even be used to select icons or items from a list. That capability is particularly useful in situations where a voice command isn't realistic or a gesture can't be made (i.e., when the user is carrying a load with both hands).

Eye trackers use built-in sensors to track eye movement as a way of controlling a device, application or game. This can act as a control interface and could help to detect user focus, interest, as well as emotion – the ultimate turnkey to simulate natural human-human interactions. For example, the product Eye Tribe uses a high-resolution, high-speed camera aimed at the eye. Even the smallest eye movements are detected and interpolated by the software to see what the user is looking at (source: PWC, The Eye Tribe)

Exhibit 46: User in front of an eye tracker
Eye Tribe product uses a high-resolution, high-speed camera aimed at the eye to detect even the smallest eye moments and interpolated by the software to see what the user is looking at



Source: The Eye Tribe

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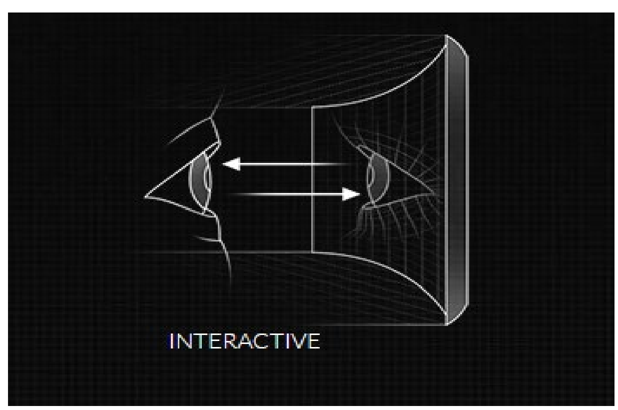
Exhibit 47: FOVE VR eye tracking
Eye trackers use built-in sensors to track eye movement which could help to detect user focus, interest, as well as emotions



Source: Fove

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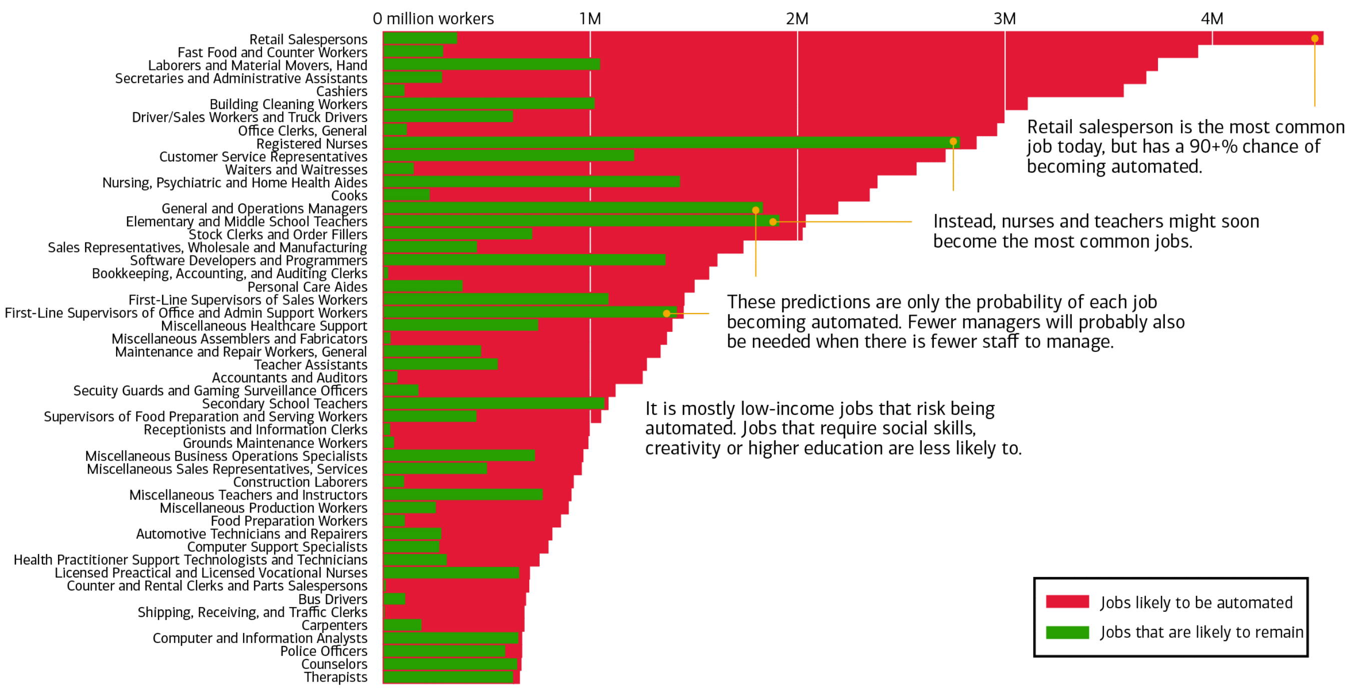
What can we do with EAI?

EAI can potentially be used in two use cases. First, as most of our decision-making is emotional, EAI can fit the right product/service to our emotional state. Improving detection of emotions is key for fitting the service/product and generating further interaction in the future. Second, EAI can go a step further to influence our emotional state and drive us to action. EAI could complete and provide the "full human relationship" experience and, combined with deep learning, the integration will be more accurate over time.

- **EAI can personalize interactions**. It doesn't matter if the interaction is by humans or machines (smart speakers, chatbots or avatars), humans are looking for personal interaction and the feeling that the counterparty understands them. The human relationship experience could improve interaction results and lead to further actions, especially when we are seeing more interaction with digital aids. By 2024, there will be more voice assistants than humans on the planet (source: Jupiter Research). Amazon sells 70 Alexa devices every 60 seconds (Visual Capitalist). 90% of retail sales staff could be replaced by automation by 2030 (WEF). As a result, the personal experience that EAI can provide will be key to filling the gap. EAI does not apply only to robotics, smart speakers or bots replacing humans, but could provide better tools for humans to improve interaction and understand clients/ counterparties needs. Retail and commerce is a good example but EAI could also be applied in the "care economy", helping doctors better understand their patients, teachers improve and tailor interactions with students and psychologists analyse and perfect patient treatments.

Exhibit 48: Future of employment: retail salesperson's jobs has 90% chance of being automated whereas nurses/teachers have less automation risk
Likelihood of job automation (today vs next 20 years) where red bars denote jobs likely to be automated and green bars denote those likely to remain



Source: US Bureau of Labor Statistics, Frey & Osborne, The Future of Employment, Henrik Lindberg, Visual Capitalist

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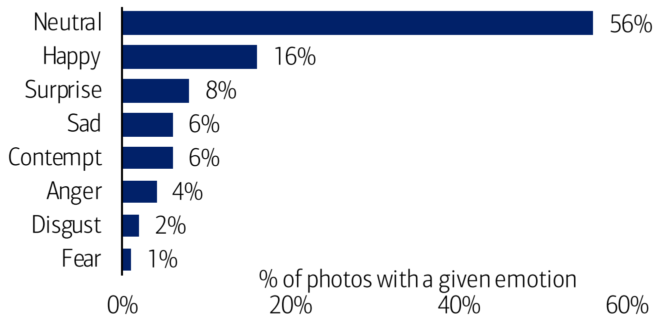
An average person is exposed to 5,000 branded messages a day. 12 will be remembered, far fewer will prompt action (Captivate Group)

- **EAI can influence decision-making**. Since 90% of decision-making is emotional, being able to understand emotions and interpret such feelings would be key to leading people to action. This is the "missing link" between identifying needs and driving for action. As a case study, Sotrender used their AI detector to gauge the sentiment of leading figures such as Elon Musk and Richard Branson using facial recognition technology to analyses their emotions and opinions for online content.

Exhibit 49: Elon Musk emotions recognized by AI

Elon Musk came across as Neutral in 56% of his 76 images analysed, while the model detected happiness in only 16% of the images worked with



Source: Sotrender

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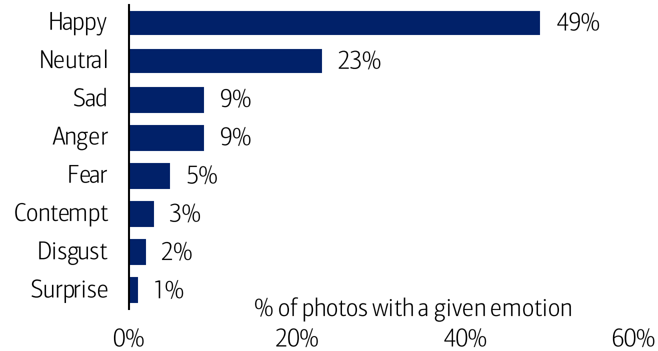
Exhibit 50: Richard Branson emotions recognized by AI

Branson appears to be happy in almost half of his social media images



Source: Sotrender

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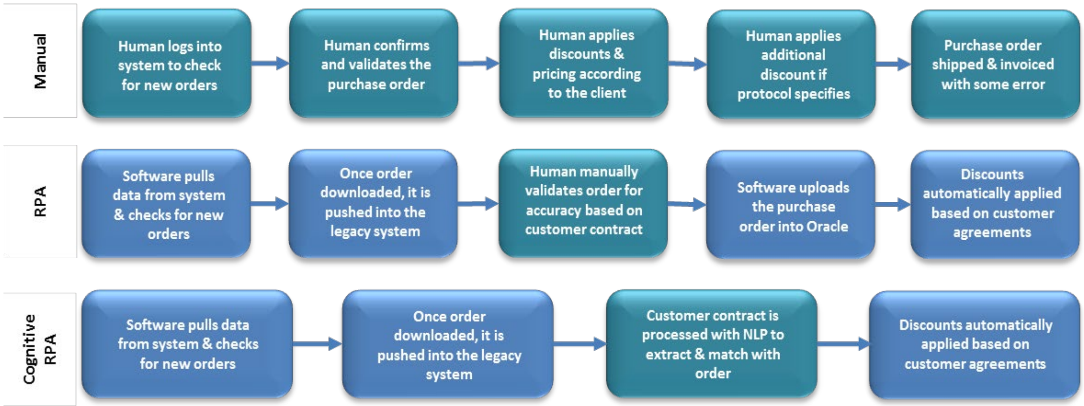
- **EAI improves human capabilities**. For example, in the education system where EAI can detect different emotional states among students such as boredom, confusion and anxiety. It can therefore help improve interaction with the teachers, learning aides and tailor programs. Already, EAI is an integral part of several online education systems. In healthcare, EAI can monitor the emotional state of patients 24/7, and monitor other physical statistics, thereby improving and personalizing treatment.

- **Cobots** – increasing efficiencies. We believe some of the future job market will be automated and some of the tasks that humans do now will be done by robots. That said, we don't see humans and robots as zero sum, because ultimately the endgame is greater collaboration ('cobots'). Due to advancements in technology and motion-sensing capabilities, a new type of industrial robot has emerged known as the **collaborative industrial robot** (or "cobot"). These are defined as small and nimble robots specifically designed to move around the factory floor to assist human workers. Cobots are typically smaller, cheaper and easier to program than traditional industrial robots. Deep learning algorithms are "in charge" of improving this interaction and making it more efficient. However, by adding EAI capabilities, we believe efficiency gains could be maximized.

Exhibit 51: Manual Labor vs RPA vs Cognitive RPA
Diagram show cognitive RPA allows for automation of processes involving unstructured data



RPA = Robotic Process Automation. NLP = Natural Language Processing
Source: BofA Global Research, Deloitte, Automation Anywhere

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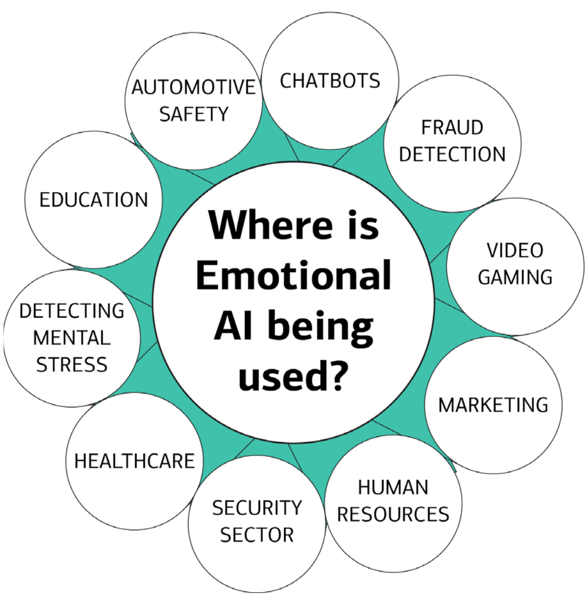
Risks: privacy and maturity of technology

The technology itself is neither good nor bad. The overall impact of this tech is decided by those who control it. Facial recognition, for instance, could speed up the identification of criminal suspects and track down trafficked children online. However, caution is necessary before agreeing to universal monitoring and use of such tech. The two main challenges are: (1) privacy: EAI collects much more data on the person; and (2) maturity: the technology is still young and so the quality and quantity of data is still limited because EAI is still new.

Industries that could benefit

Almost every industry can gain from EAI: call centers, services, recurring agencies, car safety (monitoring emotional state of drivers), retail and so on. Here are some key industries that we believe can benefit the most:

Exhibit 52: EAI application for different sectors
EAI is applicable in almost every sector and industry, however education, gaming, security and retail among the ones to see the fastest adoption



Source: BofA Global Research

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- **Education** – better understanding of student needs and improve education interaction. EAI can spot emotions like anxiety, frustration or fear among students. These capabilities are already implemented in some online education systems and they can spot emotions that even students find hard to define. Emotions, the level of concentration or lack of interest could all be identified and analysed by EAI and by that personalized iteration. EAI could spot problems and early achievement indicators that students are not even aware of. The next level is to develop EAI-based learning aides that could be personalized for students and give teachers another tool to improve results.

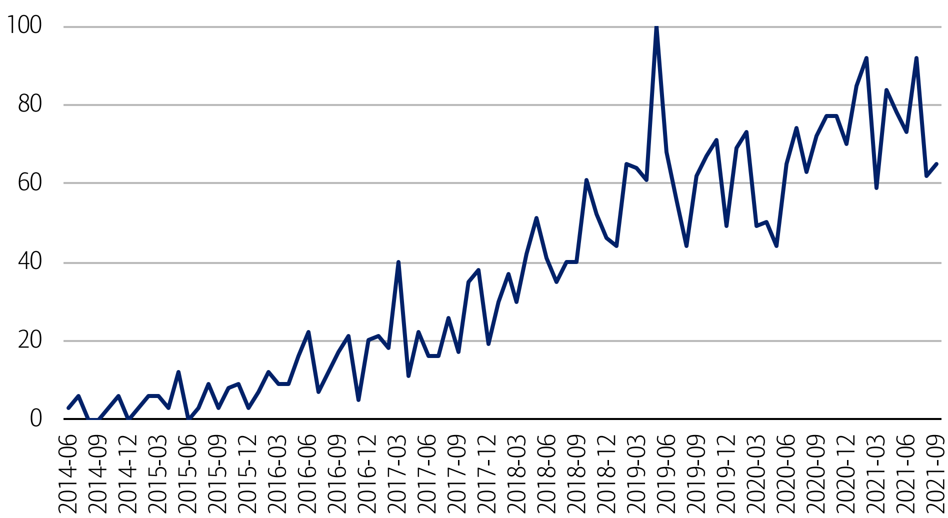
- **Commerce and Retail**: understanding consumer behaviour is key. EAI could improve the consumer experience by targeting shopping needs much more effectively. EAI could also drive consumption process by influencing decision-making and driving consumers to take action. By improving the accuracy of needs detection, the likelihood of a client returning increases. Also, EAI could replace the inefficient and expensive process of surveys or focus groups that are trying by statistical measures to predict consumer behaviour.

- **Healthcare**: EAI can improve the capabilities of remote patient monitoring. In 2019, more than 10% of the US had smart watches while 70% are already using smartphones, In addition, smart-watch capabilities continue to improve. A 2018 Gartner report suggests, by 2022, that 10% of all personal devices like smartphones or smart watches will have EAI capabilities, tracking emotional conditions 24/7. A fifth of US adults have a mental or emotional disorder, according to Peterson-Kaiser health analytics, implying demand for more accessible and on-demand services. As a result, a new wave of behavioural and digital-health companies are emerging that are finding cost-effective, scalable ways to reach affected people in this space (source: Rock Health).

Communication failure is the route of 70% of serious adverse health outcomes in hospitals (Visual Capitalist)

Exhibit 53: On-demand Google Searches for "mental health services" in US since 2014

Demand for mental health services increased exponentially during Covid from around 3 people in Jun'14 to92 people in Jul'21



Source: Google Trends

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- **Gaming**: Detecting emotions via sensors and cameras could personalize the gaming experience and increase usage and involvement. Gaming is considered one of the most emotionally involved industries, thus analysing emotions in real time could enhance gamer experience and involvement, thus bringing many benefits to the gaming companies. EAI could shorten the learning phase of a new game and improve the quality of interaction and thus scoring. As a result, gamers are more likely to spend more time on games with EAI embedded in them. The combination of EAI and VR (virtual reality) systems offer exciting opportunities for the future of gaming. Entertainment has a lot of potential to add value to some of the latest consumer technology. VR is a prime example of this, giving gamers or spectators of eSports leagues the ability to get up close to the in-game action, building on gaming's already noteworthy presence in the VR industry.

- **Security and fraud detection**. Many industries already use different AI capabilities to determine fraud. Voice analysis is the most common when changes in tone might indicate anxiety levels when not telling the truth. EAI could provide tools to detect fraud when analysing emotions. Ping An, a financial services company is China, is using micro-expression technology to detect involuntary facial movements that may give away early signs of fraud in potential borrowers. The company tech can detect 54 micro-movements that usually appear for 4-7% of a second, such as rapid blinking or eyeball movements and claims it can cut credit losses by 60% with the technology.

Up to 30% of users have admitted to lying to their car insurance company in order to gain coverage (Gartner)

What is the market potential?

According to Gartner, by 2022, 10% of personal devices will have emotional AI capabilities. Emergen research forecasts that by 2028 the total market size for Affective Computing or Emotional AI could be $284.73bn, up from $28.7bn in 2020 growing at a 32.5% CAGR. The research quoted the automotive industry as one of the key sectors that could lead the revolution. According to the research the smart car will use affective computing to improve safety capabilities by analysing the emotional state of the driver and even effect decision making in some extreme cases. Grand View research projects a 33% CAGR of the EAI market between 2020-2027 and an estimated market of c$200bn by 2027. Fraud market, virtual assistance and retail are just some of the industries that were mentioned as spearheading the revolution.

2) HUMAN TECH
Synthetic Biology: harnessing nature for engineering

What is it? Synthetic biology (synbio) is a field of science that harnesses nature by redesigning organisms for useful purposes by engineering them to have new applications

The answer to: 'Will synbio be the next CRISPR'?

Did you know? While 'gene editing' *transfers* ready-made genetic material between organisms, 'synthetic biology' builds new genetic material from scratch

By 2030: Some scientists believe most people will have eaten, worn, or used something created through synthetic biology

Market size: US$34.51bn by 2026

Sectors affected: materials, healthcare, medicine, manufacturing and agriculture, space and energy

Synthetic biology is genetic engineering on an industrial scale

Synthetic biology is a field of science that combines features of molecular biology, genomics, chemistry, engineering, machine learning and computer science. At its core, 'synbio', as the field is commonly known, takes advantage of the vast diversity of nature to make biomolecules that traditional chemistry cannot. While similar to genetic engineering, which has historically focused on the manipulation of a few genes to produce known biomolecules (e.g. insulin), synthetic biology encompasses the design of artificial gene networks to rapidly create new biological systems and microorganisms that can produce biomolecules with novel or enhanced qualities. Ultimately, synbio is an area of scientific research that involves editing and redesigning the biological components, systems, and interactions that make up life. By doing this, synbio can grant organisms new abilities that are beneficial to humans.

What is synthetic biology?

Synbio has applications across a myriad of fields, with research covering everything from space exploration to drug discovery. Here's a look at 5 of its real-world applications (source: Visual Capitalist):

1. Medical Technologies: Synbio has a wide range of medical applications, including drug discovery, antibody production, and vaccine innovation (it's been key in the fight against COVID-19). It also plays a significant role in "living drug" development, which is the use of living microbes to treat chronic or severe illnesses.

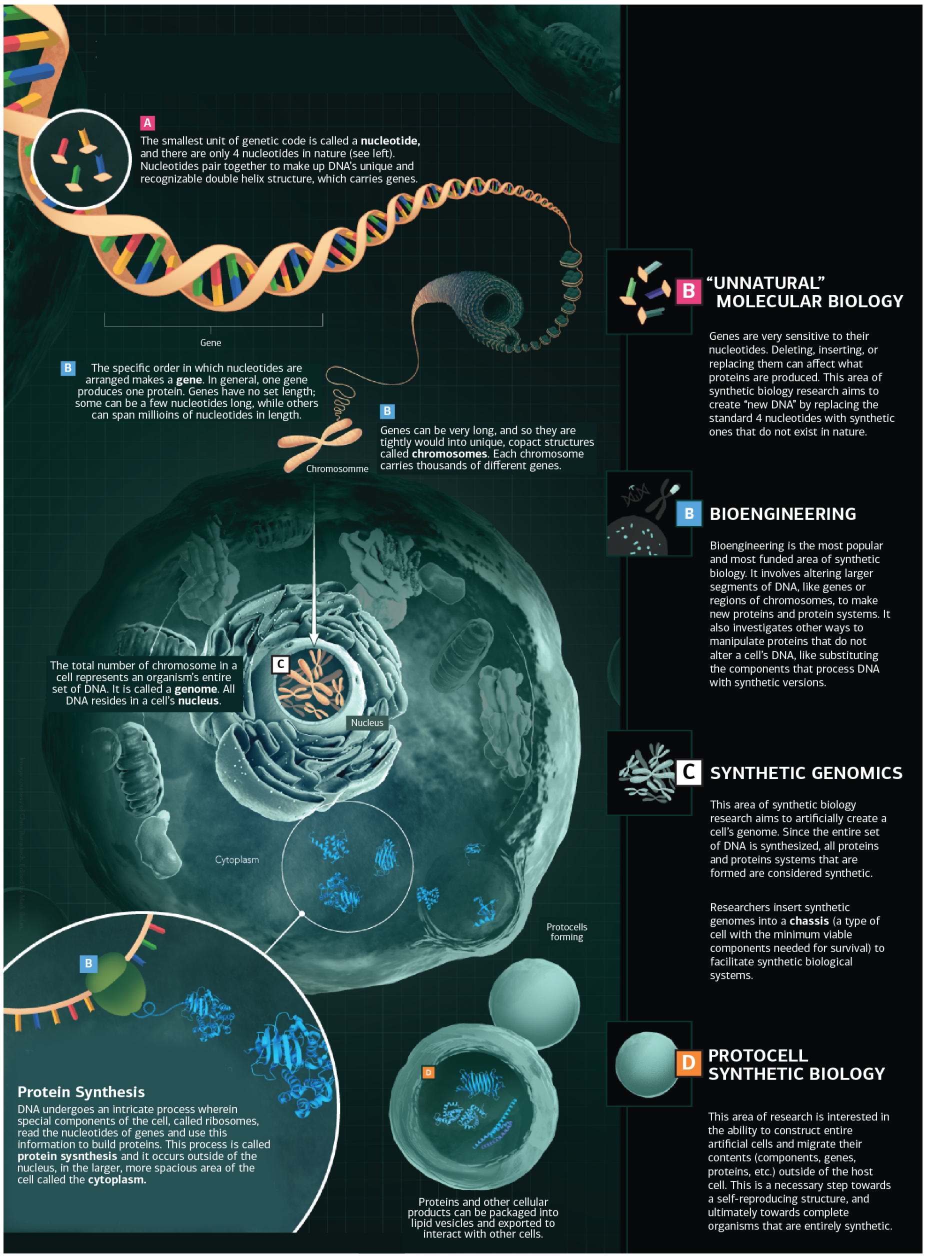
2. Sustainable Energies: Biofuel, which is renewable energy that's derived from living matter, could replace petroleum and diesel in the near future – and synthetic biology technology is helping develop fermentation processes that will produce biofuel more efficiently.

3. Bioremediation: uses living organisms to restore polluted sites to their original condition. This field uses synbio to try and make the decontamination process more efficient, and to expand the list of contaminants that bioremediation can target.

4. Food and Agriculture: Synbio plays a significant role in cellular agriculture – agricultural products coming directly from cells rather than livestock or plants. These modified foods might have higher nutritional value, or might be void of allergens. For instance, they can be used to make plant-based burgers taste more like meat.

5. Space Systems and Exploration: Synbio and 3D printing have huge potential to sustain life during space exploration. Using synbio technology, cells and bacteria could be modified to produce a host of materials from plastic to medicine, and even food. Astronauts could print these synthetically engineered materials on-demand while in space.

Exhibit 54: How synthetic biology is redesigning life
Illustration depicting how a typical cell's DNA is organized, and how DNA is used to create proteins



Source: Visual Capitalist

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The science behind synthetic biology

In order to understand the scientific mechanics of synbio, it's important to explore the relationship between DNA and protein production. Proteins are the drivers of life in a cell – they're responsible for carrying out all of life's functions. They are created through a process called protein synthesis, which relies heavily on DNA. Why is DNA so important in protein production? Because it houses all the information a cell needs for protein synthesis. Once a protein is formed, it embarks on a complex journey throughout the cell, interacting with a number of other proteins and cellular components to perform functions needed for the cell's survival. This process of protein production and cellular interaction is an example of a biological system. And it's this biological system that synthetic biologists investigate and try to manipulate (source: Visual Capitalist) – see Exhibit 55.

5 main areas of research

While early research in synbio struggled to finish real-world projects, innovation in this field has ramped up quickly in the last decade. Synthetic biology products are becoming increasingly more pervasive in everyday life – so much so that by 2030, some scientists believe most people will have eaten, worn, or used something created through synthetic biology. There are currently 5 major areas of synbio research:

- **In Silico Synthetic Biology:** meaning "via computer", this area of synbio research uses computational simulations to design and predict new biological systems. It's like using a drawing board before starting a project.

- **"Unnatural" Molecular Biology:** An area of research focused on altering the smallest unit of DNA: nucleotides.

- **Bioengineering:** This area of research deals with larger segments of DNA like genes or chromosomes, and sometimes other cell components that interact with DNA. It aims to create new proteins or protein systems and is the most popular area of synbio research.

- **Synthetic Genomics:** Focused on altering and manipulating whole genomes (which is the complete set of a cell's DNA).

- **Protocell Synthetic Biology:** This field aims to construct whole cells and is a step towards creating organisms that are entirely synthetic (source: Visual Capitalist).

If you build it, will they come?

There are a number of risks, chiefly that there is no guarantee customers will accept the products that synbio companies can make and produce them at scale. Companies in this space are still in the early stages of launching products, and while feedback from customers has been positive, it has yet to be incorporated into any major devices. As newcomers, disruptive synbio companies are not only competing against well-entrenched traditional players, they must also convince customers that they can deliver. There are also potential regulatory risks given the development and use of genetically engineered microbes.

Biofacturing

What is biofacturing?

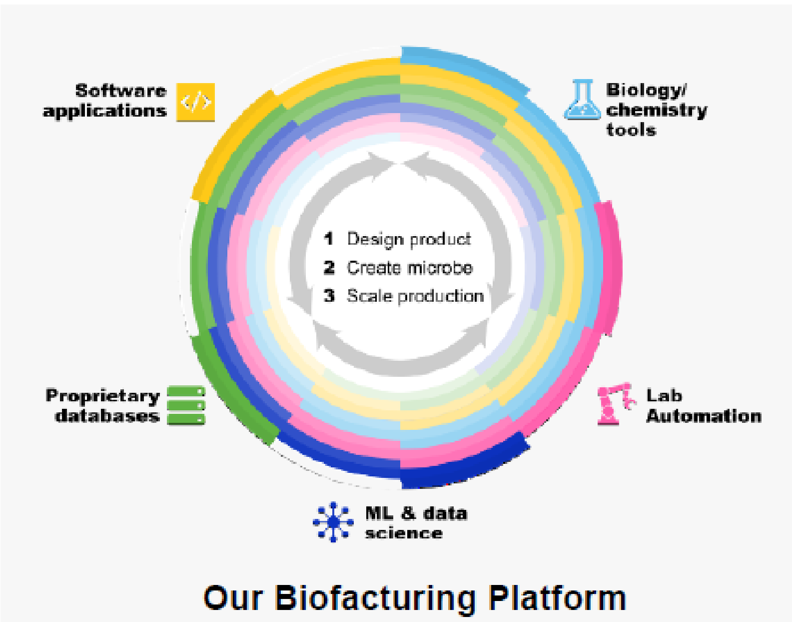
The business of 'biofacturing' is the design, development and commercialization of novel products derived or made by biological micro-organisms. It involves leveraging the power and diversity of biology to transform traditional production development, by genetically engineering cells to produce biomolecules that can be used to create better products, faster, cheaper, and in a more sustainable manner than traditional synthetic chemistry.

Overview of the biofacturing platform

The biofacturing platform integrates molecular biology, chemistry, materials science, lab automation systems, software applications, and proprietary databases and machine-learning algorithms to drive product development and manufacturing. In essence, biofacturing platforms help discover biomolecules, engineer microbes that can produce those biomolecules, and scale up production processes – see Exhibit 57.

While each product development step is distinct, the platform is flexible and each can be completed independently or in parallel. Moreover, the platform has the potential to improve its machine-learning workflows through its routine use, as each product design and gene-optimization exercise generates more proprietary data that can be used to fine-tune and optimize the overall process (source: Zymergen).

Exhibit 55: Zymergen 's biofacturing platform
Biofacturing platform assets and major product development steps



Source: Zymergen

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Economics, market size and TAM

The global synthetic biology market in terms of revenue was estimated to be US$7.54bn in 2019 and is expected to reach US$34.51bn by 2026, increasing at a CAGR of 21.9% from 2020 to 2026 (source: Bradessence Research).

Synbio reduces time & cost

The average time from idea to production is <5 years at an average cost of US$50mn vs. traditional chemicals & materials (9 years, US$400mn) and pharmaceuticals (13 years, US$500mn), according to Zymergen.

Capex-light business model

Synbio companies use contract manufacturers for scale production and working capital requirements are lower vs. traditional petrochemical-based manufacturers (source: Zymergen).

Focus on ESG sustainability

The business model is ESG-friendly in that companies have the potential to create materials that are manufactured more cleanly, create less waste, and are less harmful to the environment (source: Zymergen).

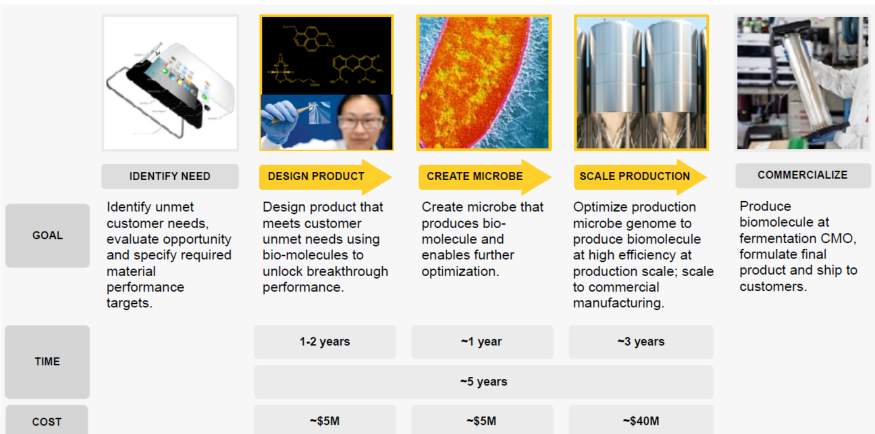
Business model overview

The synbio business model consists of 5 major steps: 1) identify need; 2) design product, 3) create microbe, and 4) scale production through the biofacturing platform; and 5) commercialize. We describe each in detail below.

Potential to manufacture better products in 1/2 the time and at 10% the cost

According to Zymergen, initial results suggest that with its biology driven platform it has the potential to develop, manufacture, and commercialize novel, high-value products in about half the time and for one-tenth the cost of what traditional materials and chemicals companies can do.

Exhibit 56: Business model lifecycle
Product journey summary



Source: Zymergen

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Market could be hard to convince

The market may be sceptical of the viability and benefits of products because they are based on relatively novel and complex biotechnology and, as a result, the sales cycles could be lengthy and market acceptance is uncertain. Furthermore, there can be no assurance that products will be understood, approved, or accepted by customers, regulators and potential investors or that the company will be able to sell its products profitably at competitive prices and with features sufficient to establish demand.

Pipeline uncertainty – hard to forecast time and cost

It is difficult to predict the time and cost of development of pipeline products and, in some cases, products may not be scalable or profitable. There is no certainty that the biofacturing platform will continue to deliver viable pipeline products. In addition, some commercial products do not contain any bio-based ingredients or components and if companies are unsuccessful at developing a bio-based version then business could suffer.

Technology and highly competitive

Even if companies succeed in expanding the biofacturing platform, rapidly changing technology and extensive competition in the synthetic biology and petrochemical industries could render the company's products and pipeline either obsolete or non-competitive. Incumbent companies have greater name and brand recognition, financial and legal resources, and larger sales forces or distributor networks.

Manufacturing – securing enough capacity

Synbio companies relies on contract manufacturing organizations (CMO) and if the company cannot secure enough capacity ahead of time, this may hurt the scale-up and production of products.

Intellectual Property (IP) and cybersecurity
If companies don't successfully defend their IP, databases, and/or engineered microbes, then business could be impaired.

Lingering COVID-19 related headwinds
The coronavirus pandemic has impacted commercialization efforts and could continue to do so; the pandemic could also harm supply chains.

Biological safety, product liability, and regulatory risks
Companies involved have exposure to hazardous biological waste and pipeline products may cause undesirable clinical or environment side effects. Regulations governing the use of genetically engineered or modified organisms (GMOs), especially those that impact the food chain, could impact the company's business. If the company cannot secure regulatory approval for its products or if it faces material ethical, legal, and social concerns about the use of its GMOs, then the business could be adversely affected.

Immortality: can we disrupt death?

What is it? By treating aging as a disease rather than an inevitable part of life human beings can disrupt death through lifespan extension

The answer to: from the Holy Grail to the Epic of Gilgamesh and the Fountain of Youth, could humanity's quest for eternal life be nearing an end?

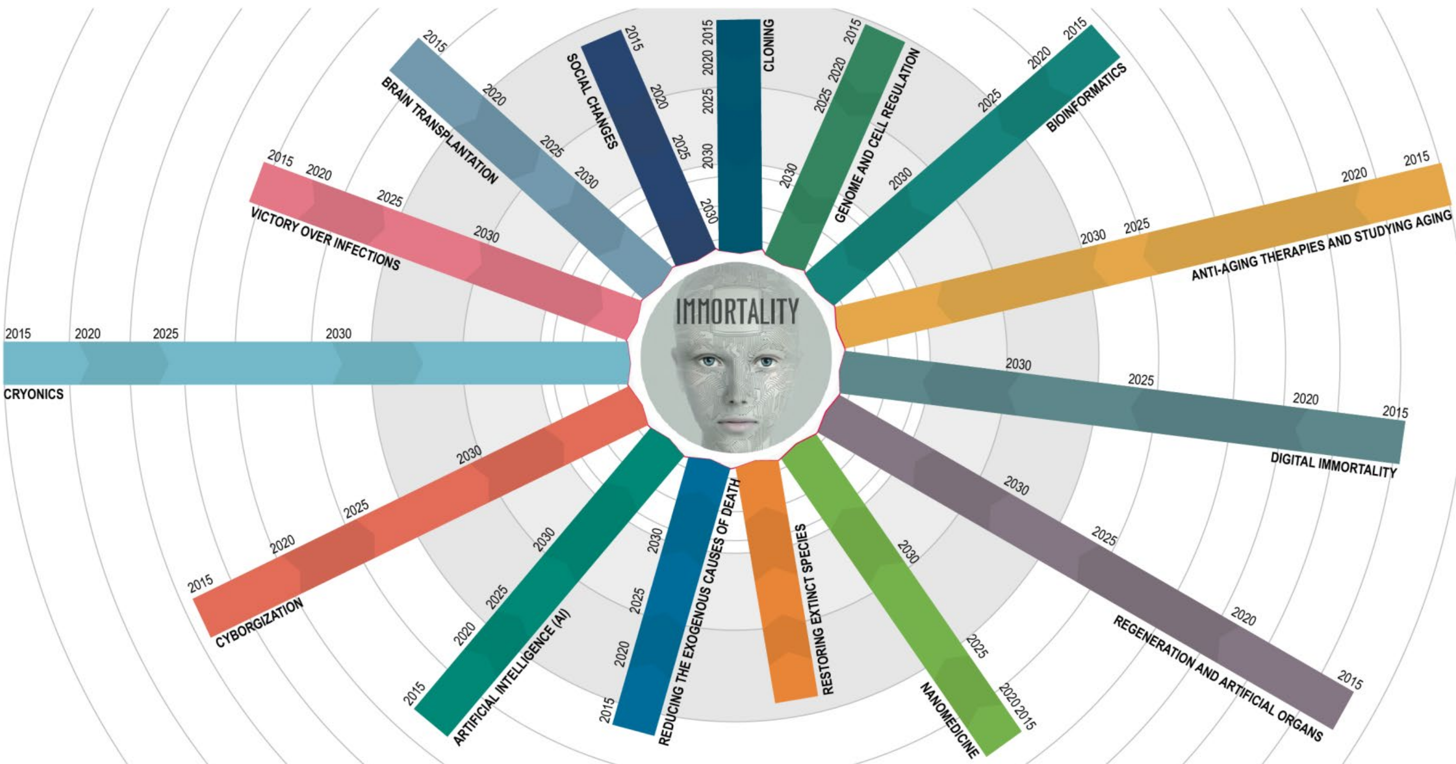
Did you know? The oldest ever-recorded person lived to 122 years

By 2029: humans could become 'immortal' and live forever according to Ray Kurzweil (Google Futurist)

Market size: US$20bn by 2025E

Sectors affected: Healthcare, biotech, insurance, pensions and wealth management

Exhibit 57: The roadmap to 'cheating death'?
From anti-aging therapies to digital immortality



Source: Life Extension Foundation, Maria Konovalenko

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Moonshot Medicine: can we really achieve immortality?

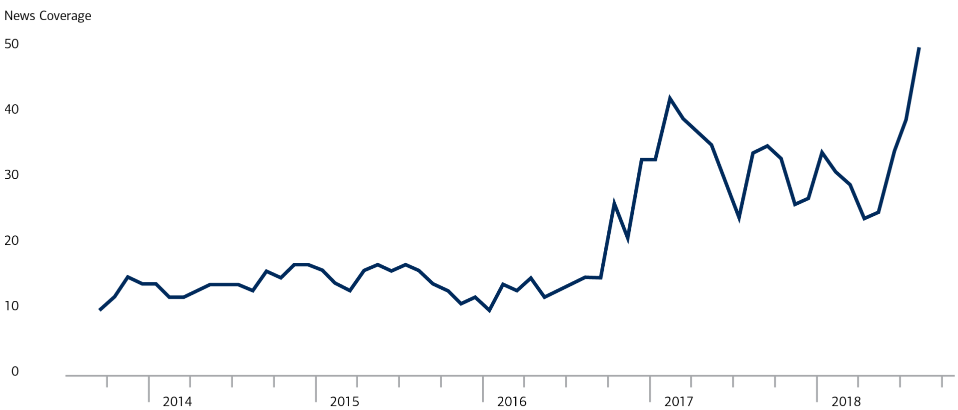
Hayflick Limit – is the concept that states that a normal human cell can only replicate/divide itself 40-60 times before it enters cell death

Gompertz Law – is a law of human mortality that states your probability of dying during a given year doubles every 8 years

New breakthroughs in moonshot medicine could result in radical life extension that 'disrupts death'. Traditionally, aging has not been viewed as a treatable disease but this is changing. Actors in this space are increasingly looking to tackle the hallmark of aging via pathways such as 'genomic instability, telomere attrition, mitochondrial dysfunction and cellular senescence'.

Exhibit 58: Interest in anti-aging / longevity related research is on the rise

News mentions of senolytic, senescence or age-related diseases from around 10 in Sept 2013 to close to 50 in Aug 2018



Source: CB Insights

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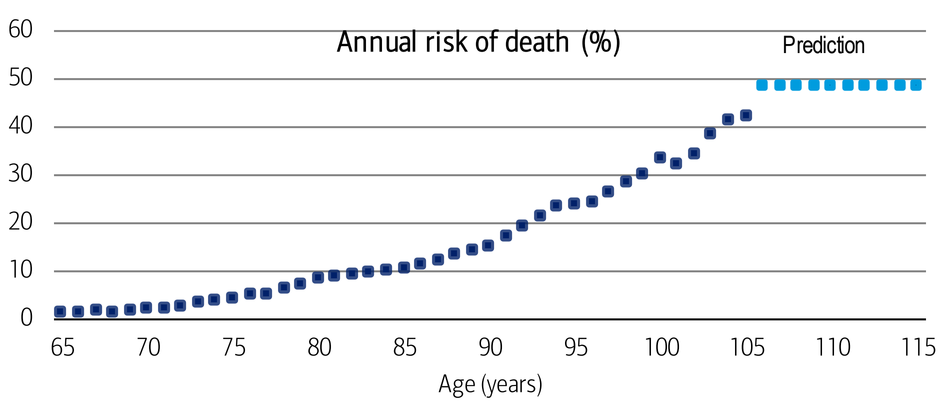
Will more people live to 100 and beyond?

The oldest-ever person was Jeanne Calment who lived to 122 years. We ask the question: could more people live to this age and beyond in the coming decades? In 2016, Jan Vijg *et al* rekindled the debate when they analyzed the reported ages at death for the world's oldest individuals over a half-century. They estimated that human longevity hits a "hard limit ceiling" at about 115 years with a maximum of 125. By analyzing global demographic data, they show that improvements in survival with age tend to decline after age 100, and that the age at death of the world's oldest person has not increased since the 1990s.

Exhibit 59: Annual risk of death (%)

Human longevity hits a "hard limit ceiling" at about 115 years with a maximum of 125



Source: Nature.com

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According to a study by Barbi *et al*, which is based on data from Italians aged 105 and older, probability risk of mortality is constant at extreme ages but at levels that decline somewhat across cohorts. Human death rates increase exponentially up to about age 80, then decelerate and plateau after age 105. Essentially the risk probability of death — which, throughout most of life, seems to increase as people age — levels off after age 105, creating a 'mortality plateau'.

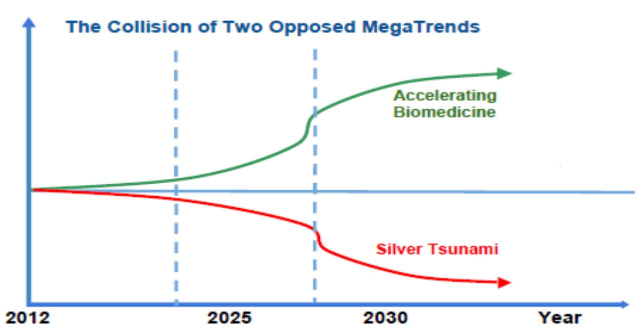
Indefinite Lifespans: biomedicine advances are key

> "The most profound limitation we have is that of our lifespan…I believe we will reach a point around 2030 when medical technologies will add one additional year every year to your life expectancy… by that I don't mean life expectancy based on your birthdate, but rather your remaining life expectancy" – **Ray Kurzweil** interview April 2016

Ray Kurzweil is an American futurist who is a Director of Engineering at Google, He believes humans could start seeing immortality beginning in 2029 and he also predicts the Technological Singularity in 2045 driven by the 'law of accelerating returns' in biomedicine. In his quest for immortality, Ray Kurzweil was once spending US$1mn each year consuming 250 supplements a day, which is now down to 100 including 30 pills in the morning. All in all, he predicates his predictions on the basis that over the next few decades:

- Eliminating a specific list comprising 50% of medically preventable conditions e.g. cancer, hypertension etc could extend human life expectancy to over 150 years
- Preventing 90% of medical problems, life expectancy grows to over 500 years
- At 99%, life expectancy goes to 1,000 years

Exhibit 60: Longevity could be the greatest opportunity or disruptor
Collision of two opposed megatrends in Accelerating Biomedicine and Silver Tsunami



Source: Deep Knowledge Ventures

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Exhibit 61: Human Life Expectancy (number of years)
From 18 in Cro-Magnon era to 78 years now in United States

Cro-Magnon Era	18
Ancient Egypt	25
1400 Europe	30
1800 Europe and United States	37
1900 United States	48
2014 United States	78

Source: Ray Kurzweil, Singularity

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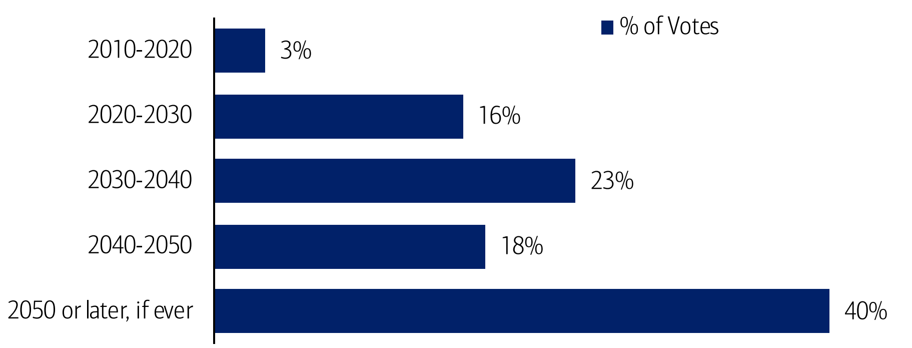
Longevity Escape Velocity and indefinite lifespans

> Biogerontologist **Aubrey de Grey**, the co-founder of Strategies for Engineered Negligible Senescence Foundation (SENS), believes the infinite extension of life expectancy could be within reach within our lifetimes. He estimates that there is an 80% possibility that a person alive today will be able to escape old age and ill-health indefinitely. And he believes that the first person to live to 1,000 is already alive today.

Longevity Escape Velocity (or Actuarial Escape Velocity) is a term used in the life extension movement. It is a hypothetical situation in which life expectancy is extended longer than time that is passing. For example, in a given year in which longevity escape velocity would be maintained, technological advances would increase life expectancy by more than the year that just went by. More than one year of research is currently required for each additional year of expected life. Longevity escape velocity occurs when this ratio reverses, so that life expectancy increases by more than one year per one year of research, as long as that rate of advance is sustainable. The concept was first publicly proposed by David Gobel, co-founder of the Methuselah Foundation (MF) and has been championed by biogerontologist Aubrey de Grey (the other co-founder of the MF) and futurist Ray Kurzweil.

Indefinite lifespan (also known as indefinite life extension or bio-indefinite) is a term used in the life extension movement and in transhumanism to refer to the hypothetical longevity of humans (and other life-forms) under conditions in which aging is effectively and completely prevented and treated. Their lifespans would be "indefinite" (that is, they would not be "immortal"), because protection from the effects of aging on health does not guarantee survival. Such individuals would still be susceptible to death by disease, starvation, accidents, or deliberate killing. Semantically, "indefinite lifespan" is more accurate than "immortality" which, especially in religious contexts, implies an inability to die.

Chart 2: When will Longevity Escape Velocity be achieved for wealthy individuals?
40% believe it will be 2050 or later, if ever



Source: Singularity 2050, The Futurist

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Geroscience: treating aging as a disease

Traditionally, aging has not been viewed as a disease that can be “treated”. However, increasingly the scientific community is viewing this natural part of life as treatable. This emerging field is known as Geroscience. It is an interdisciplinary field that seeks to define the biological mechanisms of aging that give rise to numerous age-related diseases and disorders. During the process of aging, an organism accumulates damage to its macromolecules, cells, tissues and organs. In 2018, the WHO took an important step towards labelling aging as a disease by adding an extension code for “aging-related”, disease which is helping to make this field of science mainstream.

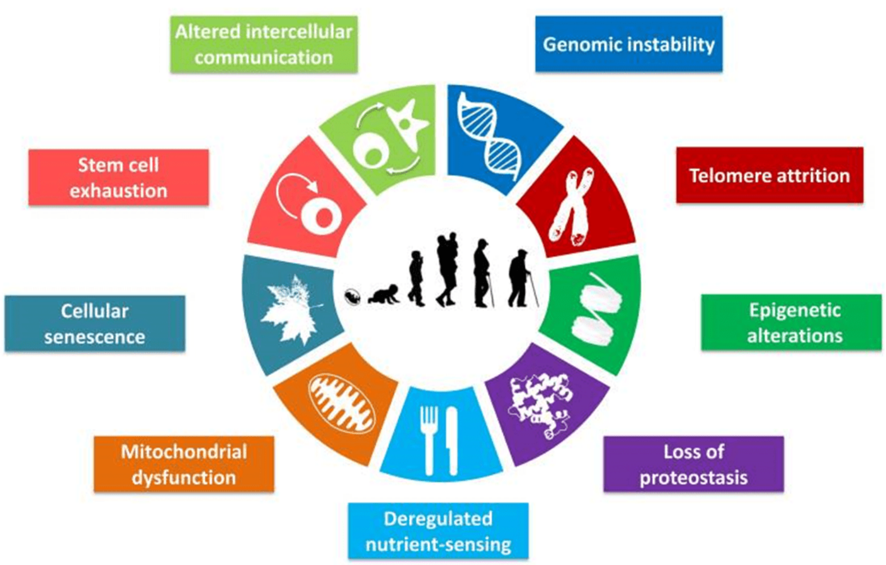
In 2018, Calico published a paper in the journal eLife presenting evidence that the ‘naked mole rat’ doesn’t face increased mortality risk due to aging.

Hallmark pathways of aging

In a seminal paper published by Lopez-Otin *et al* in 2013, the authors outlined nine hallmark pathways to aging as outlined below (source: CB Insights). Since the publication, however, viewpoints have varied on how many hallmarks there are (e.g. 8 rather than 9) but in principle these are the areas identified by the science behind aging.

1) **Genomic Instability**: Throughout one's life, both internal and external factors that cause genetic damage start to build up in the body. This is known to accelerate aging.
2) **Telomere Attrition**: Telomeres – the protective "caps" located at the ends of our chromosomes (which house our genetic material) – start getting shorter each time a cell divides. Over time, this results in cells no longer being able to divide, which can lead to disease.
3) **Epigenetic Alterations**: There are changes in gene expression (not changes to the DNA itself) via an individual's life experiences or environmental factors which affect aging.
4) **Loss of Proteostasis**: With age, cellular proteins become mis-folded and so lose their homeostatic functions. A build-up of these damaged proteins is observed with aging or age-related diseases.
5) **Deregulated Nutrient-Sensing**: There are metabolism-regulating pathways, whose proteins (e.g. mTOR, sirtuins) are influenced by nutrient levels and also implicated in promoting aging.
6) **Mitochondrial Dysfunction**: When the mitochondria (considered the energy powerhouse responsible for regulating metabolism in our bodies) starts to malfunction with age.
7) **Cellular Senescence**: "Older" cells can't be cleared out as fast and their build-up can lead to harmful health effects.
8) **Stem Cell Exhaustion**: Activities of the 4 types of stem cell, which all help in regenerating new tissue cells, decline with aging.
9) **Altered Intercellular Communication**: Communication between cells is disrupted with age, resulting in inflammation and tissue damage.

Exhibit 62: The 9 hallmark pathways to treat aging as a disease
From Genomic instability to Altered intercellular communication



Source: CB Insights, Lopez-Otin et al

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In addition, scientists continue to draw inspiration from how long humans could live from other animals too. According to the Animal Ageing and Longevity Database, the list of organisms with negligible aging includes: Blanding's turtle (77 years); the olm (102 years); the Eastern box turtle (138 years); the Red Sea urchin (200 years); the Rougheye rockfish (205 years); and the Ocean quahog clam (507 years).

From studying these species emerge methods of extending maximum lifespan in model organisms such as nematodes, fruit flies, and mice include caloric restriction, gene manipulation and administration of pharmaceuticals. Another technique uses evolutionary pressures such as breeding from only older members or altering levels of extrinsic mortality. Some animals such as hydra, planarian flatworms, and certain sponges, corals, and jellyfish do not die of old age and exhibit potential immortality.

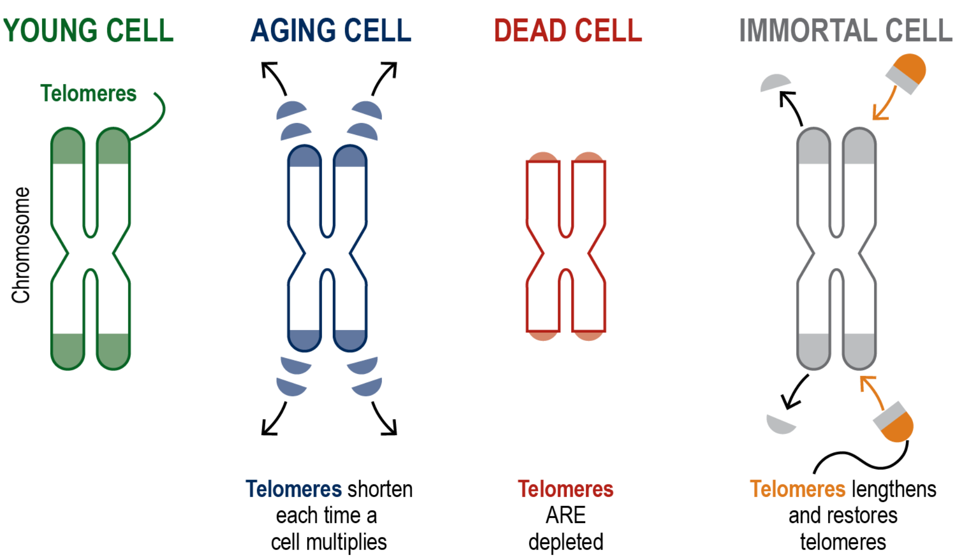
Extending telomeres, adding years

From a scientific perspective, aging and cell death are caused by a combination of telomere shortening, oxidative stress and glycation, all of which could be prevented to an extent. Telomeres are protective caps on the ends of strands of DNA called chromosomes, which house the human genome. Telomeres shorten with every cell division and cells stops dividing or die when the telomeres reach a certain length.

Elizabeth Blackburn won the Nobel Prize in Medicine in 2009 for discovering telomerase, the enzyme that lengthens telomeres. Professor Helen Blau from Stanford University has found ways to lengthen human telomeres, which could turn back the internal clock of the cells by the equivalent of many years of human life. According to Blau, this paves the way toward preventing or treating diseases of aging.

Longevity and Space? US astronaut Scott Kelly's telomeres in his white blood cells got longer compared to his identical twin Mark Kelly's while onboard the ISS for a year as part of the NASA Twin Study

Exhibit 63: Telomeres in the lifecycle of a cell
Telomeres shorten with every cell division and cells stops dividing or die when the telomeres reach a certain length



Source: Factorialist

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Biogerontology, life extension and senolytics

Biogerontology is a sub-field of gerontology studying the biological processes of aging and better understanding senescence, i.e. why humans age over time. Biomedical gerontology, also known as experimental gerontology and life extension, is a sub-discipline of biogerontology that endeavours to slow, prevent and even reverse aging in both humans and animals.

Life extension is the idea of extending the human lifespan, either modestly – through improvements in medicine – or dramatically beyond its generally settled limit of 125 years. Researchers in this area believe that breakthroughs in tissue rejuvenation, stem cells, regenerative medicine, molecular repair, gene therapy, pharmaceuticals, and organ replacement will eventually enable humans to have indefinite lifespans (agerasia) through complete rejuvenation to a healthy youthful condition.

Researchers believe breakthroughs in tissue rejuvenation, stem cells, regenerative medicine, molecular repair, gene therapy, pharmaceuticals, and organ replacement (e.g. artificial organs or xenotransplantations) will eventually enable humans to have indefinite lifespans (agerasia) through complete rejuvenation to a healthy youthful condition. The ethical ramifications, if life extension becomes a possibility, continue to be debated by bioethicists (issues emerging from advances in biology and medicine).

What could help you live past 100 years?

- **Metformin** – a medication doctors currently prescribe to patients with diabetes; but also may reduce DNA damage and keep cells working normally.
- **mTOR inhibitors / Rapamycin** – purportedly extends the lifespan and promotes healthspan in mice, as well as in simpler organisms. Treatment beginning late in life is sufficient to extend lifespan, reverse cardiac decline, and improve immune function in mice. A recent study also reported that a rapamycin derivative significantly boosts immune function in elderly people.
- **Telomerase/TA-65** – said to increase telomerase activity, is available to buy worldwide as an anti-aging aid. Industry studies suggest TA-65 has beneficial effects on the healthspan of mice and humans.

Senolytics is a class of drugs that targets aging (or senescent) cells and destroy them via induced cell death – this is another of the growing area of research. It is part of a new, emerging area of research known as "senotherapy," in which senolytics is a key class of therapeutics. Senotherapeutics include geroprotectors — drugs that are supposed to be able to prevent or reverse aging by targeting its cellular triggers, such as damage to the DNA. These drugs are in the early stages of development and, if approved by the FDA (which does not recognize 'aging' as a standalone disease), would be prescribed to target a specific condition or disease, but would carry the secondary impact of slowing aging (source: CB Insights).

Exhibit 64: 12 Innovations that could make reverse aging a reality
From Stem cell technology reprogramming aging cells to Gene deletion deleting selective genes to increase lifespan

Innovations	Method to reverse Aging
Stem Cell Technology	Reprogramming Aging Cells
Targeting Mutant mtDNA	Repairing Aging Cells
Activating Splicing Factors	Crafting Reversalogues to encourage Cell Division
Rejuvenate Biotech	Reversing the process of Aging in Dogs
Senolytic Drugs	Combining pre-existing medications to achieve Reverse Aging
Synthetic Peptides	Intervening in the Aging process
Smoothing Cells	Using Viruses to smoothen Cell Wrinkles
Young Blood	Pumping Youth back into Veins
Anti-Aging Pills	Treating Age with Medication
Reverse Aging with Cannabis	Improving Brain function with THC
Anti-Aging Bacteria	Using Bacteria to create Anti-Aging Pills
Gene Deletion	Deleting Selective Genes to increase Lifespan

Source: Interesting Engineering

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Anti-senescence genetics of aging: the elegance of worms

The first genetic mutation found to increase longevity in an animal was in *C. elegans* as discovered by Michael Klass. He discovered that lifespan could be altered by mutations, but believed the effect was due to reduced food consumption (caloric restriction) rather than genetics. Thomas Johnson later showed that the 65% life extension effect was due to the mutation itself rather than due to caloric restriction. In 1993, Cynthia Kenyon, now of Google Calico, discovered that a single-gene mutation could double the lifespan of C. elegans and that this could be reversed by a second mutation. This sparked an intensive study of the molecular biology of aging. Prior to Kenyon's study it was commonly believed that lifespan could only be increased at the cost of a loss of reproductive capacity, but Kenyon's nematodes maintained youthful reproductive capacity as well as extended youth in general. Subsequent genetic modification to C. elegans was shown to extend maximum life span 10x.

Rejuvenation medicine meets regenerative biotech

Newts can regenerate an entire limb within 7-10 weeks (NCBI)

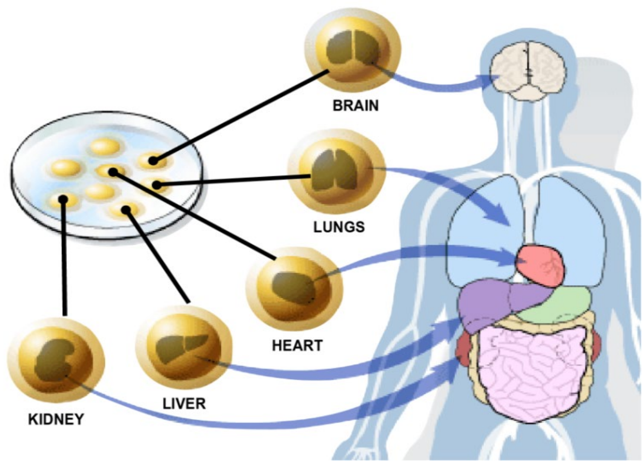
Regenerative medicine is the process of creating living, functional tissues to repair or replace tissue or organ function lost due to age, disease, or damage to restore the normal function of cells. Recently, scientists from the Swiss Federal Institute of Technology in Zurich made a 3D printer capable of using 'living ink' rather than dead matter such as plastic (Source: Schaffner et al 2017). In addition, academic groups such as the Wake Forest Institute for Regenerative Medicine (MFIRM) and the RegenMed Development Organization are developing cell culture technologies, while working with government agencies to develop standards (source: WFIRM). These technologies hold the potential to grow and/or print organs such as hearts and kidneys for transplantation.

Stem cells: building blocks of humans

Stem cell research is one of the most promising areas in moonshot medicine as cells are essentially the building blocks of the human body. Because stem cells can differentiate and produce specific cells and tissues, they may hold the key to treating age-related issues. Essentially researchers can manipulate a given set of stem cells under a controlled setting and stimulate them to differentiate into the desired cells they want. In particular, stem cells taken from an embryo can be very useful, as these can be induced to become virtually any cell — a key difference from adult stem cells. This type of technology could give way to a new frontier for anti-aging research, using stem cells to regenerate cells or tissues that have lost functions (source: CB Insights).

An example of use is that researchers at the Hebrew University of Jerusalem have found a way to transform skin cells into the three major stem cell types that comprise early-stage embryos. The types are the embryo itself, the placenta and the extraembryonic tissues, such as the umbilical cord. Research indicates that it may be possible to create an entire human embryo out of human skin cells in the future, without the need for sperms or eggs. This discovery will enable researchers to better understand and address embryonic malfunctions and diseases such as placental insufficiencies or miscarriages, as well as solving certain infertility problems.

Exhibit 65: What stem cells could be used for in human regeneration
Stem cells from kidney, liver, heart, brain, and lungs



Source: Science

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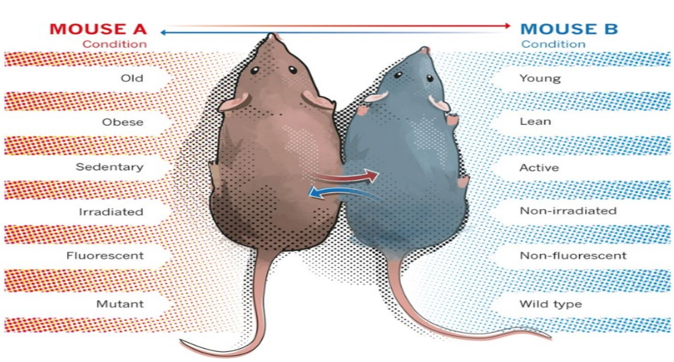
Parabiosis: the fountain of youth?

Blood transfusions from a younger individual to an older one could soon become a reality too. Such young blood transfusions — known as "parabiosis" — has been a pillar of anti-aging research due to the rejuvenating effects found in aged mice. Parabiosis is an experimental procedure that circulates shared blood between a younger and an older animal, according to the National Institute of Aging (part of NIH). This concept traces back to the 1950s, when Cornell scientists joined the circulatory systems of two mice together. Many companies have started exploring this technique, e.g. daily GDF11 protein injections from younger to aged animals can ultimately treat age-related diseases. Moreover, partnerships have developed in blood plasma-derived therapies targeting aging diseases such as neurodegenerative disorders like Alzheimer's. That said, in early 2019, the FDA brought the practices of a leading young blood transfusion company, Ambrosia, to a halt stating it was "unproven and unsafe".

Exhibit 66: Parabiosis or young blood transfusion in action
Parabiosis has been a pillar of anti-aging research due to the rejuvenating effects found in aged mice



Source: Nature

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Cryonics: persevering & freezing life forever

Cryonics is the freezing of a human corpse after death at ultra-low temperatures with the hope of revival in the future if technology permits. Other concepts in this space include the "Cryogenic Noah's Ark" – where for two decades architect Stephen Valentine has been designing, planning and developing though not yet building, "The Timeship". The building is stable enough to operate for an estimated 100 years in case of human or natural catastrophe, with the plan to house 1,000s of frozen organs for transplant, the DNA of extinct or near-extinct species and about 10,000 cryopreserved people.

Digital Immortality: mind in the cloud afterlife

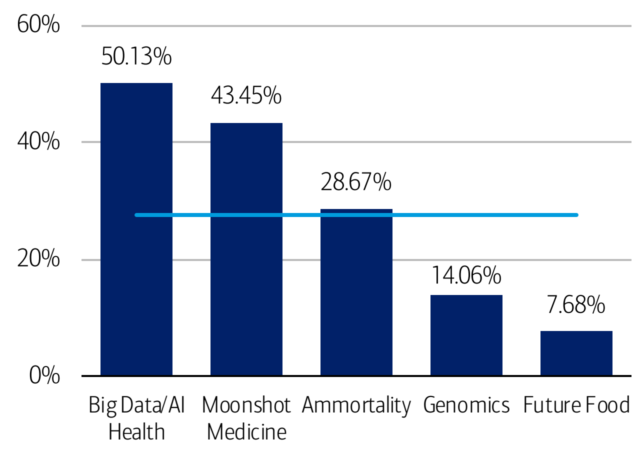
The concept of a virtual afterlife whether it's through "The Matrix" or something akin to "Black Mirror" is also a discussion point as to whether humans can achieve 'digital immortality'. Ray Kurzweil believes that, we will be able to upload the human brain to a computer, capturing "a person's entire personality, memory, skills and history", by the end of the 2030s. Humans and non-biological machines will then merge so effectively that the differences between them will no longer matter.

In addition, academics from Oxford University also recently published a paper which found the dead "may well outnumber the living" on the social media platform before the end of the century. According to their analysis, at least 4.9bn Facebook users will pass away by 2100, if Facebook continues to grow at its current rate. Academics noted that this would lead to vast volumes of "digital remains" being left behind — personal data that continues to be stored online after a user's death.

Anti-aging: US$20bn potential market

According to UFX / Inc.com, the market for anti-aging therapies and technologies that bring us closer to immortality is currently valued at US$1.6bn, but by 2025 it could grow to US$20bn. An EIU survey of physicians looking forward to the next 25 years believe that designer babies, man-made organs, nanotechnology and brain computer interface (BCI) could become part of reality.

Chart 3: Market segment CAGR between 2018 and 2025 (CAGR %)
Overall average market CAGR of 27.6%



Source: BofA Global Research, Global Market Insights. NB Ammortality includes HealthTech
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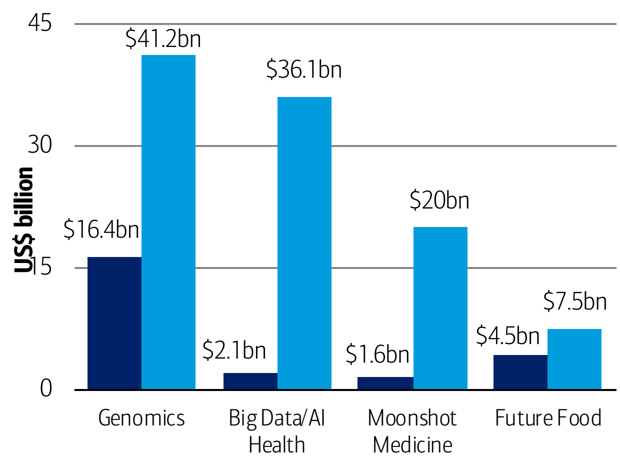
Chart 4: Market size between 2018 and 2025
+ Ammortality market omitted below but grows from $86.4bn today to $504bn by 2025



Source: BofA Global Research, Global Market Insights
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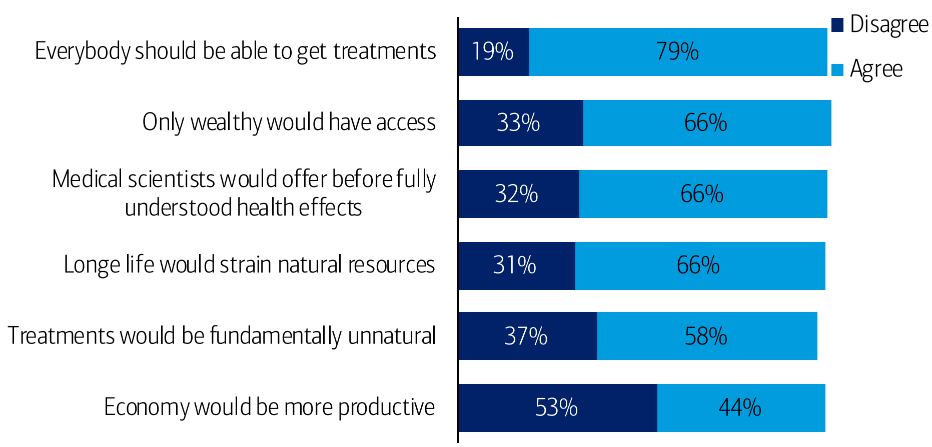
Risks

- **Inequality:** 2 in 3 Americans polled about radical life extension thought the option would only be available to the wealthy (source: Pew Research). Israeli historian Yuval Noah Harari, author of Sapiens and Homo Deus, believes expensive human enhancements will lead to a society more unequal than ever. Developments such as AI, bionics, and genetics could lead to the 21st century possibility of creating biological castes, with real biological differences between rich and poor. He believes that such developments may give the techno super-rich "godlike attributes": the ability to extend lifespans and even 'cheat death'. He also claims that the redundancy of labour, supplanted by efficient machines, could create an enormous "useless class", without economic or military purpose.

- **Ethics:** There remains a lack of ethics-based regulation globally on the use of genomics. This was underscored by a Chinese scientist claiming to have successfully genetically edited twin girls' genes while in their mother's womb to be HIV-resistant in December 2018. The global scientific community quickly condemned this announcement, as gene-editing on humans is banned in most countries/regions, including the US and Europe. New rules could also emerge against using genomic data to discriminate, while providing various services, especially in healthcare and insurance. 2 in 3 Americans polled said they believed scientists would offer life-extension technologies before their impact was fully understood (source: Pew Research).
- **Morality:** Is it 'moral' to really live forever, or longer? Ethically, philosophers have stated that what gives life meaning is that ultimately death follows. Hence, there is only a finite period of time for any one being and the passing on of their genes to the next generation is part of natural selection.
- **Overpopulation:** radically extending lifespans could create a new age Malthusian problem. If anti-aging therapies really enter the market, there is fear that overpopulation may become a reality whereby people living longer puts more pressure on the world's limited resources e.g. food, land etc.

Chart 5: What would a future with radical life extension look like?
79% of US adults agree that everybody should be able to get treatments



Source: Pew Research
Note: "Don't know"/ refused responses not shown.

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Bionic Humans: rise of the robo sapiens

What is it? Bionic human is a technology designed to increase human productivity and/or improve the capabilities of the human body

The answer to: 'will bionics allow humans to have superpower like abilities'?

Did you know? The world's first walking, talking bionic man with artificial limbs and a beating heart was unveiled in 2013

In 2020, Belgian scientists developed an artificial iris fitted to smart contact lenses that correct a number of vision disorders. **In 2021**, Israeli surgeons implanted the world's first artificial cornea into a bilaterally blind 78-year-old man

Market size: US$206.9bn by 2024E

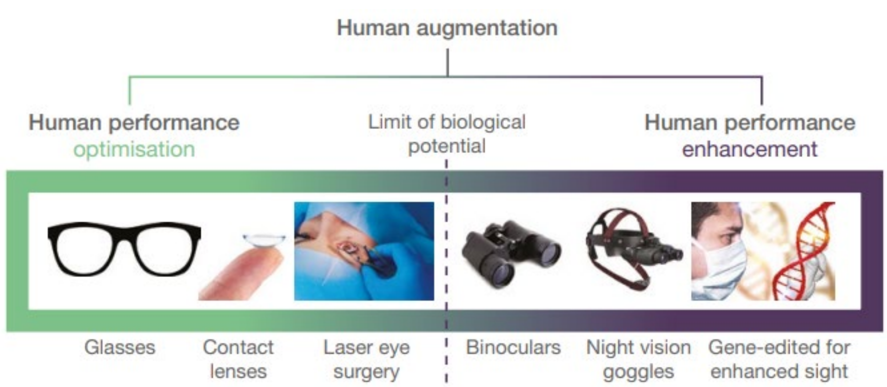
Sectors affected: Medical, retail, industrials, logistics and military

Science-fiction becoming a reality: the path to superhuman

"The goal is not to replace the human being. The ultimate goal is to provide technology to fix a broken person" Dr. Bertolt Meyer, University of Zurich

From the 'Bionic Woman' to the 'Six Million Dollar Man' and 'Robocop', science fiction has fired the imagination of augmenting humans with man-made prosthetics. The original premise behind bionic humans is to help physically impaired people regain the normal function of their body parts. However, human augmentation will likely form a critical part of our future where we are given the ability to redesign ourselves so that we live longer, healthier and stronger and faster with superhuman capabilities. In one sense, humans are already bionic cyborgs as we are constantly connected via our smartphones and outsource much of our knowledge and memory to external digital devices.

Exhibit 67: Human augmentation definitions
Enhancing human performance beyond biological potential limit



Source: UK GOV, MoD

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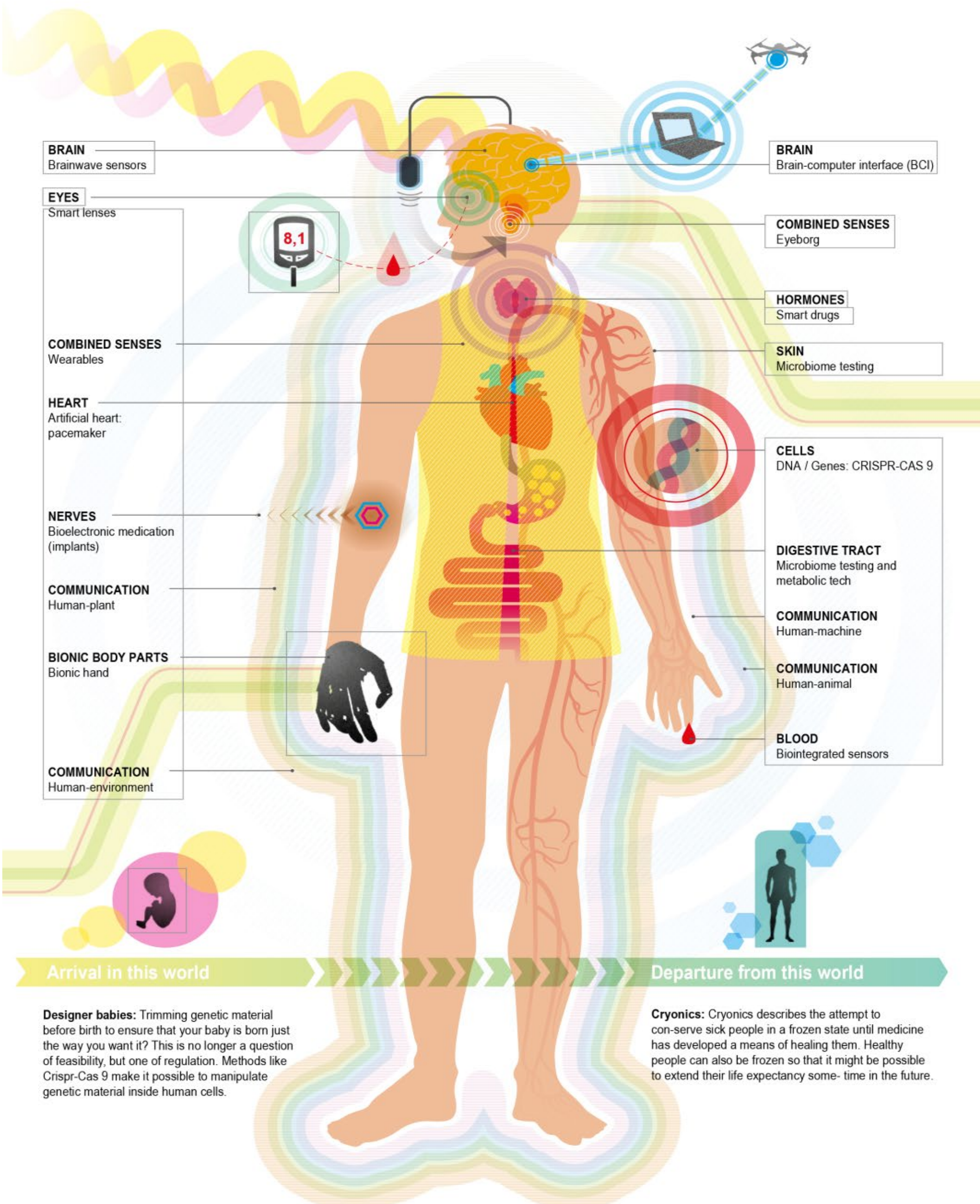
Exhibit 68: What could the future augmented human look like?
From smart lenses to the brain computer interface to bionic hands



Source: Global Wellness Institute

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Silicon Valley's robo sapiens quest

There are increasingly a number of focus areas with the objective of using science to augment humans (source: Google).

- **Intelligent Disease Management** – Comprehensive solutions that combine devices, software, medicine and professional care to enable simple readings for people with chronic diseases like diabetes.
- **Liftware** – A spoon designed to counter the tremor from diseases like Parkinson's.

- **Baseline Study** – Partnership projects with Stanford and Duke University to collect genetic, molecular and wearable device information from enough people to create a picture of what a healthy human should be.
- **Tricorder** – A disease-detecting nanoparticle platform working with the wristband, a project called Tricorder.
- **Surgical Robotics** – Advancements in partnership with medtech companies.
- **Smart Shoes** – For health tracking and fall detection.
- **Contact Lenses** – That allow people with diabetes to continually check their glucose levels using a non-intrusive method.

Exhibit 69: Power-assist suit
Photo of ATOUN exoskeleton used by worker

Source: ATOUN

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Bionic Humans – faster, stronger, smarter

> "Humans are already honed for technological augmentation, thanks to our interaction with mobile devices: with human augmentation, we'll need a few pioneers and some success stories" Prof. Julian Savelscu Oxford Uehiro Centre for practical Ethics at Oxford University

Bionic human/human augmentation is a technology that seeks to extend and expand human capability; this could be invasive (implant) or external (exoskeleton). Despite our various skills and capabilities, humans are still limited in many ways in terms of both our biology & physical abilities. That's where human augmentation can fill the gaps. These technologies are beneficial to amputees and disabled people, often assuming the form of bionic arms or legs, or robotic exoskeletons which enable the paralyzed to walk. These can come in the form of physical attachments or remotely operated exoskeleton robots that can maneuver like a human being. However, the operator of the exoskeleton doesn't have to be present to move it. The operator can control it remotely or even use a virtual reality (VR) headset to control the robot. This kind of bionic human augmentation can also be used in industrials, warehouses and logistics. Wearable technology is also a form of human augmentation which is non-invasive and usually requires some sort of interface to control.

Exhibit 70: eSight,
A technology that allows the blind to see

Source: eSight eyewear

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Bionic Humans: this is just the beginning; we could all be going bionic

Across the globe, engineers, entrepreneurs and policymakers are rapidly exploring new and marketable applications for human augmentation technology.

eSight; A wearable device similar to glasses that enables legally blind individuals to see their environment. The device has cameras on the front that take in the environment in near-eye quality and display it on a screen that sits right in front of the wearer's eyes.

Sarcos Guardian: This technology is an example of an industrial exoskeleton that allows a human worker to lift up to 200 pounds, perform precise operations with heavy machinery and handle repetitive motions without strain.

Zapata Flyboard Air: This technology is a turbine-powered hover board. The driver stands on top of it like skate board or surfboard and can fly up to 500 feet in the air.

Exhibit 71: Sarcos Guardian
Industrial exoskeleton that allows human worker to lift up to 200 pounds

Source: Sarcos Guardian

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Exhibit 72: Zapata Flyboard Air
Turbine-powered hover board enabling driver to fly up to 500 feet in the air

Source: Zapata

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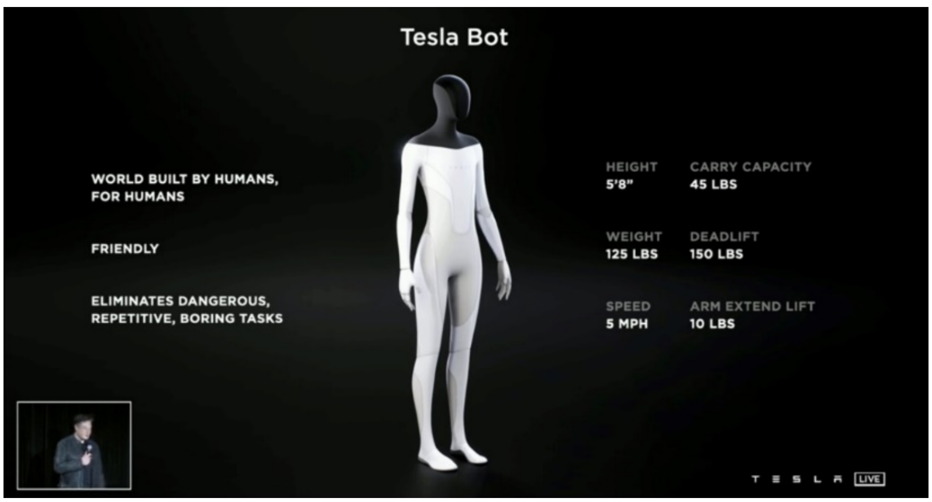
Sectors Impacted: ecommerce to medtech to cybersecurity ethics

COVID could be the catalyst for the adoption of bionic humans where workers increasingly rely on human augmentation to increase productivity indirectly via automation. For example, the accelerated shift from bricks & mortar to ecommerce in retail means bionic humans might become more important in increasing productivity by using technology to automate activities as well as lift heavier loads in logistics and industrials for example.

Use in Healthcare settings could also gain traction with more R&D to complement existing devices. In particular, the use of exoskeletons in medtech is growing. Exoskeletons are being deployed gradually, and the market is anticipating further rapid development of the technology.

The main pushback against bionic humans is the total reliance on connected technology, which makes it susceptible to hacking by cyber criminals. Kaspersky (a Russian multinational cybersecurity and anti-virus provider flags that the "main concern with human augmentation is the bio-hacking community itself. We will see vendors producing kits to augment health elements, whether its eyesight, strength or something else, and we'll see a lot of copycats trying to copy that kind of technology, which is not licensed or tested. We might find a black market for body enhancement kits because it's unregulated").

Exhibit 73: Tesla Bot
The humanoid robots stands at 5 feet 8 weighing 125lbs and travels at speed of 5mph



Source: Tesla

BofA GLOBAL RESEARCH

Haptics: bodysuits and smart gloves

Haptic technology, also known as 3D touch, refers to technologies that can create an experience of touch by applying forces, vibrations, or motions to the user. These technologies can be used to create virtual objects in a computer simulation, control virtual objects, and enhance the remote control of machines and devices. Haptic technology facilitates investigation of how the human sense of touch works by allowing the creation of controlled haptic virtual objects. Most researchers distinguish three sensory systems related to the sense of touch in humans: cutaneous, kinaesthetic and haptic. The sense of touch may be classified as passive and active, and the term "haptic" is often associated with active touch to communicate or recognise objects.

Smart gloves

Smart gloves are an input device for human-computer interaction worn like a glove using various sensor technologies to capture physical data, such as the bending of fingers. These can also provide haptic feedback, which is a simulation of the sense of touch. Wired gloves are often used in virtual reality environments and to mimic human hand movement by robots.

Headgear

Several players have demonstrated new VR headsets (Realmax, HTC, Pico) for several gaming/reality experiences (such as Sony's Playstation VR), and glasses, e.g. North/Thalmic Labs, NReal).

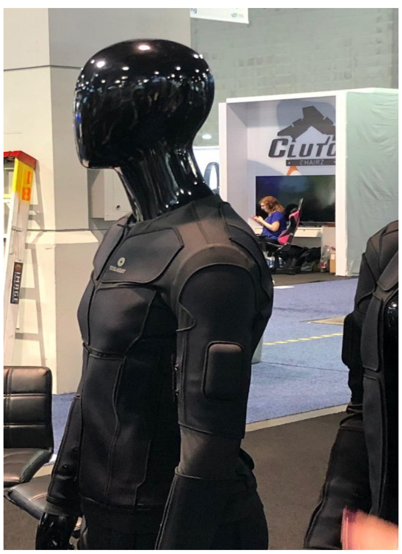
Haptic bodysuits

The world's first body haptic VR body suit was exhibited at CES 2019 earlier in the year by Teslasuit. The suit provides haptic, vibration, cooling and heating functionality. Teslasuit gives developers a software development kit (SDK) to enable them to use the suits for their own needs/experiences:

- **Use cases**: The key use cases for the Teslasuit were seen as gaming, rehabilitation medicine, and training (for enterprise, military and emergency services). Skillsets can be improved 30-40% by using VR, and demonstrated use cases applied to fire fighters, building escape, terrorist responses, and military drills. The suit can be adapted/programmed to be used in any scenario developers want.

- **Reality hurts**: The suit has 60 haptic electro-stimulation channels (for haptic feedback to simulate a sensation or movement) and 10 inertial sensors (for motion). The suit was tested in a few scenarios; in particular, the vibrations used to gradually build up sensations to patients' arms/legs (electric muscle stimulation and transcutaneous electrical nerve simulation) was the most realistic (and painful!).

Exhibit 74: Teslasuit haptic bodysuit
Feel augmentation with a body wearable



Source: Teslasuit, CES 2019
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Exhibit 75: Smart Gloves
Interactive with hand movements

Source: HTC
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Delta Airline case study

At CES 2019,. BofA joined a booth tour and investor meeting with the CEO of Delta airlines to discuss Delta's vision for flying in 2025. This included a combination of technologies focused on customer convenience, and efficiency for operators to improve safety, sustainability, and operational intelligence to reduce costs. Key highlights of the meeting included the demonstration of an exoskeleton machine that helps employees to lift heavy bags and equipment, such as plane tyres, to improve safety and functionality; also the use of machine learning on previous schedules linked with data (e.g. taxi times, conditions of the day such as weather, passenger volumes) to improve operational intelligence and performance metrics.

Exhibit 76: Exoskeleton for lifting heavy equipment/baggage
Bionic human tech to improve customer experience & operations

Source: Delta Airlines, CES 2020, BofA Global Research

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Exhibit 77: Exoskeleton for lifting heavy equipment/baggage
Bionic human tech to improve customer experience & operations

Source: Delta Airlines, CES 2020, BofA Global Research

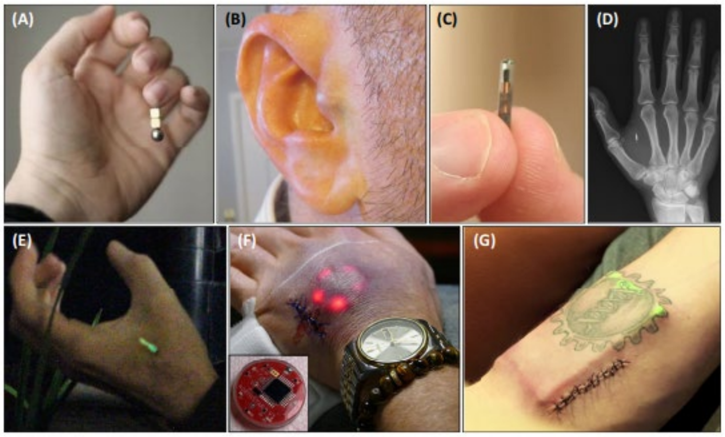
BofA GLOBAL RESEARCH

Biohacking: taking charge with "DIY biology"

> "I've grown to relish and rely on the technology. The electric lock on the front door of my house has a chip scanner, it's nice to go surfing and jogging without having to carry keys around. For some people without functioning arms, chips in their feet are the simplest way to open doors or operate some household items modified with chip readers" **Zoltan Istvan** – Grinder, former US presidential candidate and head of Transhumanist party

Biohacking is the attempt to manipulate brain and body (merging body modification with technology) to optimize performance, outside the realm of traditional medicine. Biohacking aims to improve overall wellbeing by optimizing nutrition, sleep, mind, heart, gut, fitness and any other lifestyle factors that influence our health. Biohacking has a popular subset called 'grinders'. These are biohackers who implant devices like computer chips in their bodies. The implants allow them to do everything from opening doors without a fob to monitoring their glucose levels subcutaneously.

Exhibit 78: Implants used by biohackers
(A) Neodymium magnet in a finger. (B) Magnets in the tragus of an ear. (C) RFID tag. (D) RFID tags implanted in the webbing between the metacarpal bones of the index finger and thumb, positioned parallel to the index metacarpal. (E) Tritium lighting implants. (F) LEDs in hand. (G) Continual temperature sensor in forearm.



Source: CellPress Reviews

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The rise of open medicine

> "All modern medicine is hacking, but people often call folks "hackers" as a way delegitimizing them" Rob Carlson, an expert on Synthetic Biology

Experimenting with implants and the development of new applications outside of traditional medicine have an immense implication for broader society. Biohacking raises questions about the limits of medical data privacy, and it opens up the possibility of cryptography (having control over your own data) use for medical data storage. Also, advocating for patients to be able to access their own implant-generated data, which are considered propriety by device manufacturers, is a key driver of open medicine.

Exhibit 79: Implants used by biohackers, and their properties
From Neodyium magnets coated with titanium nitride to LEDs chip containing a processor, LED, and embedded batteries

Implant	Features	Geometry/size	Implantation method	Implantation site
Neodyium magnets	Coated with titanium nitride	Dec (3 x 1 mm)	Surgical incision	Fingers
MF 1 IC S50 (NXP)	13.56 MHz (ISO 14443A) Emulates MF 1 IC S50 1k chip 7 byte UID and writable sectors	Cylindrical glass capsule (3 x 13 mm)	Hypodermic needle (9 g)	Hand webbing
NTAG216 chip (NXP)	13.56 MHz (ISO 14443A) and NFC Type 2 7 byte UID and 880 bytes of user read/write memory	Cylindrical glass capsule (2 x 12 mm)	Hypodermic needle (11 g)	Hand webbing
ATA5577 RRD chipset (Atmel)	125-134kHz (ISO11784/785) EM41xx/EM4200/HID/Indala compatible	Cylindrical glass capsule (2 x 12 mm)	Hypodermic needle (11 g)	Hand webbing
I-CODE SLI RFID Chipset (NXP)	13.56 MHz (ISO 15693) 8 byte UID and 112 bytes of user read/write memory	Cylindrical glass capsule (2 x 12 mm)	Hypodermic needle (11 g)	Hand webbing
Bio-Thermo Lifechip RFID tag (Destron Fearing)	134.2kHz (ISO11784/785) Temperature sensor (25-43°C)	Cylindrical glass capsule (2 x 12 mm)	Hypodermic needle (11 g)	Skin near the arm pit
DESFire EV1 RRD chip (NXP)	13.56 MHz (ISO 14443A and NFC Type 4)	Polymer coating (10 x 22 x 0.5 mm)	11mm wide incision	Arm
NTAG216 RFID chip (NXP)	13.56 MHz (ISO 14443A and NFC Type 2)	Polymer coating (8 x 22 x 0.4 mm)	11mm wide incision	Arm
Tritium lighting implants (Cyberise.me)	Radioluminescent tritium gas	Cylindrical borosilicate glass and lead oxide capsule (3 x 5 x 21 mm)	Hypodermic needle (8-9 g)	Hand webbing
LEDs (Northstar, Grindhouse Wetware)	Chip containing a processor, LED, and embedded batteries	Polymer coating	Surgical incision	Hand/forearm

Source: Harvard CellPress Review

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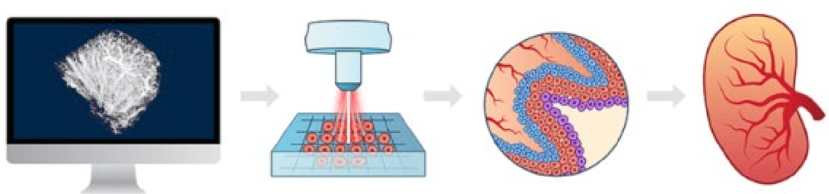
Bioprinting & organ regeneration: therapeutic clone replacement

Some life extensionists suggest that therapeutic cloning could one day provide a way to generate cells, body parts, or even entire bodies (generally referred to as reproductive cloning) that would be genetically identical to a prospective patient. As a vital part of regenerative medicine, 3D bioprinting of tissues and organs present a novel way to restore lost structures or functions. These would replace damaged counterparts, potentially prolonging an individual's lifespan. This type of technology could be able to create more robust tissues and organs that naturally deteriorate as people age. Another benefit here is that those waiting for organ transplants could have access to specific organs that won't get rejected, which could possibly prolong their lives (source: CB Insights). Among recent innovations in this space include Biobots, which is a 3D bio-printer that prints human cells using "bio-ink". Furthermore, other nextgen health devices include the XPrize Scanadu Scout 'tricorder' that measures heart rate, blood oxygen level, temperature, blood pressure, ECG, respiratory rate and emotional stress.

Exhibit 80: Illustration of how organ regeneration could work
3D bioprinting could create more robust tissues and organs that will naturally deteriorate as people age



Source: CB Insights

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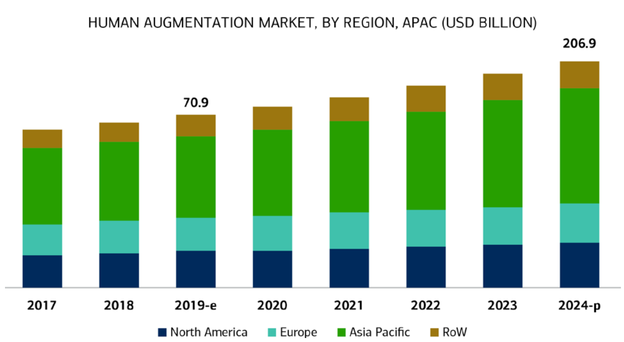
Market size: US$206.9bn by 2024E, 23.9% CAGR

The bionic human market includes nextgen wearables, bionics and neuroprosthetics among other items. Human augmentation has a multitude of benefits, regardless of which type people employ. Whether invasive, non-invasive, bionics or neurotechnology, each wearable tool has a specific function to enhance human abilities. Advances in materials, information systems, and human science are setting the stage to significantly enhance human capabilities, pushing the physiological, cognitive and social human performance frontiers. According to a 2020 survey by Kaspersky, 92% of people would change a physical aspect of themselves if they could, and 63% would consider augmenting their bodies with technology to improve them either permanently or temporarily. According to Markets and Markets, the human augmentation industry could grow to US$206.9bn by 2024E from US$70.9bn in 2019 at a 23.9% CAGR.

Exhibit 81: Human Augmentation market, by region, APAC (USD bn)
Industry could grow to $206.9bn by 2024E from 70.9 bn in 2019 at a 23.9% CAGR



Source: Markets and Markets Research

BofA GLOBAL RESEARCH

3) CONSUMER TECH
eVTOL: getting mobility off the ground

- **What's an eVTOL?** Light aircraft powered by electric propulsion that can take off and land vertically. **The answer to:** increasing urbanisation and congestion by democratising lower-cost/higher-frequency urban air travel for passenger and cargo transit.
- **Did you know?** Three passenger eVTOL aircraft are expected to be certified for commercial launch by 2023.
- **In 2021:** $4bn was invested in eVTOL companies in Q12021, more than in 2013-20 altogether.
- **By 2035:** the market is estimated to be worth up to $240bn.
- **Sectors affected:** Aerospace, Automotive, Transport & Logistics.

eVTOL: democratising urban air travel

Is it a car? Is it a drone? Is it a plane? No, it's eVTOL!

Electric Vertical Take-off and Landing (eVTOL) is a new classification of light commercial aircraft for passengers and/or cargo. As the title suggests, they can take off and land vertically like helicopters. Some are un-winged for short distances, like drones, some are winged and fly forward like planes. The majority of concepts use non-combustible propulsion such as batteries. The lighter weight, distributed propulsion and lower complexity are intended to make them more manoeuvrable, efficient, and lower cost vs traditional helicopters. They're designed to fly at lower altitudes than commercial aircraft, and to be piloted initially and eventually flown fully autonomously as regulation permits. The key enablers thus far are converging technologies from the aerospace, autos and tech sectors, but challenges remain to commercialisation: technical, regulatory, and public-acceptance related. Their key use cases are likely to be drone cargo (with increasing payloads), and passenger transit for short inner city and regional trips, hence the industry often is referred to as **Urban Air Mobility** (UAM).

Why do we need it? Part of the Future Mobility toolkit to improve cities

Most UAM concepts are looking to improve urban mobility by reducing (road) congestion by leveraging new capacity in the sky; cut pollution (given the aircraft would be zero emission); and improve transit times. Point-to-point air travel for a few miles could beat surface transit times considerably, cutting vehicle journey times from airports to city centres to <15 minutes – the key customer motivation to use such services.

Back to the Future: restoring Urban Air Mobility to a golden age?

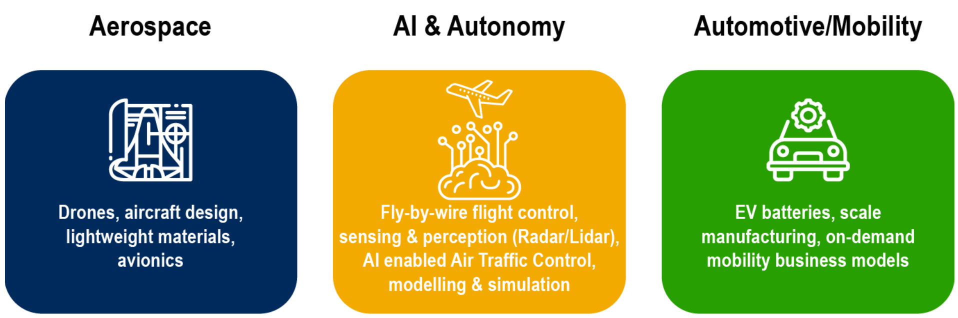
The idea of light vehicles flying across cities has long been an aspiration of customers, operators and even transit providers. London transport regulator, TFL's +100 year "vision for 2026" poster in 1926 portrayed a city of flying vehicles, for example. And there have been several commercial helicopter-based UAM operations in cities in previous decades. Many no longer exist; most famously, New York Airways' scheduled helicopter flights to Manhattan from surrounding airports from the 1950s closed in 1979 following an accident and years of controversy over noise, safety risks, increasing costs and lack of profitability. The helicopter services that operate in cities today still face similar challenges: particularly the high hourly cost of operation and noise, limiting them to playing a niche role in the urban mobility landscape thus far. eVTOL services are seen as a way to overcome some of these challenges, and could enable a return to sky-based travel above cities.

Why now? Converging technologies: Aerospace, Autos, AI

To enable this, several technologies are converging that companies are looking to exploit, particularly from the aerospace, automotive and technology industries.

Exhibit 82: EVTOL enabling technologies: combining Aerospace, AI, and Automotive

Advancing capabilities in lightweight materials, compact flight control, AI-enabled systems, improving (and increasingly cheaper) Electric Propulsion, and on-demand mobility networks are key technologies enabling eVTOL UAM from the aerospace, tech and Auto/Mobility industries



Source: BofA Global Research

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- **Aerospace**: Improving drone technology capable of increasing payloads, aircraft design (to accommodate multiple rotors and distributed propulsion), and materials (advanced lightweight composites) are all enablers of eVTOL aircraft from the aerospace industry. Improving software and digital capabilities that air-based vehicles can deploy already – such as avionics, navigation and flight control systems – are being advanced and redesigned for eVTOL.

- **Autonomy**: Combining fly-by-wire compute, navigation, and collision avoidance sensors such as radar could allow eVTOL vehicles eventually to fly autonomously. Advancing AI technologies, modelling and simulation can enable new Air Traffic Control systems specifically for Autonomous UAM that monitor and communicate with vehicles without human intervention. On the user experience side, platforms just as ridehail and on-demand mobility services are commonplace and can be leveraged to scale passenger demand.

- **Automotive**: Continually improving energy density and falling battery costs as Electric Vehicles scale are key enablers of the first eVTOL concepts to use lithium ion batteries for zero-emission travel cost efficiently. While current cell energy density/weight may limit the range of initial vehicles, improving and next-gen cell chemistries could allow longer UAM trips. eVTOL companies are already partnering with battery cell developers to design bespoke chemistries for UAM vehicles (e.g. Lilium with Customcells).

- **Manufacturing**: eVTOL companies envision higher scale (and lower cost) of manufacturing vs today's aircraft. The simpler design and fewer moving parts vs combustion-fuelled aircraft will be the key drivers of increased manufacturing. For context, Volocopter aims to be producing >1,000 aircraft by 2025, and external consultants project an addressable market as big as 250,000 vehicles by 2035 (Frost & Sullivan). This compares to ~32,000 helicopters in operation globally with annual production averaging ~1,000 per year (Statista). To enable this, many eVTOL companies have sought investments and partnerships with auto companies. For example, Joby with Toyota, Archer with Stellantis, Volocopter with Daimler and Geely, and Hyundai in its own UAM division, to leverage strategic synergies including manufacturing. However, all manufacturing will need to be certified to aerospace standards.

Exhibit 83: Tech powering eVTOLs: lightweight airframe, electric propulsion, fly-by-wire autonomy
UAM aircraft developers are competing for owned IP & partnerships to deliver a competitive market launch

Source: BofA Global Research

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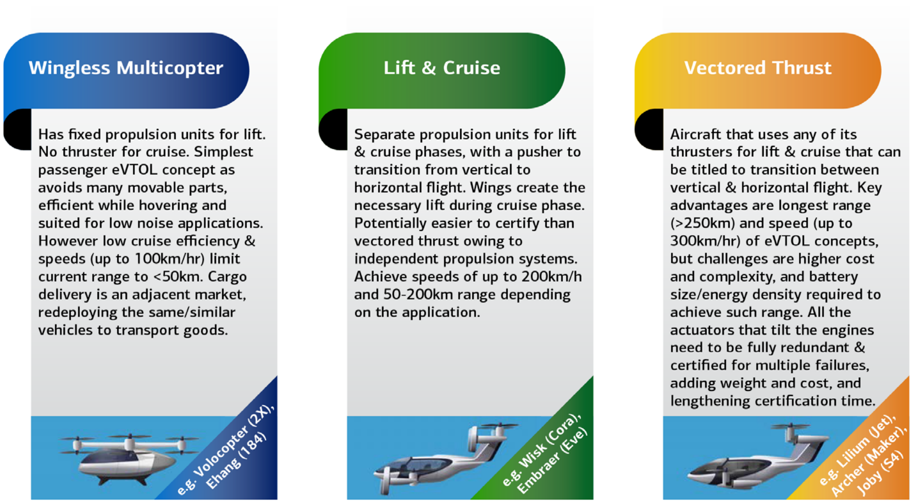
>350 UAM concepts categorised by propulsion type

The number of UAM vehicle design concepts proliferated from six known designs in 2016 to >350 in 2020, according to Vertical Flight Society, spanning 215 companies, and 129 active eVTOL vehicle developments (43 with built demonstrators). These are positioned broadly across six categories. For personal travel there are **hover bikes**: single person eVTOL aircraft piloted in a saddle or standing (all wingless configurations), and **roadable aircraft** ("flying cars") – mostly winged vehicles requiring a traditional airstrip or similar to take off. Thus, the latter are not categorised as eVTOLs but rather eSTOLs (electric short take-off and landing).

For passenger transit-based UAM, in addition to **electric rotor based** (e.g. electrifying conventional helicopters), three new categories make up the majority of the active eVTOL developments: wingless **multicopter, lift & cruise, and vectored thrust** (open propeller or ducted fan-based) aircraft. These three categories dominate current company efforts, accounting for 92 of the 129 eVTOL developments in 2020, as per Vertical Flight Society.

Exhibit 84: Three distinct categories emerging for eVTOL: multicopter, lift & cruise, vectored thrust (tilting rotors or ducted-fan based)
eVTOL aircraft are categorised by the type of design and propulsion they intend to deploy. 1) Multicopters are wingless and more akin to larger commercial drones, 2) separate propulsion units for Lift & Cruise, and 3) tilting rotors or ducted fan based vectored thrust aircraft that use the same propulsion to take off and cruise. The key difference between the three relates to the propulsion they use, impacting the range/speeds they can achieve, and certification/technical requirements to operate



Source: BofA Global Research, EASA

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Different models for different use cases

The key difference differences between these three passenger aircraft designs are the intended propulsion configuration, the range/speed they can reach, and the number of paying passenger seats they can accommodate. Multicopters are the lightest and potentially easiest to certify, but their low carrying potential (1-2 passengers) and limited range are likely to confine them to urban low- occupancy trips. Lift & Cruise aircraft are a hybrid concept (of multicopters and winged aircraft) that can achieve longer ranges but still have limited passenger occupancy similar to multicopters. The third longer-range category includes convertible aircraft concepts of tilt-wing (open rotor) thrust, and ducted vectored thrust configurations. These have the longest range and highest passenger capacity – so are likely to enable more use cases – but are the most complex and likely to take longer to certify.

Two distinct approaches are being taken by operators within this category: 1) open propeller – giving the pro of better lift efficiency but con of still being relatively noisy (e.g. Joby S4); and 2) ducted electric vectored thrust – using multiple small-ducted fans that are quieter and more compact than open rotor alternatives (enabling higher payload/passengers over time). The latter are more efficient in cruise than open rotors, but much more energy-intensive on take-off/landing (e.g. Lilium Jet).

Exhibit 85: Several eVTOL categories are forming based on aircraft design and propulsion

The key eVTOL aircraft are wingless multicopters, Lift & Cruise, and vectored thrust – each have different derivatives within them based on the propulsion technique (e.g. open rotor or ducted fan for vectored thrust) and can achieve different ranges/speeds, likely resulting in addressing different use cases and locations

Description	Wingless Multicopter	Lift + Cruise	Vectored Thrust
	Multiple rotors, Thrusters only for lift, cruise via rotor pitch	Independent thrusters for lift & cruise	Same thrusters used for lift & cruise that tilt between vertical & horizontal flight
Range (km)	35-65	50-150	200-300
Speed (km/h)	50-110	50-200	195-320
Benefits	High redundancy, simple controls, low noise, low maintenance, lightweight, low operating cost	Enhanced range and cruise efficiency vs multicopter	Longest range/speed, stabilisation by controlling thrust direction
Challenges	Limited range/low cruise efficiency, low passenger occupancy	Increased complexity, noise & certification requirements vs multicopter	High energy requirements at takeoff and landing, highest complexity for certification (all actuators need to be fully redundant & certified for multiple failures)
Companies (prototype name)	Volocopter (Volocity), Ehang (184)	Wisk (Cora), Embraer (Eve)	Joby (S4), Lilium (Jet), Archer (Maker)

Source: BofA Global Research, EASA, Altran, Volocopter

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Funding start-ups in the sky

Progression in eVTOL tech and certification pathways has attracted a big rise in the funding of eVTOL startups in particular. Initially via VC funds, but more recently via reverse merger special purpose acquisition companies (SPACs) and their related private investment in public equity (PIPE) funding. Data from Pitchbook showed that in Q1 2021 alone $3.8bn was invested into eVTOL air taxi startups. This is vs $1.1bn investment in the whole of 2020, and $448mn from 2013-19 cumulatively. The funding of these companies has been highly concentrated in a few (until recently) private companies; per

Pitchbook $3.5bn of the the $3.8bn announced in Q1 2021 was related to the SPAC/PIPE funding of Joby, Lilium and Archer Aviation.

Exhibit 86: Top 5 Funded eVTOL startups have raised 33x the next 5
Funding of eVTOL startups has been highly concentrated in the top 3 providers (largely owing to their recent SPAC transactions)

Company Name	Capital Raised ($mn)	Country	Business
Joby Aviation	2,328	US	eVTOL Aircraft Developer
Lilium	1,222	Germany	eVTOL Aircraft Developer
Archer Aviation	1,156	US	eVTOL Aircraft Developer
Volocopter	377	Germany	eVTOL Aircraft Developer
Ehang	132	China	eVTOL Aircraft Developer
Kitty Hawk	75	US	eVTOL Aircraft Developer
Aurora Flight Sciences (Boeing)	52	US	Advanced Flight Control Systems
Xwing	18	US	Autonomous flight software
Skyports	10	UK	Vertiports
Dufour Aerospace	5	Switzerland	eVTOL Aircraft Developer

Source: Pitchbook

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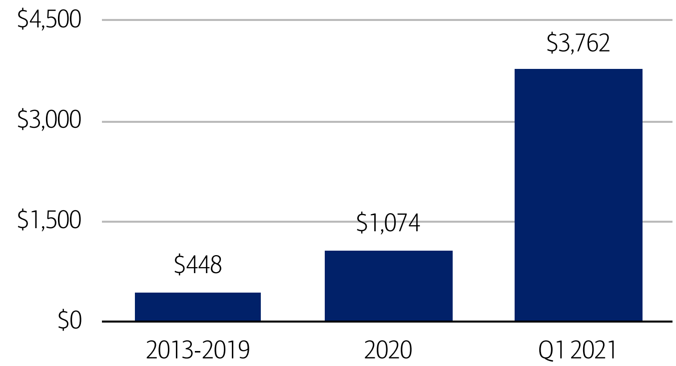
Exhibit 87: Q1 2021 eVTOL funding was 2.5x the total in 2013-20
Recent SPAC transactions have accelerated funding in eVTOL passenger air taxi companies, reaching $3.8bn, 2.5x investment from 2013-20



Source: Pitchbook Investment in eVTOL passenger air taxis ($m) up to 31st March 2021

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Incumbents are not standing still

While this gives the companies a significant cash injection towards commercialisation, several challenges remain, not least competition from established aerospace, automotive and industrial incumbents targeting the UAM market for future growth. Boeing (Aurora Flight Sciences), Airbus (CityAirbus), Bell Textron (Nexus), Embraer (Eve) and Lockheed Martin (Sikorsky, Firefly) are all investing in or acquiring companies to boost their internal eVTOL offering with a combination of aircraft, propulsion, software, and services. Whilst the levels of funding are not disclosed, leveraging the scale and expertise of parent company in e.g. R&D, manufacturing, and how to conform with the necessary regulatory standards are all potential advantages compared to start-ups.

What to watch: certification and progress towards production readiness

As shown in Exhibit 88, per EASA based on current announcements, the majority of initial eVTOL certifications are expected in 2024+, with Volocopter (2022), Joby and Airbus (2023) expected sooner, enabling commercial rollout. Progress towards certification will be the key short-term aim for all companies, in our view, followed by the ability to scale manufacturing and production readiness of the various vehicles.

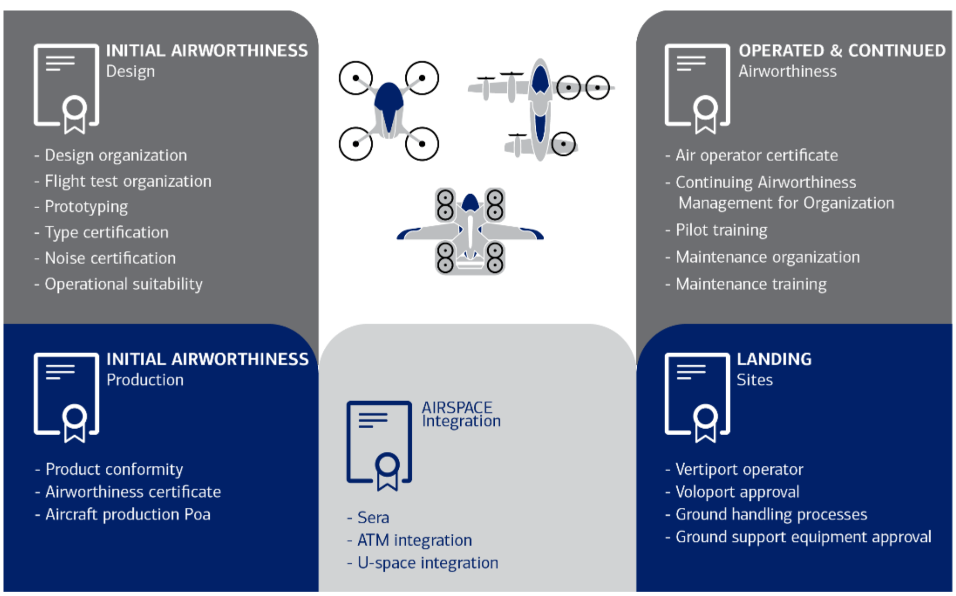
Regulating eVTOLs: airline safety for urban environments

Certification of eVTOLs is a lengthy and thus costly process as this is a new category of aircraft and it will be operating in higher-population areas, increasing collision risk. Europe's EASA guidance states that not only are eVTOL safety levels expected to match those of commercial airlines – **a one in a billion chance of catastrophic failure** – but the aircraft need to be able to undertake a controlled emergency landing in such an event. While regions vary slightly on their requirements, the certification to launch eVTOL passenger services commercially will require: 1) a type certificate (TC) indicating an aircraft design is safe and airworthy; and 2) a production certification authorising the manufacture of duplicate aircraft under an approved design.

Case study: regulation: Special Condition for Small Category VTOL
Europe's regulator EASA published a "Special Condition for Small Category VTOL (SC-VTOL) Aircraft" in 2019 and subsequent "Proposed Means of Compliance with the SC-VTOL" in 2020 clarifying conditions on the certification pathway being formed in Europe for such aircraft, and the safety and design objectives that all categories of VTOL should adhere to. Both cover: 1) **aircraft worthiness** (with varying conditions whether piloted or autonomous); 2) **operational requirements** for operators and infrastructure providers; 3) **airspace integration** regulation covering air traffic management & navigation services in low-level airspace <120m (the "U-Space") within and without line of sight; 4) continuous audits & monitoring to ensure **continued airworthiness**; and 5) **landing sites** & infrastructure approval.

The US regulator, the FAA, has similar end objectives but intends to vary certification standards using 14 Code of Federal Regulations dependent on the aircraft's concept of operations, e.g. placing higher requirements on passenger transporting city operations vs single passenger regional light aircraft concepts. Thus, operators targeting multiple regions with the same aircraft may face additional administrative and certification requirements unless standards are harmonised.

Exhibit 88: eVTOLs will require aerospace levels of: design/type/production certification to launch
In addition to airworthiness and production approval, airspace integration, landing, and continuing airworthiness certification will be needed to operate eVTOLs commercially for passengers



Source: BofA Global Research, Volocopter

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$240bn addressable market by 2035 depending on use cases, pace of adoption

The addressable market for UAM eVTOL operations could be vast. How quickly that is realised will depend on the mitigation of the regulatory, technical and public-perception challenges cited above.

Up to a $240bn TAM

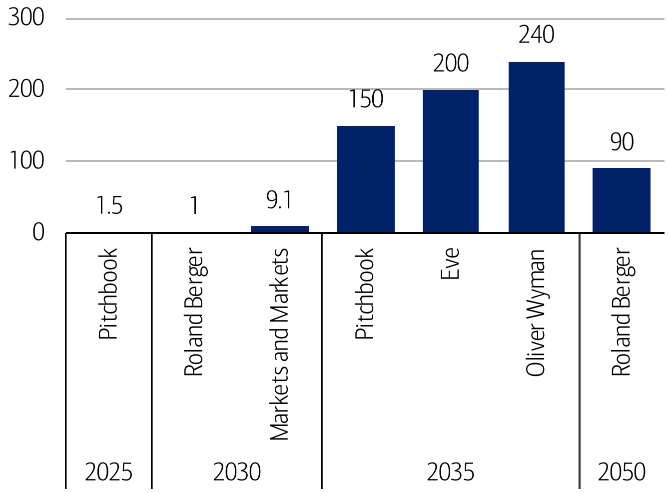
Several external industry forecasts for eVTOL vary in their assumptions of revenues and number of aircraft required in the long term. Most don't foresee a significant uptake until 2035, depending on the use cases addressed, penetration/rate of adoption, and utilisation/operating hours of the vehicles.

- **Revenue**: 2025-30 revenue projections from UAM Services range from $0.5-9bn, but rise rapidly post 2035, ranging $90-150bn for passenger services (equivalent to 19% of current global airline revenue, as per Pitchbook), increasing to $240bn when including logistics drone delivery.

- **Aircraft**. The assumed number of eVTOL required depends on assumptions around number of cities served and use cases/utilisation levels. In the studies reviewed, the long-term aircraft volumes were 45-400k.

Exhibit 89: Long term eVTOL TAM projections from various providers range from $90-240bn

External forecasts for eVTOL market vary depending on assumptions on: 1) use cases addressed, 2) penetration/rate of adoption, and 3) utilisation and operating hours



Source: BofA Global Research $bn UAM industry revenues review of cited sources: Pitchbook, Roland Berger, Markets & Markets, Oliver Wyman/Volocopter, EVE

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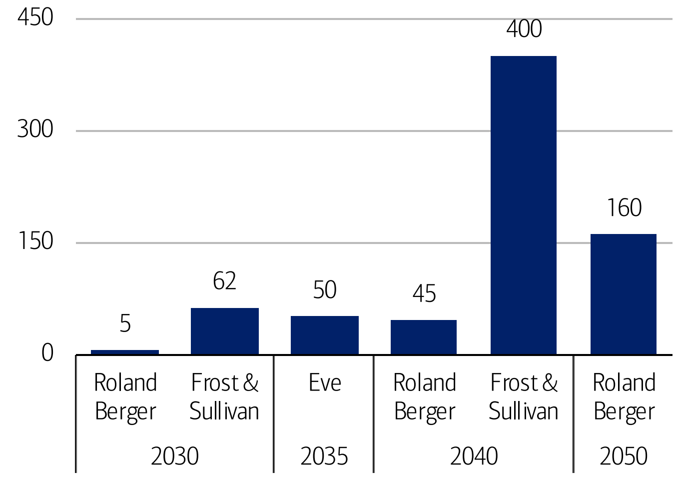
Exhibit 90: Assumed eVTOL aircraft required in the long term ranges from 45-400k

As eVTOLs begin to be certified for commercial operations in the next few years, their volume is expected to proliferate: external forecasts for 2030-50 ranged from 45-400k depending on aircraft per city and use cases assumed



Source: BofA Global Research, eVTOL passenger aircraft forecasts, review of cited sources: Roland Berger, Frost & Sullivan, EVE

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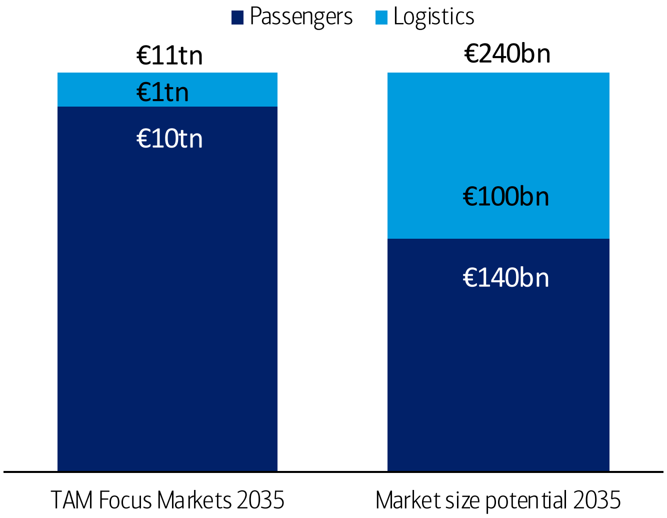
UAM use cases: taxi and airport shuttle obvious targets

To achieve the $240bn TAM forecast by Oliver Wyman for Volocopter, UAM aircraft would need to service the equivalent of 25% of urban parcel deliveries, 10% of taxi & car rental, 5% of city-to-city bus transit trips, and 1% of intercity train travel and private car use each by 2035. This therefore assumes 60% of the revenue potential for urban & metro use cases (see Exhibit 92). Similarly, in Roland Berger's 2050 scenario, of the 160,000 aircraft required, 29% are expected to serve intercity journeys (scheduled flights on defined routes of 50-250km) with the remaining 71% made up of city taxi and airport shuttle trips.

Exhibit 91: Urban air mobility addresses a multi-trillion opportunity
Olivery Wyman expects that UAM will reach market potential of €240bn by 2035



Source: Oliver Wyman

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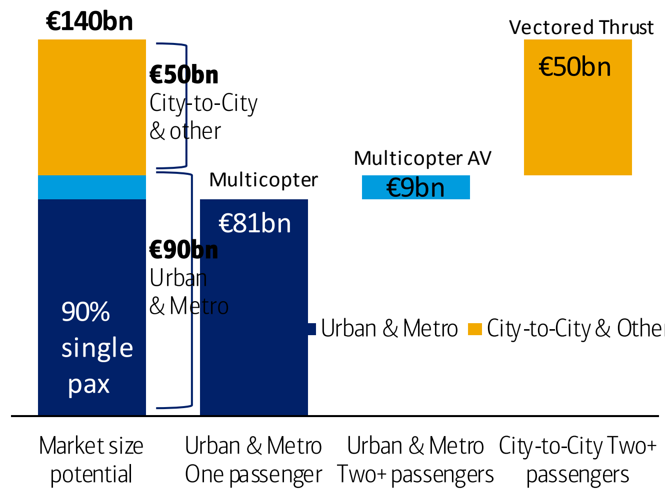
Exhibit 92: Urban air mobility is predominantly single passenger
Market will develop from urban single passenger (90% of demand) to larger capacity and distances



Source: Oliver Wyman / Volocopter

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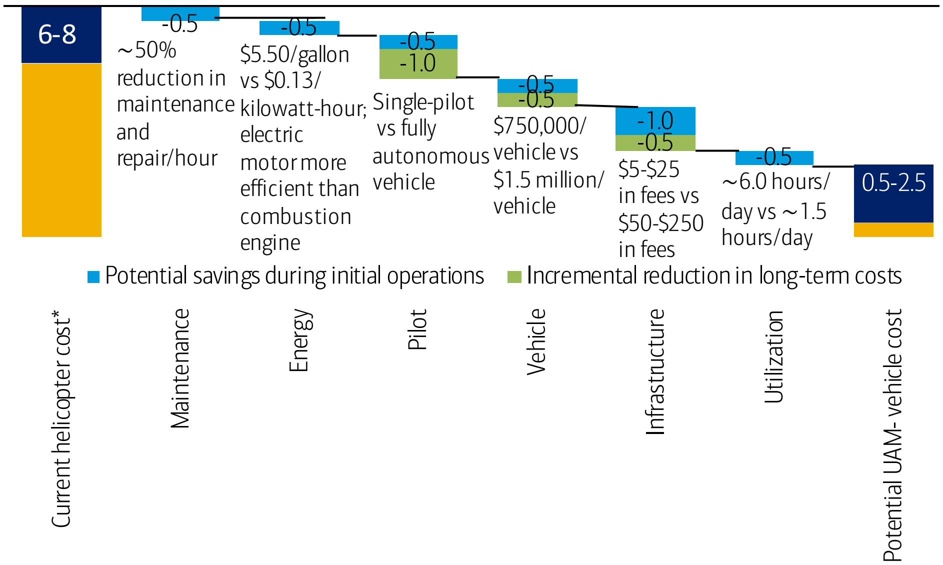
Key enablers of an accelerating UAM addressable market include:

Operational cost – for UAM to be successful at a larger scale than current helicopter services requires rapidly reducing operating costs. For comparison, helicopters currently cost ~$6-8 per seat mile (McKinsey). EVTOL operators are projecting initial costs per mile of ~$4 for mid-regional distances (source: Joby) or $5/20% cheaper than current helicopters for shorter urban missions (source: Volocopter). This is due to expected lower costs related to maintenance (fewer moving parts), energy (electric being cheaper than combustion engine), and vehicle infrastructure driven by increased vehicle utilisation.

To enable a higher addressable market, costs would need (and are expected) to fall. McKinsey projects UAM operating costs to decline towards $0.5-2.5 per seat mile – an 80% reduction vs the cost of helicopters today – if further improvements in infrastructure and manufacturing are achieved with higher scale, and pilot costs are removed as UAM vehicles become autonomous.

Exhibit 93: Operating costs could evolve for urban-air-mobility vehicles
Potential evolution in operating cost per seat-mile for urban-air-mobility (UAM) vehicles, $



Source: McKinsey
*Current costs vary depending on various factors, including number of passengers and helicopter type

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Accelerated production. To scale from 0 to ~50,000 UAM vehicles by 2035 would require far higher production rates than those generated by light aircraft currently: there are >32,000 helicopters in operation globally with ~1,000 per year in production (source: Statista).

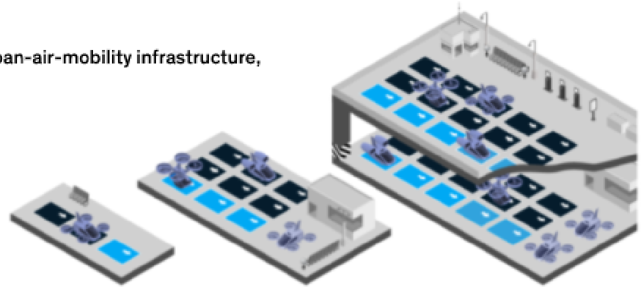
Physical infrastructure – vertiports the new airports? To operate UAM vehicles commercially would require places to take off, land, recharge, and undergo any maintenance. The benefit of eVTOLs is their lower expected weight and energy requirements (and ability to use electricity rather than require combustible fuel to be stored at each location). This means that each location could be cheaper than existing heliports/airports, although their scalability could be limited by the number of such locations and their need to be created or retrofitted in many instances. McKinsey estimates a vertiport for an individual vehicle would require $200-400k to build and $600-900k per year to operate, with larger bases (three active take-off locations and six further parking spaces for UAM vehicles) needing $500-800k and $3-5m, respectively. The larger hub-based locations (at e.g. airports) could cost $6-7m to build and $15-17m to operate. The number of locations required will vary by city, but naturally will define the capacity of UAM in that location assuming the aircraft are regulated to take-off and land only at these approved sites.

Exhibit 94: New Infrastructure for New Mobility: vertipads, bases, and hubs to enable UAM

Each city would require a different combination of single vehicle locations (Vertipads) with larger base and hub style locations accommodating multiple vehicles taking off and landing (and waiting) simultaneously

There are three potential archetypes for urban-air-mobility infrastructure.

Potential archetypes for urban-air-mobility infrastructure, illustrative



	Vertipad (new or retrofit)	Vertibase (new or retrofit)	Vertihub (new)
Dimensions	100 × 60 feet	230 × 100 feet	400 × 175 feet (2 floors)
Landing/takeoff pads	1	3	10
Parking/charging spots	2	6	20
Capital expenditures, $ million	0.2–0.4	0.5–0.8	6.0–7.0
Operating expenditures, $ million	0.6–0.9	3.0–5.0	15.0–17.0

Source: McKinsey & Co

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Cost of alternatives: Adding new surface transportation capacity in urban areas is costly, >$500m per mile for subways, for example (source: McKinsey), alongside lengthy approvals and civil requirements. While UAM is not a viable replacement for mass transit (owing to throughput capacity limitations), it could offer a cost-effective alternative for less-dense areas without existing transit options, or plug gaps in transit provision.

Case study: Can eVTOLs be green? Better still: use less energy than (electric) cars?

A key driver of eVTOL development is the zero emissions at the point of use, by virtue of zero emission electric propulsion technologies. This automatically makes their use more sustainable than combustion engine air alternatives such as helicopters. However, given advances in the aircraft design and efficiency (particularly in cruise mode), the equivalent energy use could be lower per seat mile than car-based alternatives, as low-drag aerodynamic forms are not practical on cars. Furthermore, using renewable energy to power the trip could enable a truly zero-emission travel alternative.

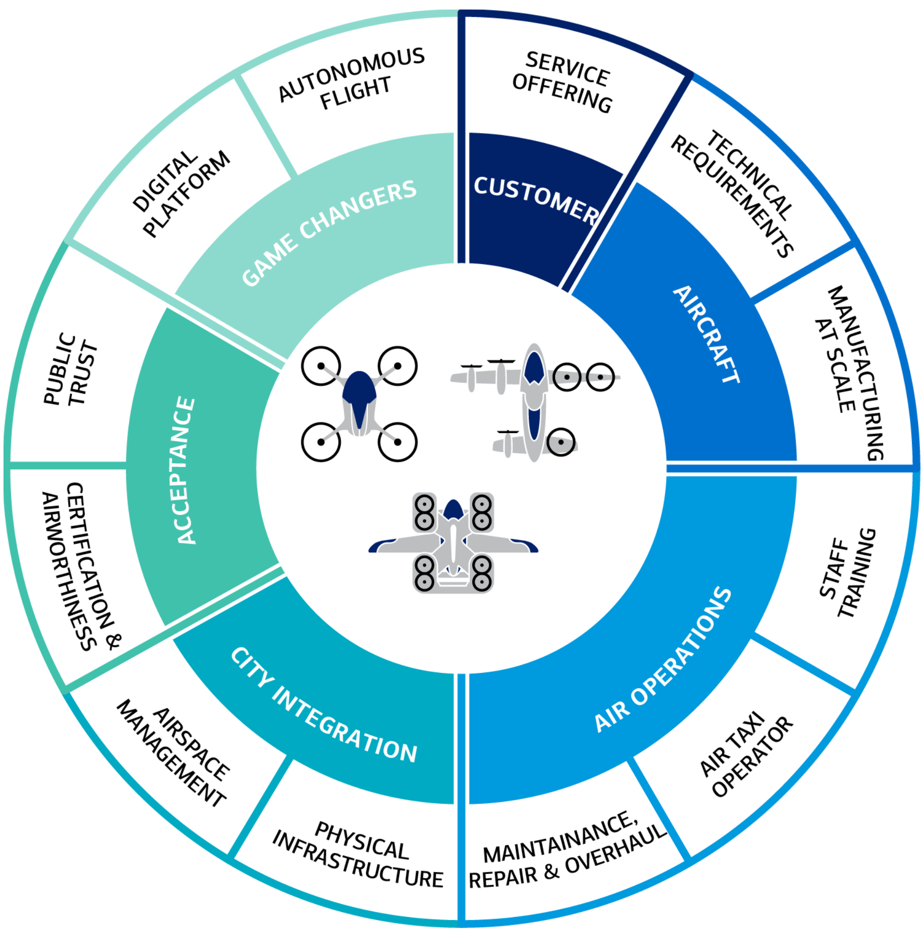
"A Nissan Leaf uses ~275 Wh/m when travelling at 50mph, with an average occupancy of 1.6 that's 171Wh per passenger mile (ppm). The Heaviside prototype uses 120Wh ppm at twice the speed of the Leaf, and can save another 15% energy as whilst roads aren't straight, flight paths usually are. Altogether Heaviside requires 61% as much energy to go a mile…to put it another way, if your commute is the US average (16 miles), if you travelled in a Heaviside type vehicle: 3 rooftop solar panels would power your commute, both ways" Damon Vander Lind, GM, Kitty Hawk, per Kitty Hawk blog post

Operating ecosytem: to vertically integrate or not?
Two diverging business models are possible: 1) a vertically integrated manufacturer /operator model; and 2) an ecosystem of manufactures, operators and service providers more akin to current airline/transit offers.

- **Vertical integration**: Given the nascent stage of the eVTOL industry, some companies are targeting a "full stack" provision of aircraft development and manufacturing, flight operations, air traffic management, and managing customer user experience in the flight and during the front-end booking and payment (see Exhibit 95). Partnerships are already being formed to try to exploit this. For example, is Volocopter creating "VoloIQ" with Lufthansa and Microsoft to develop a cloud-based software platform to link flight and ground operations, battery management, and customer interface.

- **Traditional manufacturer & operator** model: As and when more eVTOLs are certified, a more traditional operating dynamic may be more viable to enable replicable and scalable operation in multiple cities. For example, Airlines United, Virgin Atlantic and Azul have all already announced partnerships or committed orders for such aircraft from Archer, Vertical Aerospace and Lilium, respectively, indicating this may take precedent for the regional longer-distance flights.

Exhibit 95: Enabling UAM operating system: aircraft, infrastructure, and user experience
Enabling commercial UAM services will require a combination of aircraft, customer service, city/air traffic infrastructure integration, and customer and regulator acceptance. Autonomy could be a game changer



Source: Volocopter, BofA Global Research

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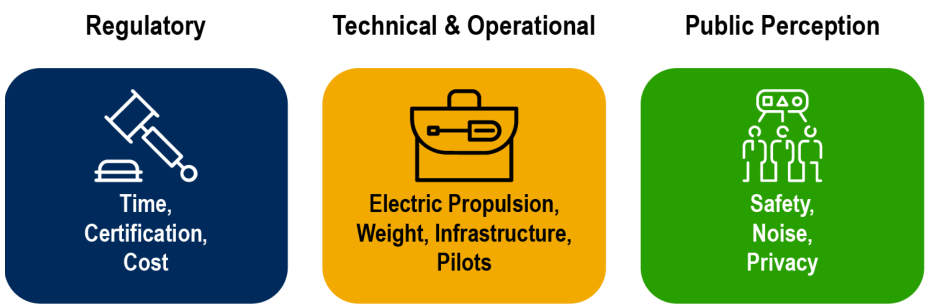
Key challenges: regulation, technical, public perception

To enable these vehicles to be commercially successful, several challenges must still be overcome: regulation, technical & operational, and public perception related.

> "To invent an airplane is nothing. To build one is something. But to fly, is everything…Sacrifices must be made" Otto Lilienthal, German Aviation Pioneer, 1896

Exhibit 96: Key challenges to eVTOL adoption: regulatory, technical & operational, public perception

Time & cost of achieving certification, proving technical capability (especially regarding electric flight propulsion), operational issues (lack of infrastructure and trained pilots) and public perception related to safety, noise and privacy are the key challenges ahead of eVTOL commercial launches



Source: BofA Global Research

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Regulatory: The ongoing R&D, testing, and iterations to reach required levels of certification for eVTOL are estimated to cost $700m-1bn (per Vertical Flight Society, Pitchbook). While this cost is expected to reduce as regulators and operators gain more knowledge/experience, it places a significant time lag and capital requirement on companies looking to operate in this market. Both Joby and Lilium cited this as a key reason for their SPAC transaction, to fund ongoing certification efforts.

Technical & operational: A number of technical challenges remain ahead of commercial launch related to:

1. Electric propulsion: requires not only increasing energy density to enable sufficient ranges, but also high power/voltage electrical systems to power both propulsion and each aircraft subsystem (avionics, in flight control actuators, etc). All require sophisticated energy management systems that are not the current state of the art

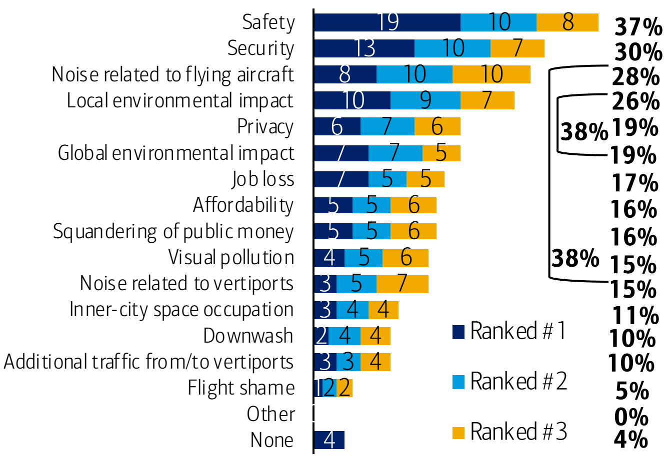
2. Payload/weight: regulators recommend max take-off weight at 3,175kg in line with helicopters; hard to achieve with increasing paying customers/luggage and heavy electric propulsion.

3. Lack of initial infrastructure (vertiports): some companies are already active in this space (e.g. Skyworks) but buildings or sites would need to be deployed in tandem with UAM rollout.

4. Pilots: would be needed until autonomous flight is approved by regulators but are in short supply (a global >60,000 helicopter pilot shortage is projected by Boeing in 2038) making UAM pilots hard to come by. Pilots also take up the space of a potential paying customer, limiting utilisation in the short term.

Public perception: Similar to any new transportation technology, public acceptance is needed to build confidence and user demand, but also for local residents/businesses to be accepting of any externalities the aircraft create. A 2021 EASA survey on the societal acceptance of UAM in Europe highlighted three key concerns from the public on drones and air taxis: safety of operation, noise, and visual/privacy intrusion (see Exhibit 97). eVTOL aircraft are much quieter than helicopters – by >20db (source: Pitchbook /Volocopter), operating at 65db vs 87db at 500 feet – but the potential increase in UAM vehicles may cause local concerns. Operators and regulators are testing a number of scenarios to alleviate these. Industry publications view the challenges slightly differently however; EASA's study, which reviewed >70 reports, showed that the top concern was the infrastructure required, followed again by safety and noise (see Exhibit 98 below).

Exhibit 97: Key public concerns on eVTOLs: safety, security, noise
Concerns on air taxi use cases ranked by % of respondents top 3



Source: EASA, survey on the societal acceptance of Urban Air Mobility in Europe, May 202
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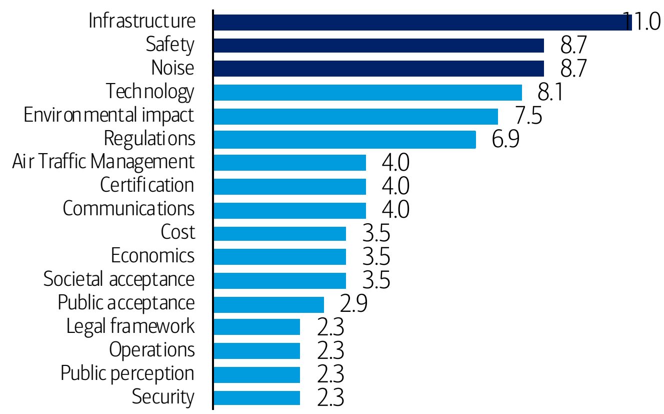
Exhibit 98: Key Industry concern on eVTOLs: Infrastructure
In review of 76 UAM industry reports by the EU regulator EASA, Infrastructure was the key cited concern, followed by safety/noise.



Source: EASA, Share of 173 mentions of concerns in 76 reviewed industry publications, May 2021
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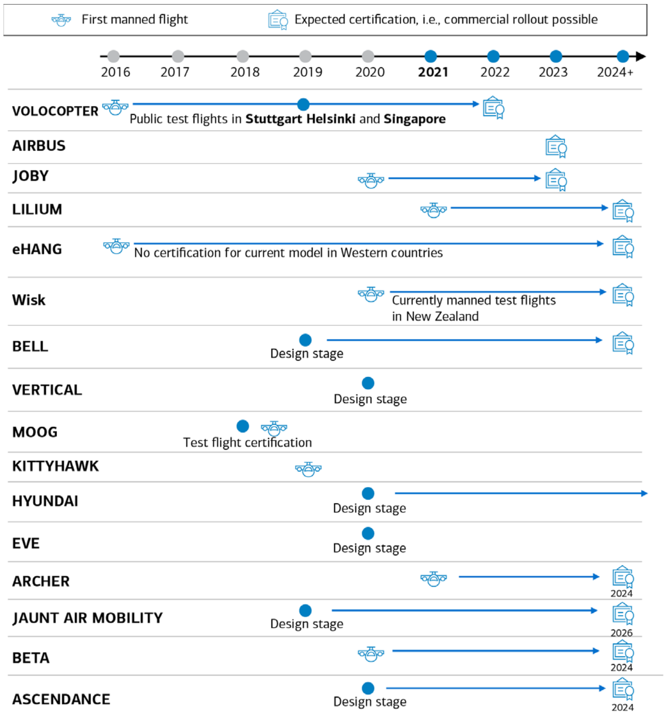
Packages before people?

Given the challenges of launching passenger air taxi services with these vehicles, commercial cargo-based services may be introduced first in some markets. This would allow regulators to become acquainted with the operational profile and real world risks of autonomous flying vehicles before passenger services are launched. Exhibit 99 and Exhibit 100 already suggest this: Google subsidiary Wing and Amazon received FAA approval for air drone delivery in 2019 and 2020, respectively, albeit in rural areas initially.

Exhibit 99: Passenger vehicle certification announcements
Several companies are aiming for certification of passenger UAM vehicles; most are targeting 2024+, but three are expected in 2022-23



Source: EASA

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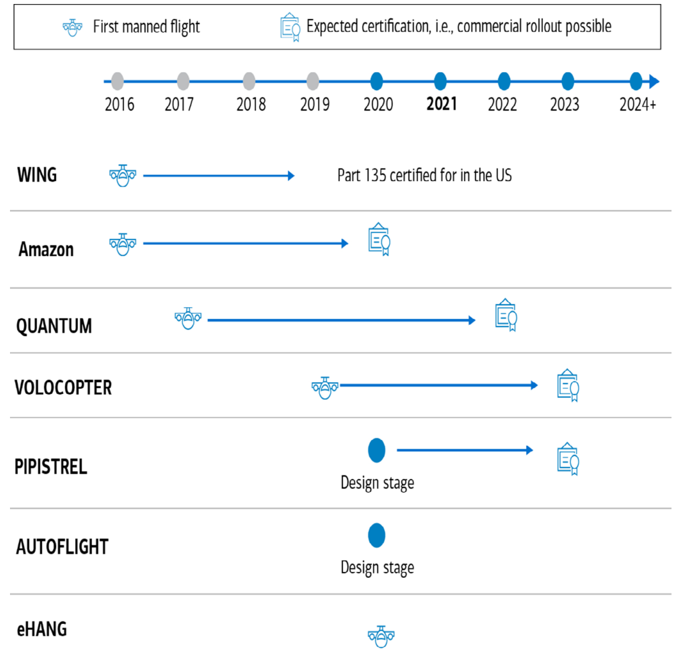
Exhibit 100: Cargo vehicle certification announcements
Certification for cargo services has already been granted for two operators (albeit not in urban areas yet), with more expected in 2022-23



Source: EASA

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Wireless Electricity: the death of cables?

What is it? The use of magnetic fields or radio waves to charge items wirelessly

The answer to: 'how do we automate charging?'

Did you know? Motorola has announced plans to develop phones that charge over-the-air a metre (3 feet) from the charger

By 2025: There will be 10 connected devices per person that each need to be charged

Market size: US$35.23bn by 2030

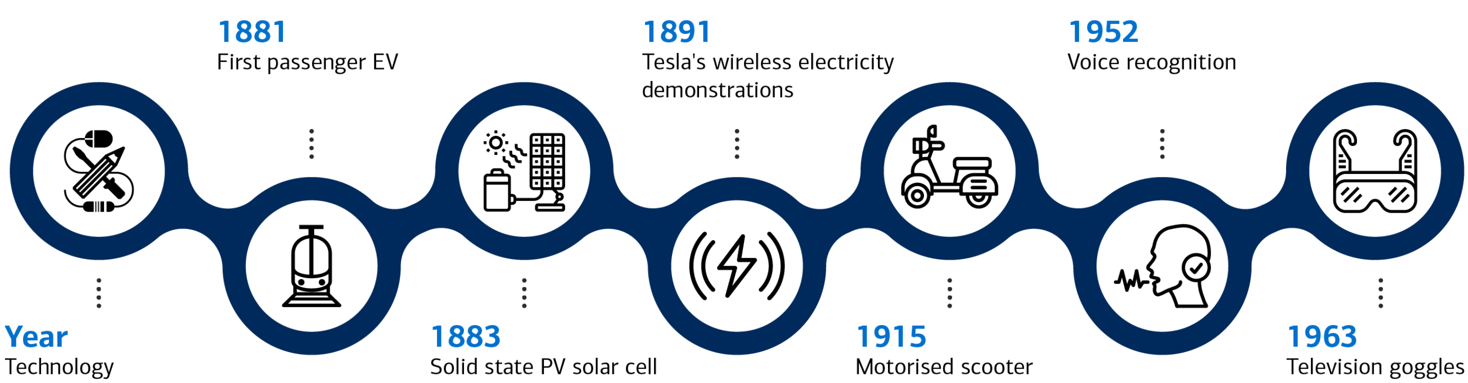
Sectors affected: Electric vehicles, smart cities, consumer connected/electrical products, factory automation and cables

'How fast can we charge a device?' is becoming an outdated question
In a world of wireless electricity, fast charging and concerns about charging infrastructure would be viewed completely differently. Rather than speeding up charging through fast-charging batteries, we could automate charging and ensure seamless charging capabilities, meaning we could even do away with batteries in some devices.

> "For a technological era that we've been calling wireless, we still have a lot of wires in our lives" *Florian Bohn, co-founder and CEO of GuRu*

Returning to old technologies: historical comebacks for old concepts in 2021
We are returning to a number of centuries-old concepts for inspiration and innovation. Just like electric vehicles or solar panel cells that were first created in the 1800s, the concept of transmitting electricity through means other than wires has been around for well over a century. We believe the growing connectedness of items and improving technology could support a more viable business argument for the development of wireless charging.

Exhibit 101: Wireless electricity was first demonstrated in 1891 by Tesla
Old technologies are hitting their stride in the 21st century



Source: BofA Global Research

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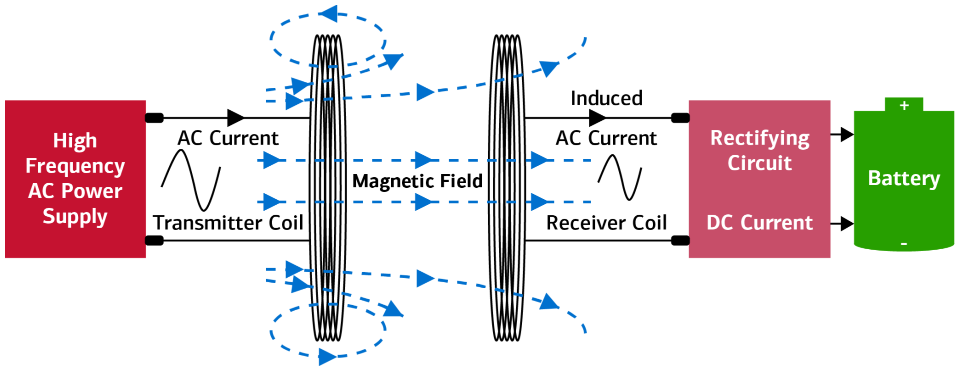
> "Electric power is everywhere present, in unlimited qualities. This new power for the driving of the world's machinery will be derived from the energy which operates in the universe, without the need for coal, gas, oil, or any other fuel." *Nikola Tesla, The Brooklyn Eagle, 1931*

How does wireless charging work? Magnetic fields or radio waves

One form of wireless charging is inductive charging which works by creating a magnetic field (see exhibit 12). A coil of electrical wires in one device has an alternating current sent through it which creates a magnetic field, which is then picked up by a second coil of wires in another device that subsequently creates an alternating current in the second circuit. Battery-reliant devices only work with a direct current, so the alternating current must then be transformed via a rectifier. The alternative form of wireless charging uses radio waves rather than magnetic fields to transmit energy.

Exhibit 102: How does inductive charging work?
Diagram of inductive charging system



Source: ResearchGate

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Depending on the application, there are 3 ways of wirelessly charging a device:

- **Radio charging:** charging via radio waves rather than magnetic fields that is effective for products that need limited power like a toothbrush, computer mouse, medical devices, etc. Research & development has also expanded to longer-distance transmission of electricity and to products for over-the-air charging.
- **Inductive charging:** charging by placing the item on a pad rather than plugging in, which can be used for medium-powered devices like phones and requires close contact.
- **Resonance charging:** much more efficient across greater distances and can be used to transfer large volumes of power for devices like electric vehicles and robots.

Exhibit 103: What technologies create wireless electricity?

Comparison of radio frequency, inductive and resonance forms of wireless electricity

	Radio	Inductive	Resonance
Technology	Charges via radio waves rather than magnetic fields	Magnetic waves from one coil is received by other coil in device that is then converted into electricity	Oscillating magnetic waves are used with devices calibrated to have the same resonant frequencies
Applications	Small power devices and devices without space for coils, e.g. medical devices, phones, headphones. Electromagnetic power transmission capable of longer distance too	Small and medium powered devices e.g. phones	Large power transmission, e.g. electric vehicles robots, helpful for fitting under desks as thickness less of an impediment to charging
Use	Development of capabilities that charge multiple devices simultaneously, can be placed on smaller devices as does not need coil embedded in device	Needs precise overlap of charger and device to efficiently charge and can only charge one device at a time	Can charge multiple devices, does not need precise overlap
Range	Development of longer-distance capabilities	Needs close contact	Works over longer distances
Efficiency of power transmission	Large variation	40-65%	30-50%
Commercialisation	Already used in consumer products	Already included in some phones	Limited commercialisation

Source: EE World Online, DigiKey, ITU

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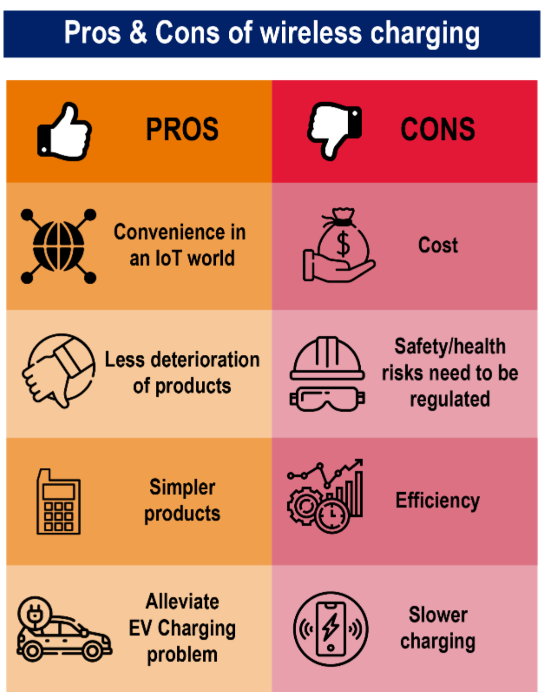
How does wireless charging compare to traditional wired charging?

Wireless charging could act as a significantly more convenient solution as the world becomes much more connected vs today's traditional wired charging. Below, we highlight the benefits and use cases vs disadvantages currently facing the technology. Predominantly, these challenges come from the early stages of the technology with developments still needed to effectively apply to all the mentioned use-case scenarios.

Exhibit 104: The pros & cons of wireless charging

Will convenience triumph in an increasingly connected world as the technology improves?



Source: BofA Global Research

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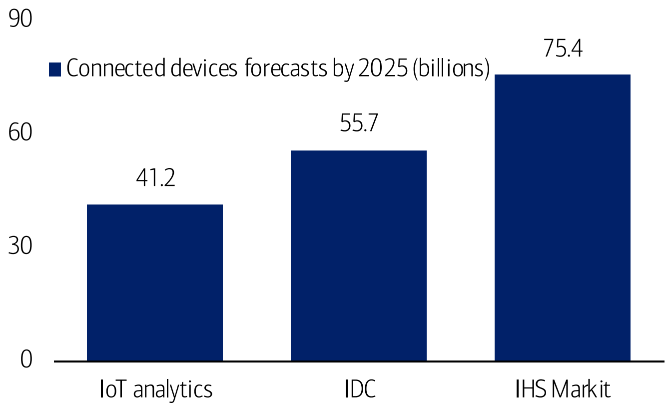
The case for wireless electricity: exponential IoT growth, EVs & remote communities

While estimates vary, it is clear that the internet of things (IoT) is expanding rapidly. For instance, IHS Markit estimates connected devices will grow 12% pa from 27bn in 2017 to 125bn devices by 2030, while Gartner estimates that connected devices will triple between 2018 and 2023 (source: IHS Markit 2017, McKinsey 2019). In total, this could mean more than 10 connected devices per person from wireless headphones and phones to wearables, smart speakers and cars that all need charging. Further, 25% of enterprises already use connected devices from monitoring remote locations to drones. Wireless electricity could provide a simple solution to charging and even enable the removal of batteries from devices that can access wireless electricity continuously.

Exhibit 105: Connected devices could be 10x as abundant as humans by 2025

Number of connected device forecasts by 2025 (billions)



Source: IoT Analytics, IDC, IHS Markit

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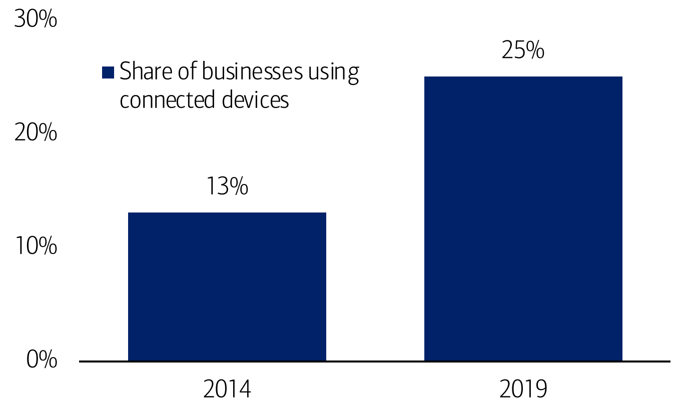
Exhibit 106: 25% of enterprises already use connected devices from monitoring remote locations to drones

Share of businesses using connected devices in 2014 & 2019



Source: McKinsey 2019

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Radio charging: going long distance for small devices

Some exciting developments are occurring in the radio-charging space that could affect consumer-device charging. Historically, wireless charging has required devices like wireless toothbrushes to be placed on a stand. However, a number of start-ups have been developing long-distance radio charging that could radically increase the applicability of radio charging:

- **WattUp** – radio frequency-based charging product by Energous that can charge up to 12 devices simultaneously within 15ft of the transmitter and charge while the device is moving.
- **Cota Real Wireless Power** — Ossia and Sensata-Xirgo Technologies have created a Cota Real Wireless Power tracker system that places wirelessly charged devices on trailers in logistics hubs to keep track of trailers 100% of the time, which saves distribution centres time, money and labour. Also, wireless power means less risk with fewer cables and fewer charging stations across the centres.
- **MagLense system** – allows medical devices implanted in humans to be charged without the need for precise placements reducing the risk of thermal wounds. This flexible range of coils can help patients that have received minimally invasive implants that move more around the body and allows for micro implants in previously inaccessible body parts that could not be wirelessly charged (source: Cambridge Consultants).

Case study: Millimeter wave technology

Start-up, Guru, has developed a wireless solution that operates in the millimeter wave spectrum (24GHz frequency) (i.e. high-frequency radio waves). The technology directs the energy beams precisely at chips that are attached to the devices rather than flooding an entire space to enable efficient power transfer. At CES 2020, Guru showcased the technology in action, which was capable of charging multiple devices over long distances as well as a roaming charging unit. In May 2021, the start-up announced a collaboration with Motorola to create the first phones that can be wirelessly charged through the air a metre away. Other startups include GuRu, Energous, Ossia, Wibotic.

Not just for small devices: New Zealand trials first long-distance transmission
Remote communities with access to only expensive electricity could benefit from wireless electricity technology. Pacific Island communities, like Tonga, for instance, experience some of the most expensive electricity with 90% of energy imported as diesel, costing over US$1/KwH (source: IMF 2019, Emrod). By developing wireless electricity in such locations, cheaper energy and new revenue streams from offshore wind could be more easily developed. Further, network resilience could be improved with fewer failure points that could result in outages whilst also reducing dependency on carbon-intensive diesel generators.

Exhibit 107: Long-distance transmission reduces the potential points of failure in an electrical network
Long distance wireless electricity transmission vs traditional grid system

Source: emRod, BofA Global Research

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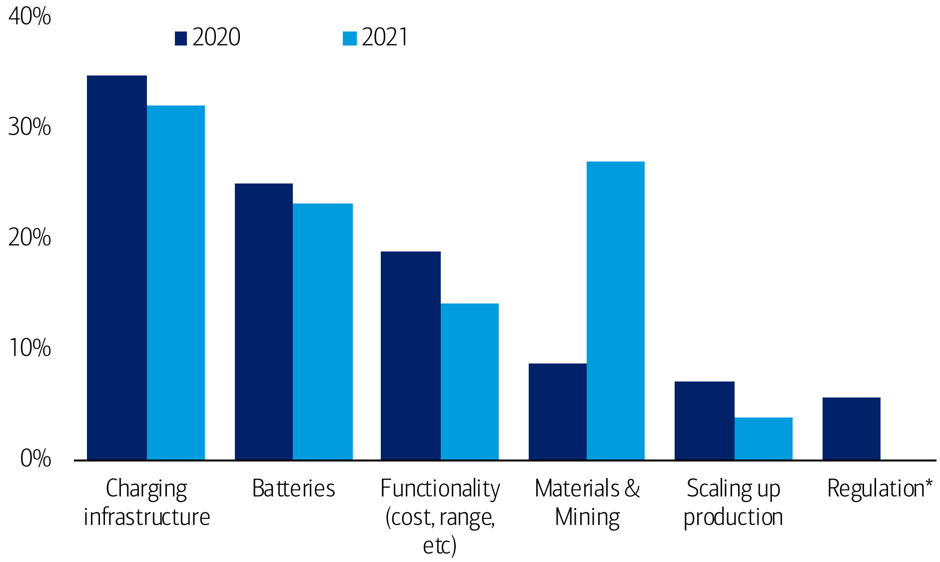
Case study: long-distance wireless electricity
To provide energy wirelessly at a distance, Emrod has piloted the first long-range transmission of electricity in New Zealand. The technology relies by sending electromagnetic waves with frequencies often used in Wi-Fi as beams directly between two points. These beams stop transmitting when objects like helicopters and birds fly into them.

Emrod estimates that Stewart Island could lower the electricity tariff by US$0.14/kWhr from US$0.60/kWhr to US$0.46/kWhr while wireless electricity could increase sustainable energy uptake by 50%, reduce outages by up to 85% and cut costs of electricity infrastructure by 65% in Africa and the Pacific Islands.

EV wireless charging: could it solve a key stumbling block for electric vehicles?
Charging infrastructure for electric vehicles has some problems to overcome, from building out capacity to reducing charging time and overcoming consumer range concerns. Indeed, charging infrastructure was seen as the biggest challenge to enabling the electric vehicle rEVolution according to 32% of respondents at our Transforming

World Conference – New York 2021. Another innovative solution beyond better batteries and fast charging could be wireless charging with pads placed in garages, public parking spaces, and even on roads. Charging this way would be a reliable, automated activity that requires no conscious effort while reducing road clutter.

Exhibit 108: What do you see as the biggest challenge to enabling the rEVolution?
Survey responses from May 2021 A Transforming World Conference, charging infrastructure remains the top issue for 32% of investors



Source: BofA Global Research Survey; n=196

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Global standards could catalyze wireless-charging car development

Historically, there have been few wireless-charging cars (e.g. BMW 530e) amid a lack of cohesive standards. However, in October 2020, the Society for Automotive Engineers (SAE) announced the first global wireless electric car-charging standard enabling the further rollout of wireless-charging car models. The SAE estimates that the systems can have 94% efficiency from grid-to-battery (source: Society for Automotive Engineers).

Exhibit 109: Inductive EV charging technology
Dynamic electric vehicle charging (DEVC)

Source: Qualcomm

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Exhibit 110: Wireless charging on highways concept
Platoon of EV truck fleet could be powered in the future by highways

Source: Shuttershock, The Conversation

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Longer term: dynamic wireless charging could destroy range anxiety

The final goal would be to enable charging during a car journey, thereby remove range anxiety. For commercial vehicles that make predictable stops like buses, taxis and vans, a mid-way solution could be placing charging pads in loading docks, taxi ranks or at stops so that vehicles charge while offloading and onboarding, thereby increasing range and reducing the number of vehicles needed. However, for completely dynamic charging, radio frequency-based wireless charging would need to be used given the prohibitive costs, such as ferrite which is needed to guide the magnetic fields safely and effectively. Professor Afridi at Cornell University expects dynamic-charging technology to be 5-10 years away (source: Cornell Chronicle).

Wireless charging at Link Transit in Washington

Momentum Dynamics has deployed magnetic-induction based wireless charging with renewable energy at a Columbia Station, Wenatchee, WA since March 2018. The system charges transit vehicles that arrive at up to 200kW which can extend the driving range by 145 miles in a single charge.

- The buses when charged for 7-10 minutes every hour for 16 hours/day could maintain 75% of their charge capacity, which can reduce the rate of battery degradation.
- By partially charging throughout the day, 190% of bus battery capacity was enabled in a day.

Further planned trials include a wireless-charging hub in Edinburgh for light commercial vans in 2021 (source: Momentum Dynamics)

Could 5G help create wireless electricity?

As 5G networks proliferate, scientists have been investigating secondary benefits from the systems. 5G networks have mm-wave energy present that could be harvested for charging the exponentially growing and energy-hungry Internet of Things. This year scientists succeeded in harvesting very small volumes of power from a 5G network at just under a 3-metre distance. The scientists expect that this distance could be increased to 180 metres (source Eid et al, scientific reports, 2021).

Unintended heightened health risks from wirelessly chargeable devices

Some unintended consequences, however, have already arisen from the proliferation of wireless-charging devices. Apple recently listed a series of products that need to be kept a 'safe distance' (15cm/6 inches) from medical devices like implanted defibrillators and pacemakers thanks to strong magnets and electromagnetic fields. In particular, those with wireless-charging capabilities need to be kept double the distance away (source: Apple).

Risks: costs, slow charging, less efficient

Some of the risks with the technology includes estimates of 15% slower charging with the same input power. Also, chargers are more expensive where the devices cannot be moved. Furthermore, the process is less efficient (transferred into heat, some battery damage); ultra-thin coils are able to work at higher frequencies reducing some problems. Finally, more devices need to be made compatible with inductive chargers (source: ZME Science).

US$35.23bn market by 2030

The global wireless power transmission market generated US$5.71bn in 2020, and is estimated to reach US$35.23bn by 2030 implying a CAGR of 21.3% between 2021 and 2030 (source: Allied Market Research).

Holograms: beam me up, Scotty

What is it? Holograms is a photographic technique that records the light scattered from an object and then presents it as 3D

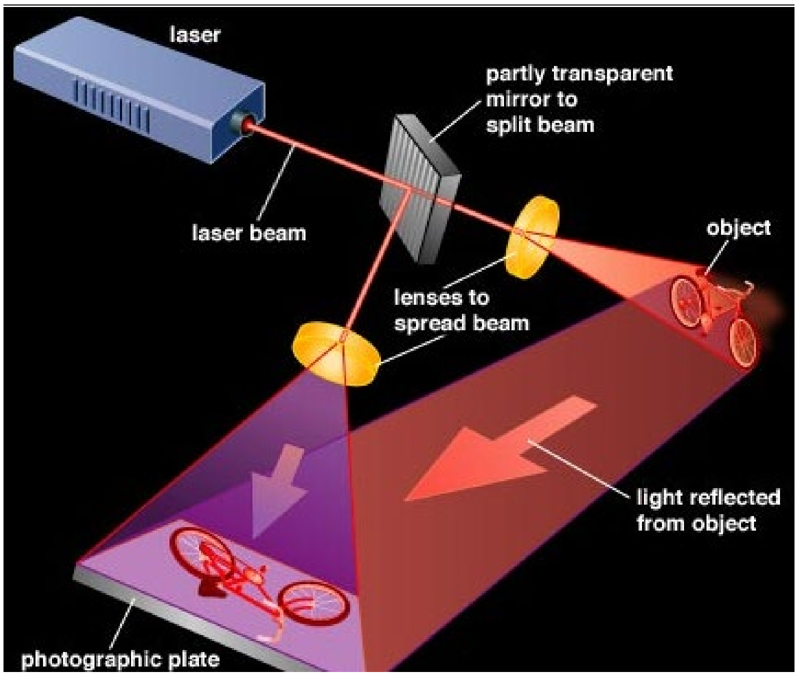
The answer to: 'The next big form factor in computing after the smartphone'

Did you know? Swedish pop band ABBA plan to release their first album in 40 years with a hologram tour

Market size: US$11.65bn market by 2030E

Sectors affected: Consumer electronics/gaming/media & entertainment, retail, medical, military and real estate

Exhibit 111: How holograms work
Holography is essentially like three-dimensional (3D) photography



Source: Britannica Encyclopaedia

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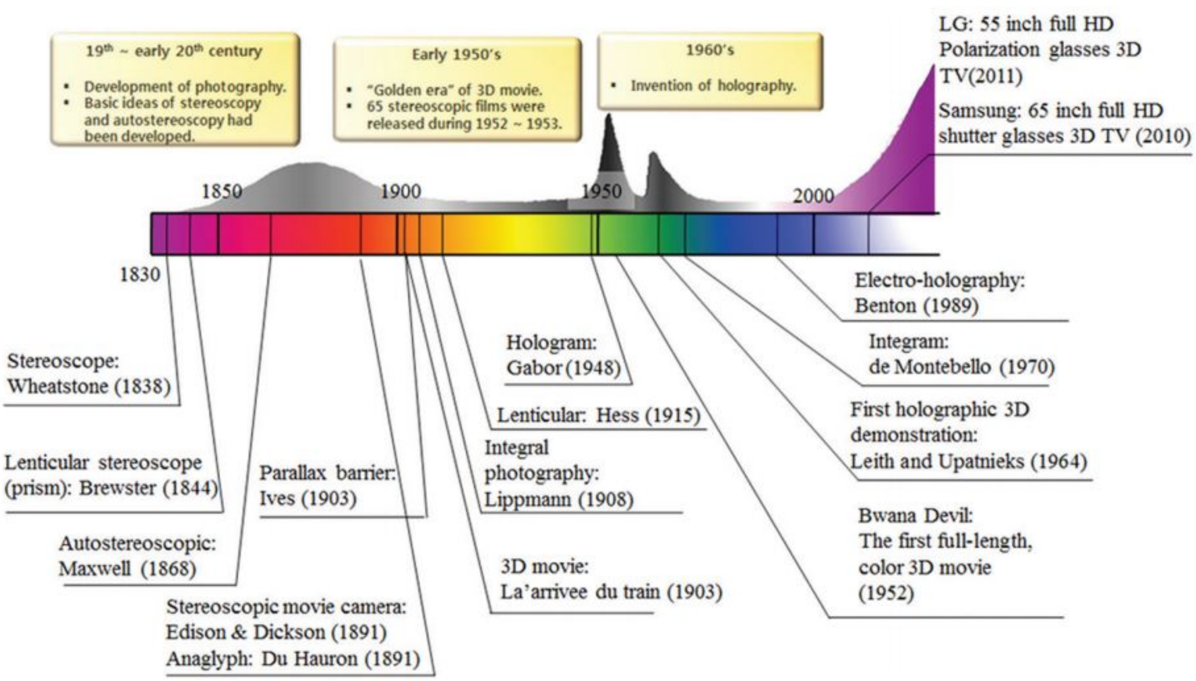
The next big thing in digital communications: the death of distance!

Holography is the technology of producing holograms – it enables a wavefront to be recorded and later reconstructed. Holography is best known as a method of generating 3D image. It is based on the principle of Interference, which occurs when the two waves meet while travelling through the same medium. Invented in the 1940s by Dennis Gabor, holograms are made by superimposing a second wavefront (normally called the reference beam) on the wavefront of interest, thereby generating an interference pattern, which is recorded on a physical medium. Essentially to make a hologram, a light of single color is needed, such as laser.

> "Imagine being able to insert yourself into the same virtual spaces as your colleagues. You can interact with or collaborate around virtual objects and 3-D whiteboards" Ivo Petrov, Executive Chairman at Imverse

Holograms have several applications across multiple sectors, representing the future of communication, as corporates explore a hybrid world. Also, it could be the next big thing in the Future of Work post-COVID for conferencing / collaboration in a 'new normal' workplace where employees are able to read body language, other physical reactions and collaborate in more interactive and engaging ways in cyberspace. Unlike VR/AR/MR, special optical glasses or head-mounted devices (HMD) glasses are not needed.

Exhibit 112: Timeline of 3D Hologram Display
From stereoscope in 1850s to 3D TV in late 2010s



Source: Radiant Vision System

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A simulated virtual world? The future is closer than you think!

> "So in the future, instead of a video chat, I'll just be sitting on my couch and your hologram can just appear on the couch next to me, or I can hologram into your house" Mark Zuckerberg, Facebook CEO

Holograms are technology capable of creating a central simulated environment that will allow everyone to come together in one virtual room with no one having to leave their physical location. This technology will require no phones to call colleagues, nor a computer command to call a particular person. The idea is to bring people to a place they couldn't have been in-person and to remove the barrier between digital reality/communication and actual reality. This type of communication will take us beyond the limits of videoconferencing. Instead of travelling hundreds of miles for business purposes, employees will be able to simply call up colleagues/business partners and join them in a shared holographic environment.

Exhibit 113: HoloLens visualization of holograms items in a living room
Project went beyond 3D models on computer screens, and took the models into the real world

Source: Microsoft, Wired

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Exhibit 114: HoloLens gesture control of virtual screens
360 degrees with a more immersive element

Source: Microsoft

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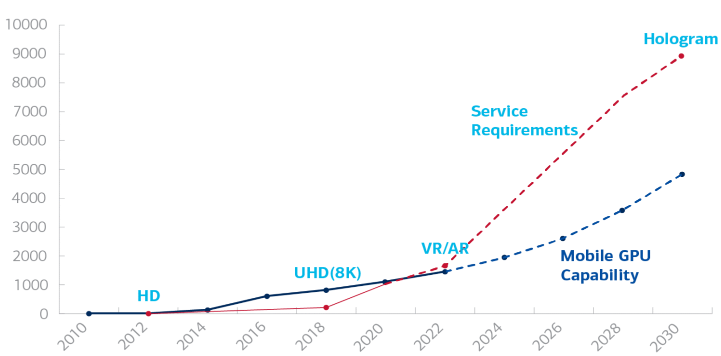
6G is key enabler of holograms

With the unprecedented rate of advances in high-resolution rendering, wearable displays, and wireless networks, mobile devices will be able to render media for 3D hologram displays. Hologram is a next-generation media technology that can present gestures and facial expressions by means of a holographic display. The content to display can be obtained by means of real-time capture, transmission, and 3D rendering techniques. In order to provide hologram display as a part of real-time services, extremely high data rate transmission, hundreds of times greater than current 5G system, will be essential. A hologram display over a mobile device (one micro meter pixel size on a 6.7 inch display form-factor requires at least 0.58 Tbps. Moreover, support of a human-sized hologram requires a significantly large number of pixels. The peak data rate of 5G is 20 Gbps. 5G cannot possibly support such a large volume of data as required for hologram media in real-time. To reduce the magnitude of data communication required for hologram displays and realize it in the 6G era, AI can be leveraged to achieve efficient compression, extraction, and rendering of the hologram data. The market size for the hologram displays is expected to be US$7.6bn by 2023 (source: Samsung).

Exhibit 115: Computing capability trend (Gigaflops/sec)
Computing power: requirement versus capability



Source: Samsung

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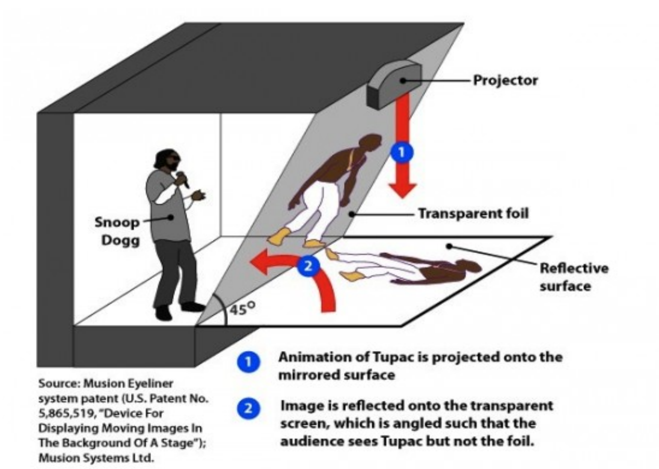
US$11.65bn market by 2030E

The global holographic display market was estimated to be worth $1.13 billion in 2020 and is forecasted to hit $11.65 billion by 2030, registering a CAGR of 29.1% between the forecast period (source: Allied Market Research)

In recent years, we've seen some interesting real-life applications of the technology from reproduction of artists' likeness to holographic 3D display. We think we are still barely scratching the surface in terms of the capability of the technology. We believe that as creators keep experimenting with it, we'll get to see more exciting developments. With the eventual rollout of 6G, companies and developers are actively working to create more immersive experiences for users. Currently, holograms are still reliant on experienced animators and creators to produce them. Users can't just pick up their phone and project themselves in a room while they speak with a friend. We believe we are closer to achieving that level of freedom with recent creativity around the technology.

> Among the most famous recent demonstrations of hologram technology was when deceased rapper **Tupac** was 'brought back to life' via hologram technology at the Coachella 2012 festival

Exhibit 116: How Coachella's Tupac Hologram worked explained
2Pac's animation projected onto the mirrored surface and image reflected onto the transparent screen



Source: Musion Systems, International Business Times, Roxanne Palmer

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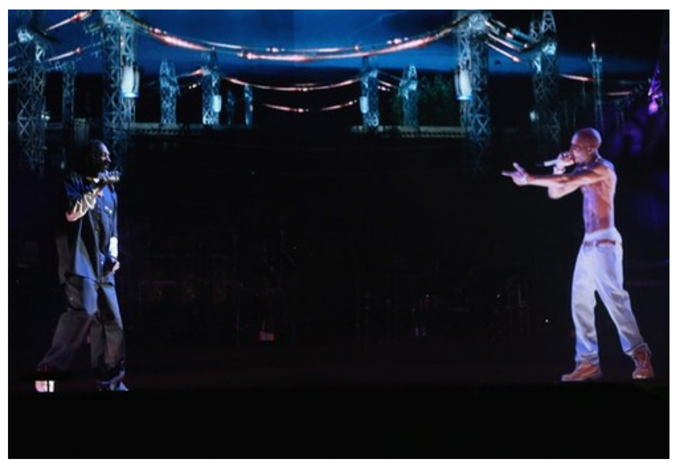
Exhibit 117: Tupac Hologram performing alongside Snoop Dogg at 2012 Coachella festival
Deceased rapper 2Pac brought back to life via Hologram technology



Source: Musion 3D

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Holograms are already playing significant roles in retail and entertainment. In the near term, we believe the technology will be crucial in the workplace when it comes to communication, collaboration, and conferencing in real-time. Also, in retail, holograms and holographic marketing are increasingly being applied to locations such as exhibition spaces, shopping centers, fairs and shops to raise sales and give lasting impressions to (potential) customers. In entertainment and media, holograms are gaining traction; they are used fairly regularly to bring performers back to life, although this has been around for a while now. Hologram is now a critical part of the medical toolkit, helping doctors examine vital organs in 3D without having to cut into the body. This technology has a great potential to improve how quickly doctors could look into the human body, giving 100% visualization.

Exhibit 118: 3D hologram display over mobile devices
Holographic images float on the screen and can be viewed at any angle without needing 3D glasses

Source: Samsung

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Exhibit 119: Future of Meetings
Colleagues as Holograms floating in space

Source: Medium.com

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What's most exciting about hologram is that it's still a work-in progress. The possibilities are endless in our view, and there's a lot of room for improvement, exploration and experimentation. Holograms are great tools for visualizing patient data while training students and surgeons. In military, geographic intelligence is an essential part of military strategy and fully dimensional holographic images are being used to improve reconnaissance.

Exhibit 120: Hypervsn Holographic solution used in Retail
Helps to raise sales and give lasting impressions to existing and potential customers

Source: Hypersvn

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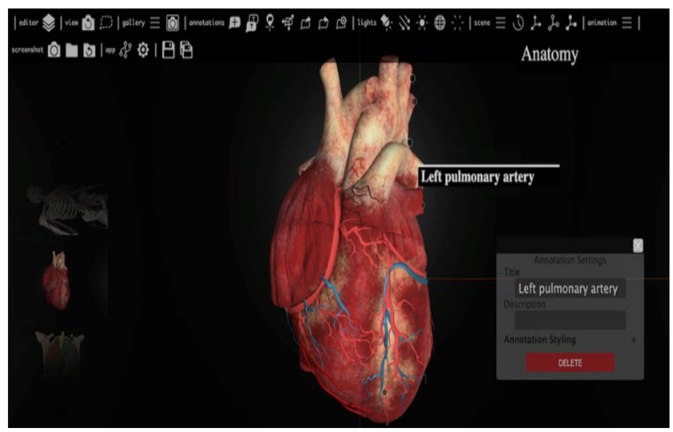
Exhibit 121: Holoxica 3D Holograms of Exterior Heart
Holograms have great potential to improve how quickly doctors could look into human interior giving 100% visualization



Source: Holoxica

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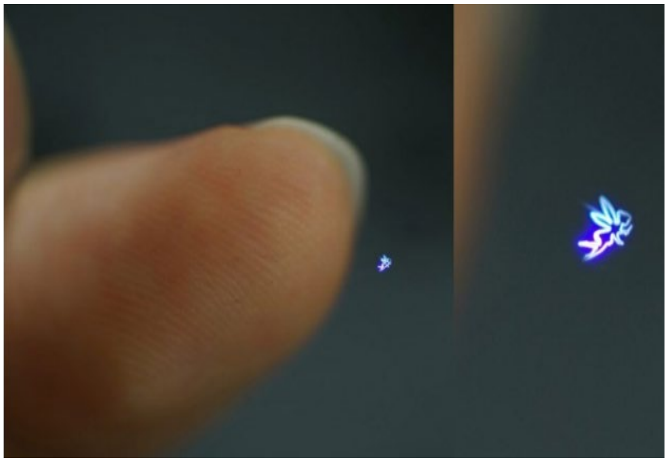
Touch holograms: 2015 was a landmark year for hologram technology with the unveiling of touchable holograms and the first-ever holographic protest. A Japanese company, Pixie Dust Technologies, created Fairy Lights in Femtoseconds – tangible holograms created by ultra-fast lasers, capable of bursting forth to create 3D images by ionizing the air (Source: Pixie Dust Tech).

Protest holograms: The first-ever hologram protest held in Madrid, Spain in 2015 by No Somos Delito, a platform of over 100 groups against the law of citizen security (Ley Mordaza, Gag Law).

Exhibit 122: Pixie Dust Tech Fairy Lights
Capable of bursting forth to create 3D images by ionizing the air



Source: Pixie Dust Technologies

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Exhibit 123: Holograms protest In Madrid
No Somos Delito, a platform of over 100 groups, against the law of citizen security

Source: Open Democracy

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'Telehuman' – disrupting non-verbal visual communication: Canada Queen's University researchers designed a Telehuman system capable of broadcasting the richest possible information, allowing users to feel more comfortable and intimate, but also more expressive and effective in their communication. The system doesn't require a head-mounted device (HMD).

> "Face-to-face interaction transfers an immense amount of non-verbal information, this information is lost in online tools. Users miss the proxemics, gestures, facial expressions, and eye contact that bring nuance emotional connotation and ultimately empathy to conversion, Telehuman 2 injects these missing elements" Roel Vertegaal, Professor of Human-computer interaction at the Queen's University School of Computing

Exhibit 124: Telehuman 2
The three-dimensional projector lets people in different locations talk as though they were standing in front of one another

Source: Digital Trends

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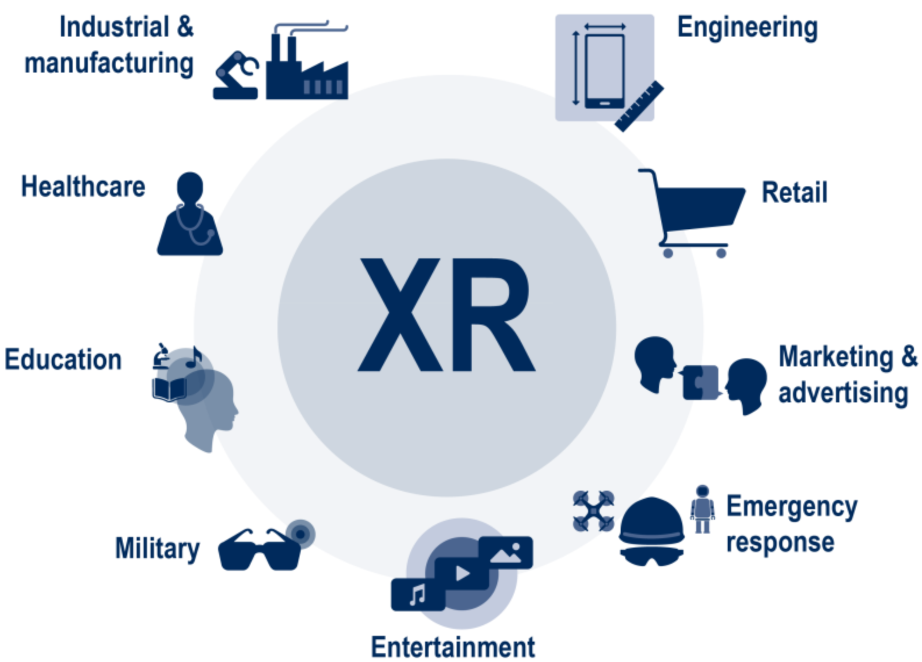
Risks: economics of tech, costs

The technology is still expensive for most people; however, corporates with large budgets can afford it. Notably, ARHT Media Holopod costs US$20,000 and some other companies charge over US$20,000 for the same technology. Traditional holograms require a team of high-definition projection technicians. However, ARHT's Holopod was designed to be a quick set-up, plug & play system that's simpler to deploy. We believe the cost will fall as use cases increase and public awareness grows. More R&D spending by key players and big tech companies could unlock ways for laptops, computers and smartphones to engage with and stream holograms emitted elsewhere.

There has been an ongoing debate about the use of holographic recreations of deceased artists in the entertainment industry mainly to do with the issues of respect and ethics. Being able to recreate someone's body and expressions means opening the gate to manipulating the person's idiosyncrasies without authorization. This might call for some industry regulation that potentially might one way or other slow down the rate of adoption.

End markets: from holograms to total / virtual / augmented reality

Exhibit 125: The potential end markets
From Industrial & manufacturing to Engineering



Source: Qualcomm

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Enterprise: long-term efficiency gains

The long-term potential for the platform is its ability to disrupt enterprises. By presenting relevant information to workers in an intuitive interface, it can reduce time, errors and cost, while improving output. In a recent pilot project, DHL found that warehouse workers equipped with augmented reality (AR) smart glasses were able to pick objects with 25% higher efficiency and fewer errors (source: DHL). This is particularly impactful as logistics accounted for 8.3% of US GDP in 2014 (source: PWC). Similarly, Boeing factory trainees assembling a mock airplane wing 30% faster and 90% more accurately using AR-animated instructions vs. PDF documents (source: Richardson et al 2014).

Exhibit 126: Project Starline booth illustration
Users sit facing a 'mirror' that beams 3D model of a person to communicate

Source: Google

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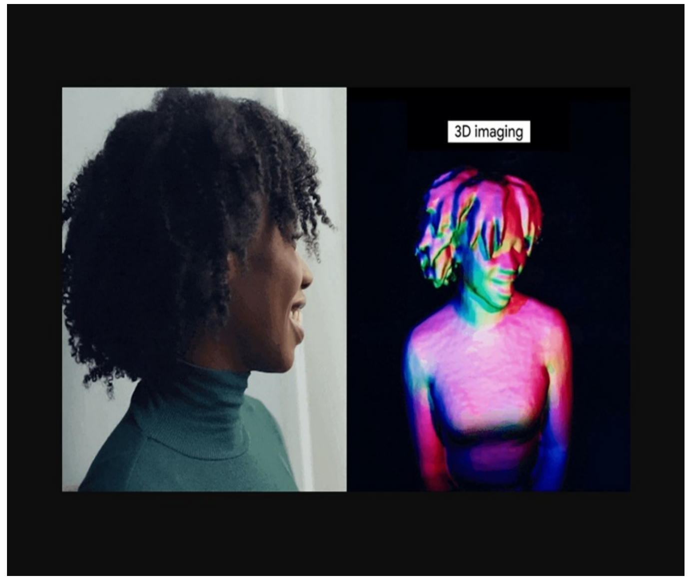
Exhibit 127: Project Starline 3D imaging technology
Camera and sensor technology detects person



Source: Google

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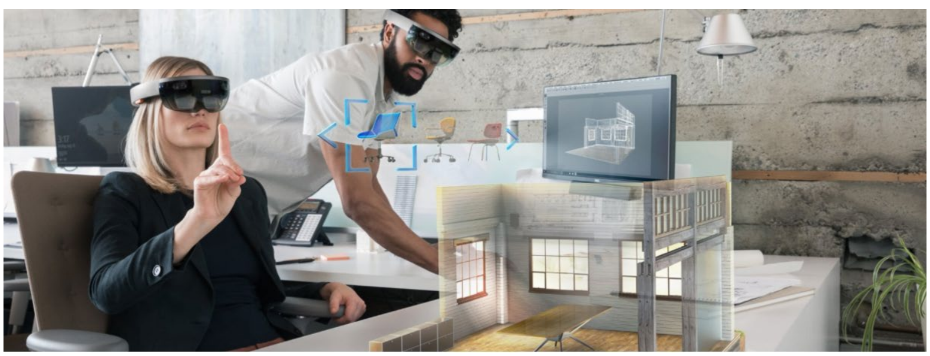
Project Starline is an experimental video communication method currently in development by Google X that allows the user to see a 3D model of the person they are communicating with

Exhibit 128: Microsoft HoloLens
Work areas could have infinite space by using open walls and open areas overlaid with digital objects



Source: Microsoft

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Transforming the office desk: Microsoft HoloLens/Autodesk Fusion case study

Platforms like mixed reality aim to transform how workplaces function. Microsoft HoloLens kicked off a joint project called 'FreeForm' with Autodesk Fusion 360. The project went beyond 3D models on computer screens, and took the models into the real world. Designers and engineers could interact in real time with models in a shared workspace. Work areas could have infinite space by using walls and open areas overlaid with digital objects. The project changed how people worked with data, the environment, peers, and their customers. The vision is for designers and engineers to be able to create and edit directly from a holographic model, and to use the same platform to pitch directly to the end client (source: Autodesk).

Exhibit 129: Autodesk's vision of 3D design using Microsoft HoloLens
Designers and engineers could interact in real-time with models in a shared workspace

Source: Autodesk

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Exhibit 130: Microsoft HoloLens for computer-aided design
Vision is for designers and engineers to create and edit directly from holographic model, and pitch the same directly to the end client

Source: Microsoft

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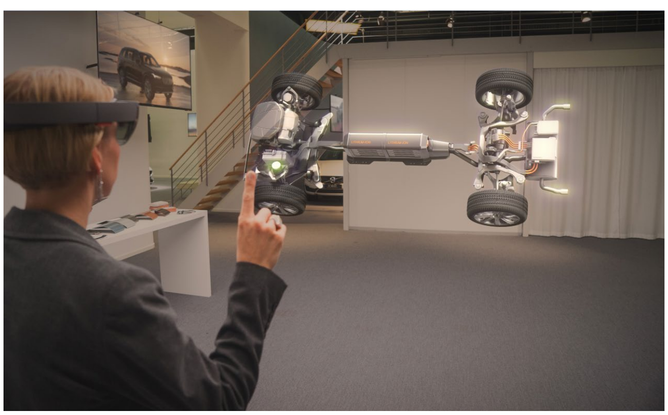
Industrials: extension of the industrial internet 4.0

Within the industrial sector, AR and VR could be highly effective in maintenance, assembly, cost avoidance, training and simulation, etc. We believe that prototyping will become more efficient and have better-designed models on the back of AR/VR. Traditional 3D computer aided design (CAD) will likely expand into AR authoring as the boundaries between the two begin to blur. The value in seeing, exploring, and evaluating solutions without the cost, risk or effort of building a physical prototype is tremendous. AR/VR can take it a step further and bring CAD to life by enabling interaction with the prototype. Industries ranging from architecture to automotive can derive benefits from this trend. Many enterprises have a library of existing CAD models of their products or assets, and AR authoring tools can help augment the models with additional images, charts, figures, videos, real-time sensor information, etc. While we are only at the nascent stages today, AR authoring will eventually work in a variety of content types including CAD files, 3D video, holographs, 360° images, etc.

Exhibit 131: Auto visualizations using Microsoft HoloLens
AR authoring tools can help augment the models with additional images, charts, figures, videos, real-time sensor information, etc



Source: Volvo

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Exhibit 132: Industrial design application of Microsoft HoloLens
AR authoring will eventually work in a variety of content types including CAD files, 3D video, holographs, 360° images, etc

Source: Microsoft

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Healthcare: technology for decentralised personalised care

> Virtual reality simulations can reduce surgical planning time by 40% and increase surgical accuracy by 10% (source: Chan et al 2013)

VR/AR in combination with sensors, Big Data analytics, artificial intelligence, bio-feedback, and increased computing power can greatly accelerate decentralized patient-focused healthcare. While the technology is only in its infancy in healthcare, interest has been ramping up. Use cases today include medical imaging & diagnostics, monitoring, simulations & training, telemedicine, and rehabilitations.

- **Training & simulation** – risk-free simulations to practise procedures, especially those that are uncommon. Surgeons can operate on mock cadavers and potentially receive haptic feedback (the use of the sense of touch in a user interface design to provide information to an end user) for a realistic immersive environment.

- **Imaging & diagnostics** – established players like GE are working on integrating AR/MR with existing medical imaging platforms. Start-up EchoPixel does this by taking computed tomography (CT) images of a patient and displaying them in 3D. Complex visualizations become simplified and can be interactive in real-time.

- **Monitoring** – virtual reality can be paired with non-invasive patient monitoring devices to give healthcare providers a heads-up view of patients' vital signs. California-based Masimo joined forces with Atheer to prototype a platform called Interactive Root Iris at the ASA Anesthesiology 2015 Conference. This could allow anaesthesiologists to visualise data from multiple sources and interact with data using motion gestures, while still caring for the patient.

- **Rehabilitation** – patients who suffer from post-traumatic stress disorder, severe phobias, etc., can receive therapy to help them recover. Swiss-based unicorn Mindmaze is using VR in early motor rehabilitation for stroke patients. It makes the brain believe that immobilized regions of the body are still working, which spurs on recovery.

- **Telemedicine** – medical professionals can see and diagnose patients from remote locations through a more interactive environment.

Exhibit 133: Microsoft HoloLens visualization inside a surgery theatre
VR simulations can reduce surgical planning time by 40% and increase surgical accuracy by 10%

Source: Microsoft, Philips

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Metaverse: virtual becoming reality

What is it? The Metaverse describes the concept of a natural successor to the internet, made up of persistent, shared, 3D shared spaces linked into a virtual universe.

The answer to: The Oasis from 'Ready Player One'

Did you know? The term Metaverse was coined in Neal Stephenson's 1992 science fiction novel Snow Crash, where humans, as avatars, interact with each other and software agents, in a 3D space that uses metaphor of the real world

By the 2030s: Virtual reality will be totally realistic and compelling and we will spend most of our time in virtual environments according to Ray Kurzweil

Market size: US$390bn by 2025

Sectors affected: media, ecommerce, payments, video games, interactive entertainment and telecommunications

What is the Metaverse?

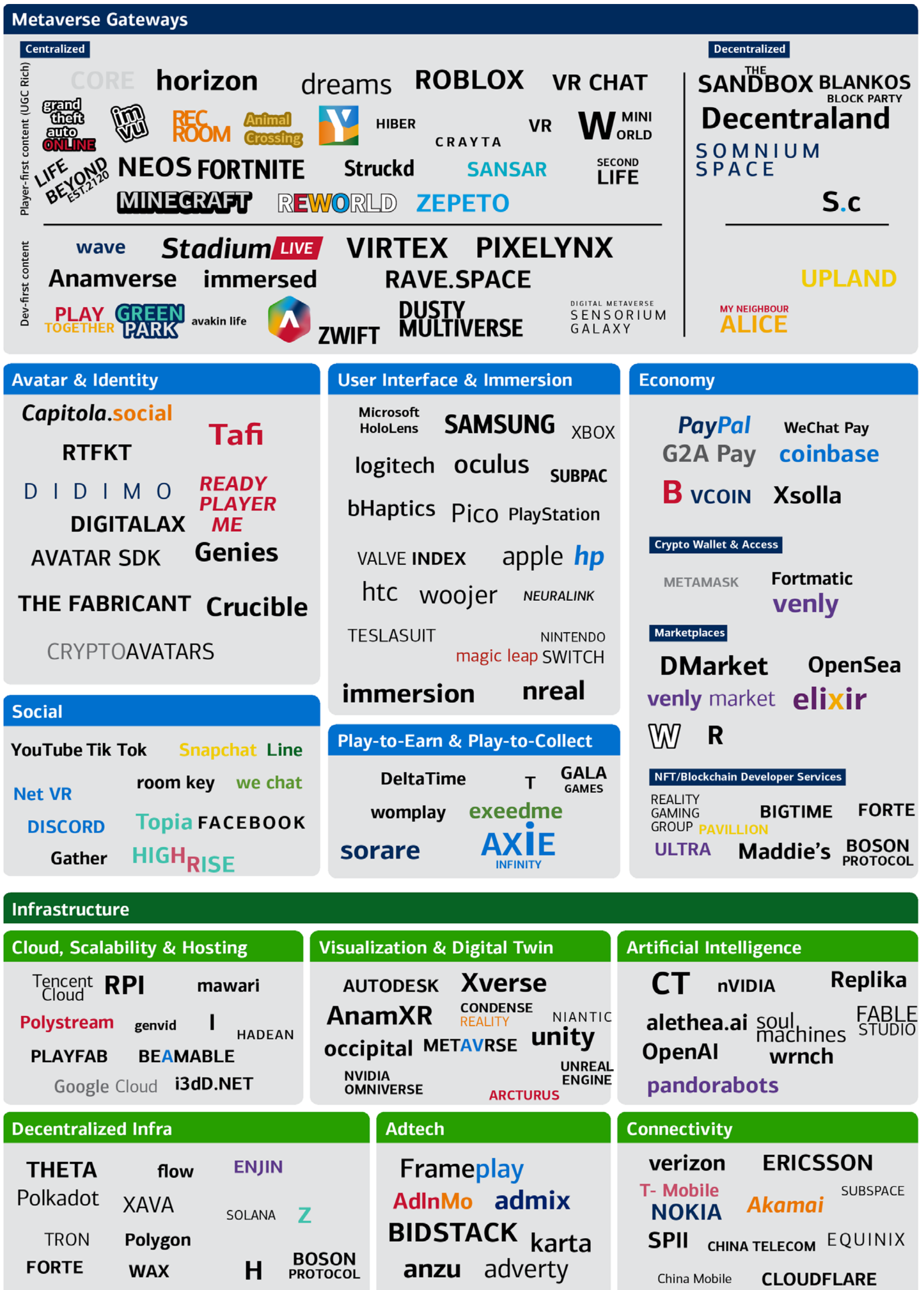
The word Metaverse is a portmanteau of the prefix "meta" (meaning "beyond") and the suffix "verse" (shorthand for "universe"). Thus it literally means a universe beyond the physical world. More specifically, this "universe beyond" refers to a computer-generated world, distinguishing it from metaphysical or spiritual conceptions of domains beyond the physical realm. In addition, the Metaverse refers to a fully immersive 3D digital environment in contrast to the more inclusive concept of cyberspace that reflects the totality of shared online space across all dimensions of representation (source: Digital Commons).

"This Metaverse is going to be far more pervasive and powerful than anything else. If one central company gains control of this, they will become more powerful than any government, and be a god on Earth" - **Tim Sweeney, Epic Games CEO**

"The Metaverse is arguably as big a shift in online communications as the telephone or the internet" **David Baszucki, Roblox CEO/Founder**

Exhibit 134: Metaverse Ecosystem Diagram

Comprising countless virtual worlds that interoperate with one another, as well as the physical world



Source: Newzoo's 2021 global games market report

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Hence, the "Metaverse" is best understood as a quasi-successor state of the Internet, just as the mobile Internet has built upon and expanded the hardline Internet of the 1990s and 2000s. The Metaverse will comprise countless persistent virtual worlds that interoperate with one another, as well as the physical world, and generate a robust economy that spans labor and leisure, while transforming long-standing industries and markets, such as finance and banking, retail and education, health and fitness, adult entertainment etc. Ultimately, the Metaverse is more than just Roblox, Fortnite or Minecraft. These are just some of the more well-known versions of virtual worlds. Just as the iPhone crystallized the smartphone revolution with new companies, the Metaverse may inspire the creation of brand new companies

Exhibit 135: 3D Virtual Worlds and the Metaverse

Major 20th and 21st century advances in Virtual World technology

Years	Event/Milestone	Significance
		Phase I: Text-based Virtual Worlds - Late 1970s
1979	MUDs and MUSHes	Roy Trubshaw and Richard Bartle complete the first multi-user dungeon or multi-user domain - a multiplayer, real-time, virtual gaming world described primarily in text. MUSHes, text-based online environments in which multiple users are connected at the same time for open-ended socialization and collaborative work, also appear at this time.
		Phase II: Graphical Interface and Commercial Application - 1980s
1986/1989	Habitat for Commodore 64 (1986) and Fujitsu platform (1989)	Partly inspired by William Gibson's Neuromancer. The first commercial simulated multi-user environment using 2D graphical representations and employing the term 'avatar' borrowed from the Sanskrit term meaning the deliberate appearance or manifestation of a deity in human form
Early 1990s	Reality built for Two, CAVE, Artificial Reality	Prototype virtual reality systems and immersive environments begin to proliferate
		Phase III: User-Created Content, 3D Graphics, Open-Ended Socialization, Integrated Audio - 1990s
1994	Web World	The first 2.5D (isometric) world where tens of thousands could chart, build and travel. Initiated a paradigm shift from precreated environments to environments contributed to, charged, and built by participants in real-time.
1995	Worlds Inc.	One of the first publicly available 3D virtual user environments. Enhanced the open-ended non-game-based genre by enabling users to socialize in 3D spaces. Continued moving virtual worlds away from a gaming model towards an emphasis on providing an alternative setting or culture to express the full range and complexity of human behavior.
1995	Activeworlds	Based entirely on Snow Crash, popularized the project of creating an actual Metaverse. Offered basic content-creation tools to personalize and co-construct the virtual environment.
1996	OnLive! Traveler	The first publicly available system that natively utilized spatial voice chat and incorporated the movement of avatar lips via processing schemes.
		Phase IV: Major Expansion in Commercial Virtual World User Bases, Enhanced Content Creation Tools, Increased Institutional Presence, Development of Robust Virtual Economy, Improvements in Graphical Fidelity - Postmillennial Decade
2003-present	Second Life	Popular open-ended commercial virtual environment with (1) in-world live editing, (2) ability to import externally created 3D objects into the virtual environment, and (3) advanced virtual economy. Primary virtual world for corporate and educational institutions.
2009-present	Avatar Reality / Blue Mars	A closed-source foray into much higher graphical realism using 3D graphics engine technology initially developed in the gaming industry.
		Phase V: Open Decentralized Development - 2007 and Beyond
2007	Solipsis	The first open-source decentralized virtual world system. Open-source development theoretically allowed new server and client variants to be created from the original code base - something that would actually become a reality with systems other than Solipsis.
2008	Imprudence / Kokua	One of the earliest alternative open-source viewers for an existing virtual world server (Second Life). So-called 'third-party viewers' for Second Life have proliferated ever since.
2009	Open Simulator	First instance of multiple servers following the same virtual world protocol (Second Life), later accompanied by a choice of multiple viewers that use this protocol. Although the Second Life protocol has become a de-facto standard, the protocol itself remains proprietary and occasionally requires reverse engineering.
2010 and beyond	Open Development of the Metaverse	Interoperability and interchangeability across servers and clients through standard virtual world protocols, formats, and digital credentials - users and providers can choose respectively without worrying about compatibility or authentication, just as today's Web runs multiple Web servers and browsers with standards, such as OpenID and OAuth.

Source: Digital Commons

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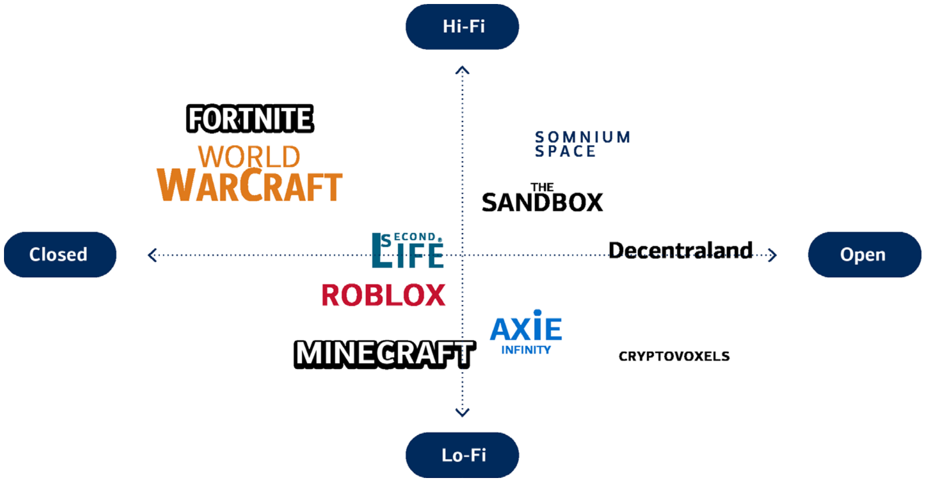
Will the Metaverse be an open or closed system?

Science fiction novels like 'Ready Player One' have described the 'Metaverse' both as a destination and dystopic process of capture and control. The parallels in the first virtual worlds we experience in gaming today and the Web more generally are striking: centralized, closed, proprietary and extractive, with shareholder supremacy over user centricity. Giving away your time and data in return for 'free' access to platforms has become normalized. There are competing visions for the Metaverse and it is not yet clear if they can and will co-exist or must be in competition. To put it simply, at least two versions of the Metaverse are emerging: one dominated by closed platforms and Big Tech like Facebook / Oculus and the other built on open protocols leveraging blockchains like Decentraland (source: Outlier Ventures).

Exhibit 136: Two versions of Metaverse emerging
One dominated by closed platforms and Big Tech like Facebook / Oculus and the other built on open protocols leveraging blockchains like Decentraland



Source: Outlier Ventures

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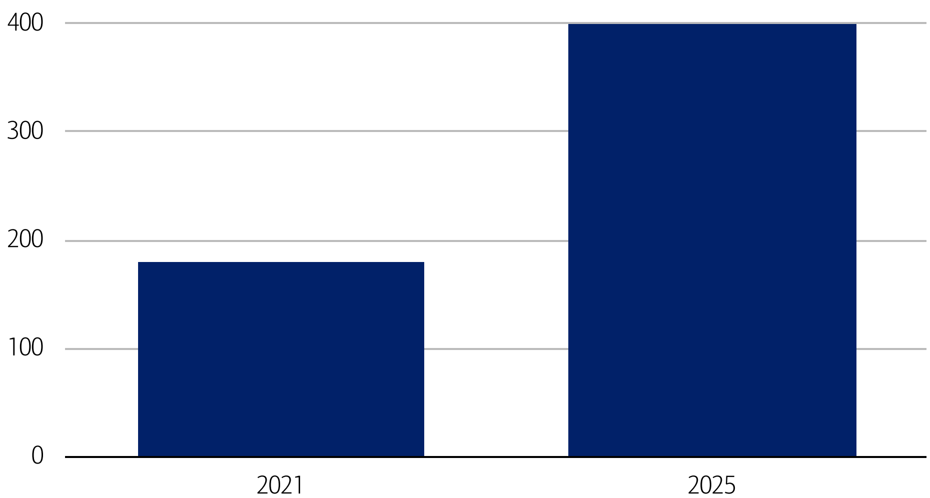
US$390bn-US$800bn market by the mid 2020s

Ark Invest estimates that revenue from virtual worlds could approach US$390bn by 2025, up from the approximate US$180bn in 2021. However Bloomberg Intelligence believes the market opportunity for the Metaverse can reach a more bullish US$800bn by 2024. Emerging technologies such as virtual reality, engines, and blockchain allow the Metaverse to take form and grow. According to Renub Research, the Global Virtual Reality Market may be US$80.16bn by 2026, compared to US$23.70bn in 2020 (source: Roundhill Investments).

Exhibit 137: Virtual Worlds revenue growth in $ billions
Ark Invest estimates that revenue from virtual worlds could approach US$400bn by 2025, up from the approximate US$180bn in 2021



Source: Roundhill Investments, Bloomberg Intelligence, ARK Invest
Note: Bloomberg Intelligence data as of 04/07/2021; Ark Invest data as of 01/26/2021

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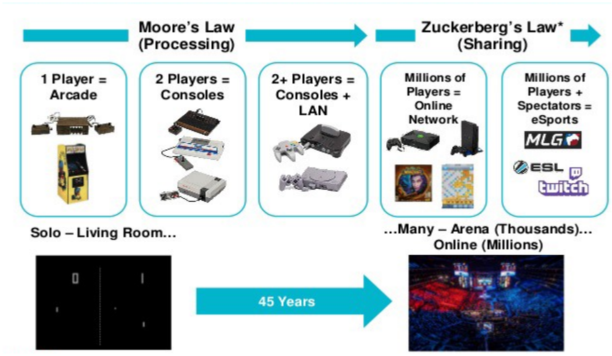
eSports > Metaverse is a natural evolution of the Fortnite craze

eSports (playing and watching organized video game competitions) are growing at an unrelenting rate, attracting more and more spectators, gamers, businesses etc. eSports entertainment has a lot of potential to add value to some of the latest consumer technology, such as Virtual Reality (VR). It gives spectators of eSports leagues the ability to get up close to the in-game action. The potential for eSports has perhaps been illustrated by Marshmello's virtual concert "attended" by 10mn people earlier this year. However, something like The Oasis metaverse from 'Ready Player One' could be the eventual final evolution phase of the eSports phenomenon.

Exhibit 138: Video games shift from individual to collaborative play
From Moore's Law to Zuckerberg's Law



Source: KPCB, Mary Meeker

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Exhibit 139: Fortnite gameplay
Oasis metaverse from 'Ready Player One' could be the eventual final phase of the eSports phenomenon

Source: Fortnite, BofA Global Research

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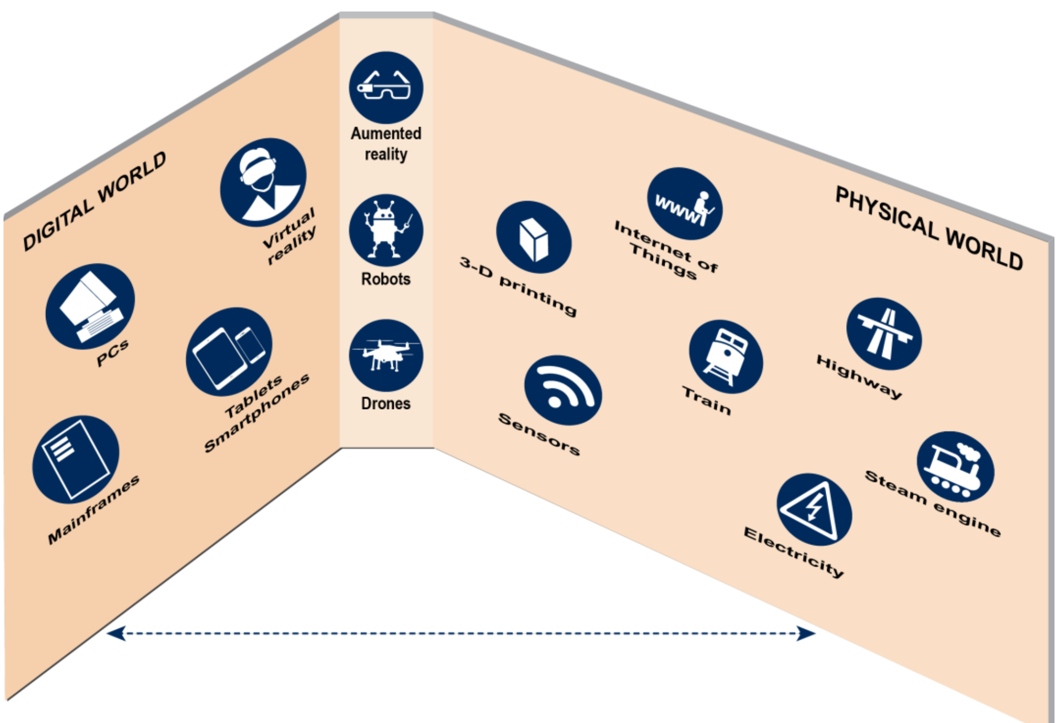
'Phygital': bridging physical + digital Transforming World

The primary value proposition is the ability to bridge the physical and digital worlds. By combining the various sensor data, the software analytics can get the full context of the user's surrounding, and augment human senses with relevant information. Although high-end platforms are already available, they are too expensive for the average consumer. As costs come down and the form factor becomes more practical, we see the Total Reality platform becoming as ubiquitous as smartphones (Source: PwC).

Exhibit 140: Total reality bridges physical and digital world
Total Reality platform becoming as ubiquitous as how smartphones changed the way we interacted with technology



Source: PWC, BofA Global Research

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> "**Mirrorworld":** someday soon, every place and thing in the real world – every street, lamp post, building, and room – will have its full-size digital twin. For now, only tiny patches of the "Mirrorworld" are visible through AR headsets. Piece by piece, these virtual fragments are being stitched together to form a shared, persistent place that will parallel the real world – **Kevin Kelly, Wired**

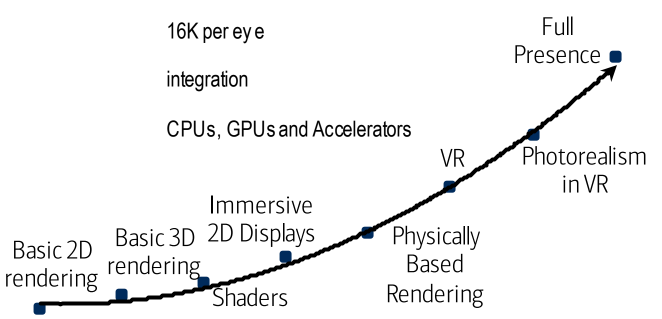
"Presence is the last true medium"

> **Presence** is shorthand for *telepresence* and is a phenomenon enabling people to interact with and feel connected to the world outside their physical bodies via technology. It is defined as a person's subjective sensation of being there in a scene depicted by a medium, usually virtual in nature

The keyword for the future Metaverse is 'presence'. It is not supposed to simply emulate reality, but rather to be reality. This is ultimately an issue of perception and psychology – where humans are trying to alter the experience that the brain is constructing and telling us what is happening. The puzzle thus entails driving the perceptual system, sensing and reconstructing reality, and enabling interaction within humans. Out of the six perceptual inputs that must be 'hacked' – vision, hearing, taste, smell, balance, and haptics – much ground on vision and hearing has been but need more progress in other senses (source: Kevin Kelly, Wired).

> "By the 2030s, virtual reality will be totally realistic and compelling and we will spend most of our time in virtual environments." – **Ray Kurzweil**
>
> "Immersive 3D content is the obvious next thing after video – **Mark Zuckerberg**

Exhibit 141: Pursuit of presence
Gained ground on vision and hearing senses, but need more progress in other senses: taste, smell, balance, and haptics



Source: AMD

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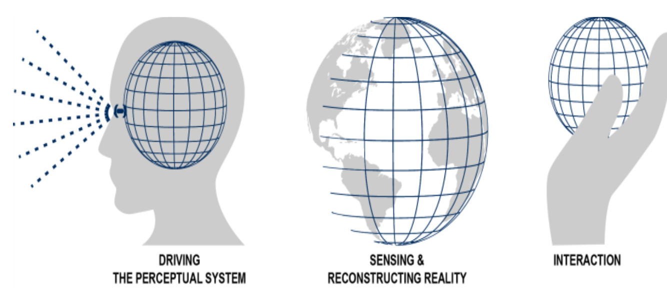
Exhibit 142: VR emulates presence
From driving the perpetual system to sensing & reconstructing reality to Interaction



Source: Oculus 2015, BofA Global Research

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Social media

Virtual hang-out spaces

Start-up company, AltspaceVR, is helping to transform 2D web content into fully immersive or holographic 3D experiences. Through the software, users are able to play games with one another and socialize in hang-out spaces completely in VR. The company recently teamed up with SensoMotoric Instruments to bring eye-tracking to VR in order to help avatars express non-verbal social cues.

Exhibit 143: AltspaceVR hang-out space
Users can socialize and play games with one another

Source: AltspaceVR

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Exhibit 144: Human avatars on AltspaceVR
Eye-tracking in VR helps avatars express non-verbal social cues

Source: AltspaceVR

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Entertainment: television, movies and music

Virtual and augmented reality have caught the attention of traditional media players of all formats. Content providers ranging from film (Disney) to television (Discovery Channel) to sports (Fox Sports) to music (Universal Music Group, Live Nation) to platform providers (Netflix) to newspapers (*New York Times*) have begun experimenting with immersive 3D experiences. Virtual reality could bring spectators directly into the movie, stadium, or concert hall where it would previously have been difficult or impossible.

Exhibit 145: Mixed reality
VR brings spectators directly into the movie, stadium, or concert hall, which would have been almost impossible previously

Source: Magic Leap

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Video leading the way in content

Video is already leading certain VR platforms, including smartphone-based ecosystems such as Samsung Gear VR. According to JV partner Oculus, 7 of the 10 most-used apps on Gear VR are video-based, and around 80% of all users are using VR video apps. Many major entertainment houses have begun embracing this trend. Disney has created its own VR app on the SteamVR platform to bring its own suite of movies directly to HTC Vive or Oculus Rift. The company has also signed a license agreement with Nokia to use its OZO 360 cameras to create 3D content. Similarly, Discovery Channel launched its own app, which includes popular shows such as *Shark Week*, *Deadliest Catch*, and *Mythbusters*, as well as *Seeker*.

Live events

VR/AR coverage of live events could amplify existing brands, while democratizing entertainment. Offering immersive "front row" seats at a sporting event, concert, or fashion show could be scalable and lucrative for businesses, while increasing accessibility for live events. California-based NextVR aims to bring live and on-demand VR content, and has covered everything from NHL and NASCAR to Coldplay concerts and CNN's broadcast of the Democratic and Republican debates. Concert promoter, Live Nation, announced earlier this summer that it would team up with NextVR to bring a steady supply of live concerts to VR headsets later this year. Viewers who experience events through immersive mediums tend to feel a deeper connection with the event than with traditional video, which could lead to higher engagement in the long run.

Exhibit 146: NextVR coverage of Monster Jam Monster Truck rally
360-degree look at what it's like to drive a 10,000 lb. Monster Jam truck

Source: NextVR

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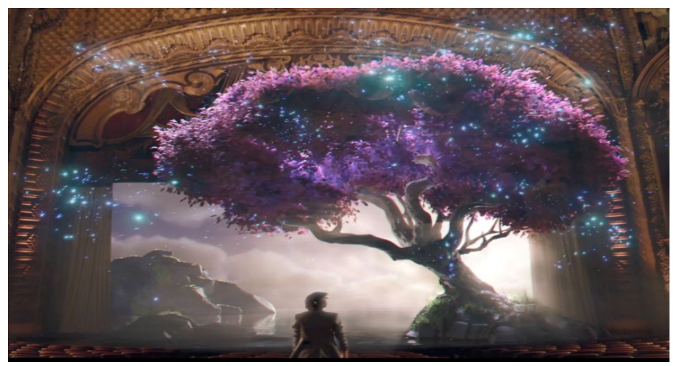
Exhibit 147: Theatre visualisation using Microsoft HoloLens
Members in audience can visualize all the special effects while enjoying live performances



Source: Microsoft

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Education

Nextgen adaptive learning

Total reality also has potential to fit into the EdTech adaptive learning ecosystem. Chinese game-maker NetDragon is developing VR-based educational material and deploying it in the province of Fujian. The company bought UK-based Promethean in November 2015 and acquired its base of 40mn students, 2.2mn teachers, and 1.3mn classrooms across 100 countries that have already taken up adaptive learning. In their vision, lessons change in response to students' reactions to the material, such as tilting of the head or even falling asleep. Additional quizzes, videos, and explanation can be added to increase understanding of the material or to liven up the lessonThe fundamental idea is based on adaptive learning, which has been around for many years. Once the software is perfected, the VR platform for adaptive learning could be scalable as VR hardware costs decline.

Exhibit 148: Sample AR classroom on EON Reality
Students get more hands-on experience while learning

Source: EON Reality

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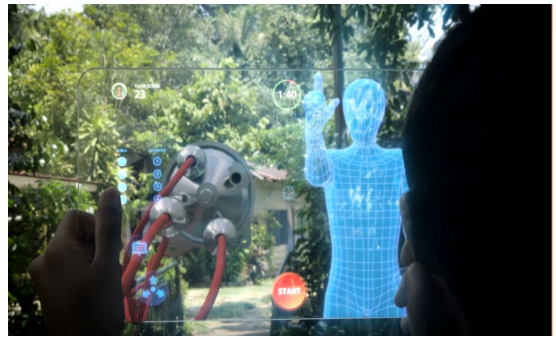
Exhibit 149: EON Reality rendition of instructional material
Full-size 3D models, Interactive 360° images, and 360° videos bring audience face-to-face with the subject matter



Source: EON Reality

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Case Western University: the augmented classroom

Universities have begun working with AR software, bringing 3D visualizations into the college classroom. Case Western Reserve University has teamed up with Microsoft HoloLens to create holographic anatomical images. Students can examine things like white-matter, fibres, and tissue in detail, or rotate organs to get a better view. Students can engage with professors in discussion even if they are hundreds of miles away. This provides immense advantages in the learning process. Case Western is now creating a full digital anatomy curriculum to push forth their AR initiative. This is not restricted to health classes. Astronomy students would be able to stand in the middle of colliding galaxies, and art history class could take place in the Sistine Chapel (source: Case Western Reserve University, Microsoft).

Exhibit 150: Anatomy class using HoloLens
Astronomy students would be able to stand in the middle of colliding galaxies and art history class could take place in the Sistine Chapel

Source: Microsoft

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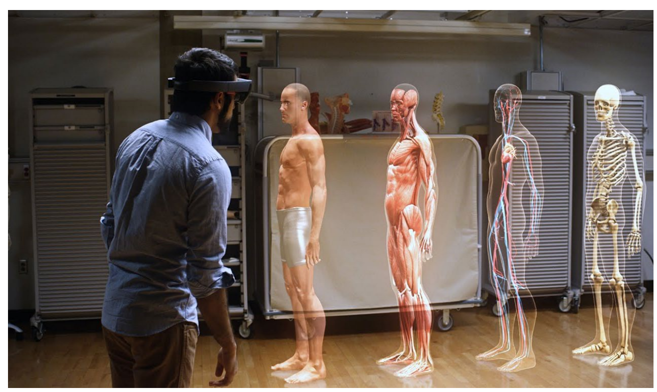
Exhibit 151: Anatomy class using HoloLens
Students can examine things like white-matter, fibres, and tissue in detail, or rotate organs to get a better view



Source: Microsoft

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4) GREEN TECH
Nextgen Batteries: enabling a cleantech rEVolution

- **What are they?** Batteries with increasing capacity to store energy and recharge more quickly and cheaply, enabled by improving chemistry and material sciences.
- **Did you know?** Battery manufacturing investment, both previous and planned to 2023, is >$150bn; market revenues could grow from $21bn in 2020 to >$350bn by 2030.
- **In 2020:** A battery capable of being used for >1 million miles was demonstrated, using "self-healing" technology to control lithium consumption.
- **By 2030:** EV battery demand is set to grow 28x compared with 2020 (per BofA APAC EV Battery team), to 4.5Twh, with demand for critical minerals such as nickel growing 140x over the same period.
- **Sectors affected:** Chemicals, Autos, Consumer Electronics, Power Storage

Next Generation batteries for a CleanTech revolution

Batteries have enabled several modern technologies and continue to advance driven by rising R&D, investment, and the scale of deployment. While initially dominated by consumer electronics end applications, improving chemistry and engineering have increased batteries' energy density, expanding their addressable markets and lowering the cost of their use for larger, more power-hungry, applications such as transportation and energy storage. This continued improvement, rapid cost reductions, and supportive government policy mean the scale of batteries required to 2030 and beyond is set to dramatically increase.

However, while the advancing technology of lithium ion in particular started this transition, there are limitations to widespread deployment of batteries. A combination of gating factors including cost, energy density, safety, and durability in particular mean that manufacturers need to make trade-offs (for example, in some industries battery life may be more important than quick charging). Improving chemistry and engineering can mitigate some of those barriers in the short term, but breakthroughs in technology and material sciences could do so at an accelerating rate in the mid-longer term. These could improve economic viability, change the structure and formation of future batteries, and ultimately expand their functionality to new use cases like ships and planes. This would not be possible at scale with the current state-of-the-art battery technology.

Several challenges still need to be overcome to take current battery breakthrough proposals from lab testing to industrialisation. However, rising demand, investment and the urgent need to meet climate action goals could accelerate feedback loops between cost reduction, energy density improvement and better-value propositions.

Mobility taking the Li-ion's share of batteries

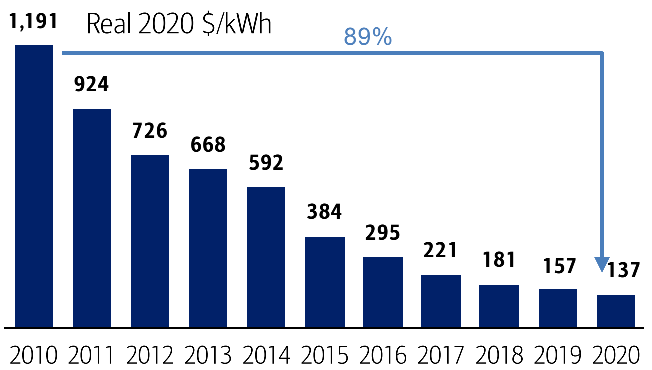
Investment in R&D and manufacturing continues

Rising investment in R&D is accelerating battery innovation and viability. Investment in prior and planned battery manufacturing to 2023 totals $150bn (source: Rocky Mountain Institute). In 2020 alone, total corporate funding of battery storage and smart grids more than doubled to $8.1bn from $3.8bn in 2019 (source: Mercom Capital).

Dramatic cost reductions increasing scope for batteries

Improving technology and increasing scale have enabled a rapid decline in the average price of lithium ion batteries. Pack prices fell 89% from 2010-20 to $137/kWh on average, with transportation increasing from 4% to 64% of battery demand over the same period. Higher demand for passenger Electric Vehicles (EVs) was the largest driver of this – accounting for over half of global lithium ion battery demand in 2020, despite just 4% of passenger car sales being fully electric (source: Bloomberg NEF).

Exhibit 152: Lithium ion battery prices fell 89% 2010-20
Improving technology and increasing scale have enabled a rapid decline in the average price of battery packs per kWh.



Source: Bloomberg NEF

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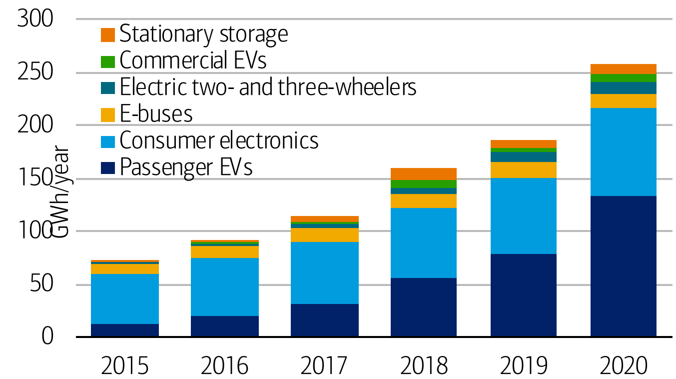
Exhibit 153: EVs have become the dominant end use for batteries
Passenger Electric Vehicles became the dominant application for lithium ion batteries in 2020, despite accounting for only ~4% of car sales



Source: Bloomberg NEF

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Battery breakthrough required for net zero

While the cost of lithium ion technology continues to come down, a technology breakthrough is probably needed to accommodate the level of demand required to reduce global greenhouse gas emissions in transportation, energy storage and beyond. Beyond the current technological limits, a combination of the scale, resources required, and politics suggest the cost decline observed during the past decade is not a given for the next decade without accelerating innovation. In summary:

- **Scale**: EV battery demand alone is set to grow 28x to 2030 vs 2020 (Source: BofA APAC EV Battery Team), and could double over 2030-2040 (Source: IEA). Economies of scale and emissions reduction regulation are likely to make the technology viable in other sectors, too, particularly energy storage for powering local grids and balancing.

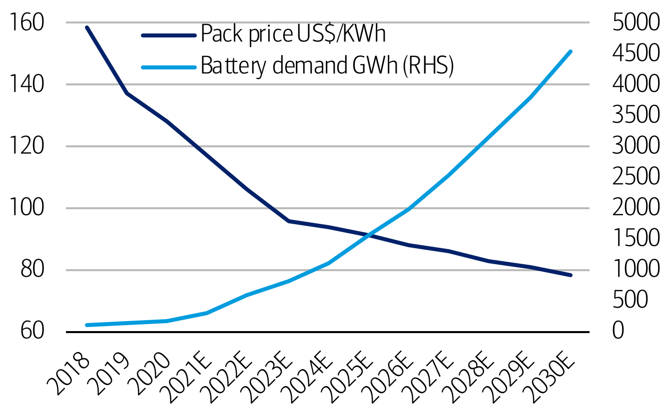
- **Resources** EVs use ~6x more minerals than combustion engine cars; the mineral demand from battery storage systems could grow 30x between 2020 and 2040 (source: IEA), but metals required more intensively in batteries such as nickel and cobalt could grow 140x and 70x, respectively, over the same period, assuming the same chemistry. Innovations in recycling, thrifting to alternative materials and chemistry that reduces the input volume of raw materials will become increasingly important.

- **Politics**: the sources and supply chains of the critical minerals required for batteries are geographically concentrated (e.g. the majority of cobalt originates from DR Congo, and lithium in Autralia & Chile per IEA). Constant supply (and price) cannot be guaranteed, as each region looks to deploy their use in batter**ies.**

2020s: 28x growth in EV battery demand, $350bn TAM

As per BofA APAC EV Battery team, the 2020s are projected to see an accelerated shift to Electric Vehicles as manufacturers launch new models underpinned by strong policy support and shifting consumer habits. Demand for batteries in EVs alone is projected to rise 28x vs 2020 to >4.5TWh in 2030, accommodating a 40-50% share of car sales going electric and creating an industry addressable market of $354bn vs $21bn in 2020. While battery pack prices are projected to fall a further 39% to 2030, the rate of reduction is far less than in the past decade. A bigger decline requires continued innovation towards a next generation of batteries that perform better on cost, resource intensity, and energy to increase the applications that can use batteries as a means of reducing emissions.

Exhibit 154: EV battery demand projected to rise 28x to 2030
Accelerating transition to EVs to create battery demand of 4.5TWh by 2030, but battery pack price reductions are decelerating (-39% to 2030)



Source: BofA Global Research

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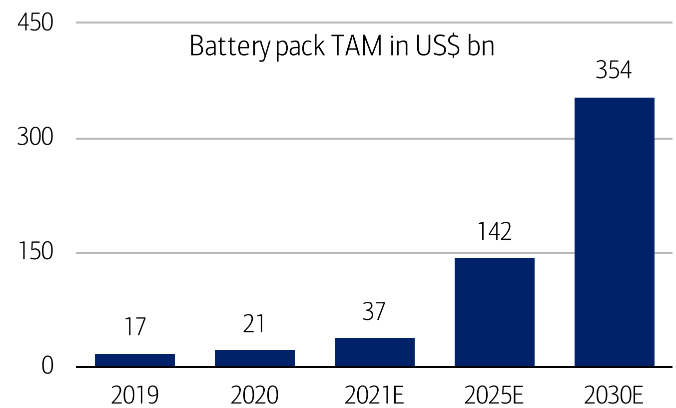
Exhibit 155: Global EV battery TAM to grow 17x to $354bn in 2030
Annual EV battery revenues are projected to rise from $21bn in 2020 to >$350bn by 2030



Source: BofA Global Research

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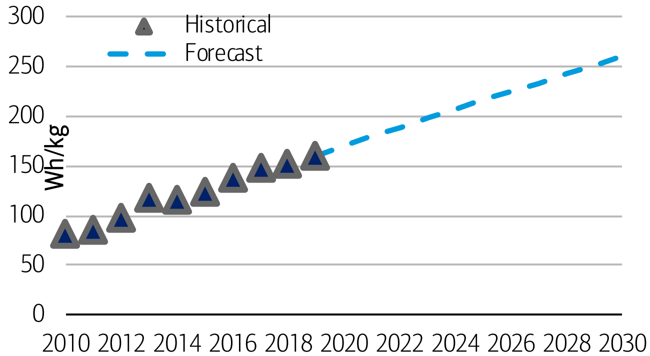
Energy densities rising – continuing the story requires innovation

The achievable energy densities of EV batteries have also increased dramatically since 2010 owing to R&D, innovation and investment, further incentivizing their adoption. Observed energy density rose 92% over 2010-20, enabling longer driving ranges as well as reducing battery prices. However, this average 7% annual improvement in energy density over 2010-20 is projected to reduce to 4% per year in 2020-30, and 3% per year in 2030-40 (source: Bloomberg NEF). 2020 actually saw a reduction in industry average energy density owing to a rising share of (lower energy density) lithium iron phosphate (LFP) batteries in China. This was partially linked to resource constraints and geopolitics given the strong government support for, and available manufacturing capacity of, LFP batteries in China.

Exhibit 156: Energy density of batteries is expected to continue to rise
Observed energy densities of batteries have improved to ~157Wh/kg in 2020 (+92% since 2010), projected to rise to >350Wh/kg by 2040



Source: Bloomberg NEF

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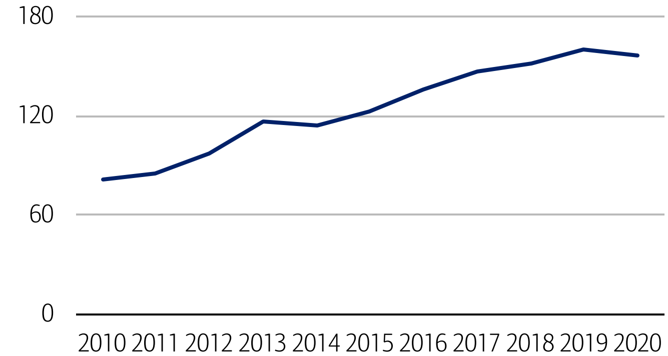
Exhibit 157: Recent density rise has slowed owing to chemistry choice
Average energy density dropped in 2020 owing to increasing share of (lower energy density) LFP batteries in China on cost, scale and resource grounds



Source: Bloomberg NEF

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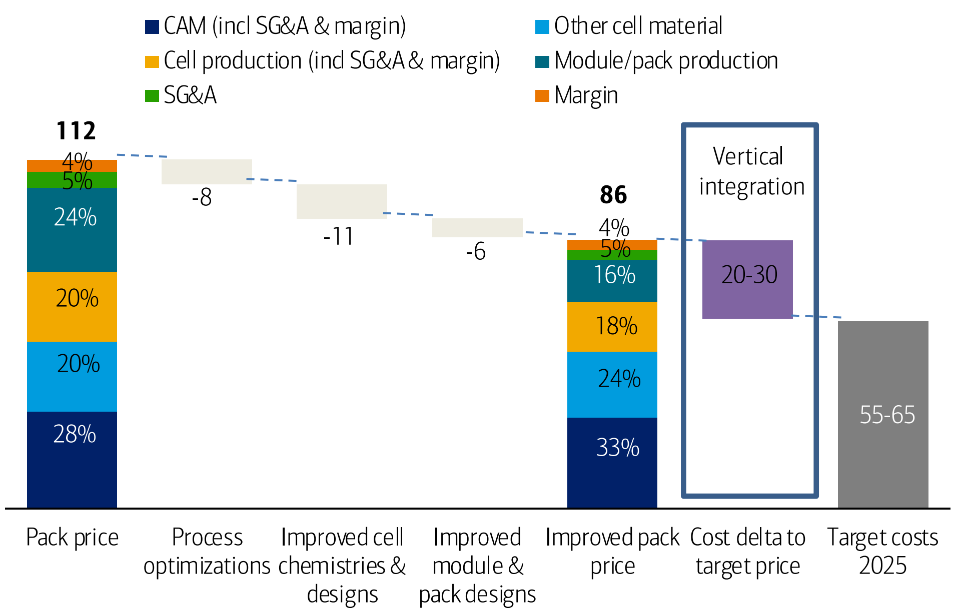
Short-term innovation focused on industrialization

Up to 2025, the cost of lithium ion batteries should continue to come down, thanks to a combination of advances in chemistry, improved cell/pack designs, and economies of scale in manufacturing. Roland Berger projects a combination that could roughly halve battery pack prices to 2025 on average, if manufacturers were to vertically integrate their production. Beyond that, notable cost reductions can only be achieved by disrupting the current technology.

Exhibit 158: Battery pack prices could halve with improved chemistry, engineering and integration
To continue the cost reductions of lithium ion battery packs would require a combination of improved chemistry and design, process optimisation, and vertical integration; up to 40-50% could be achieved



Source: Roland Berger

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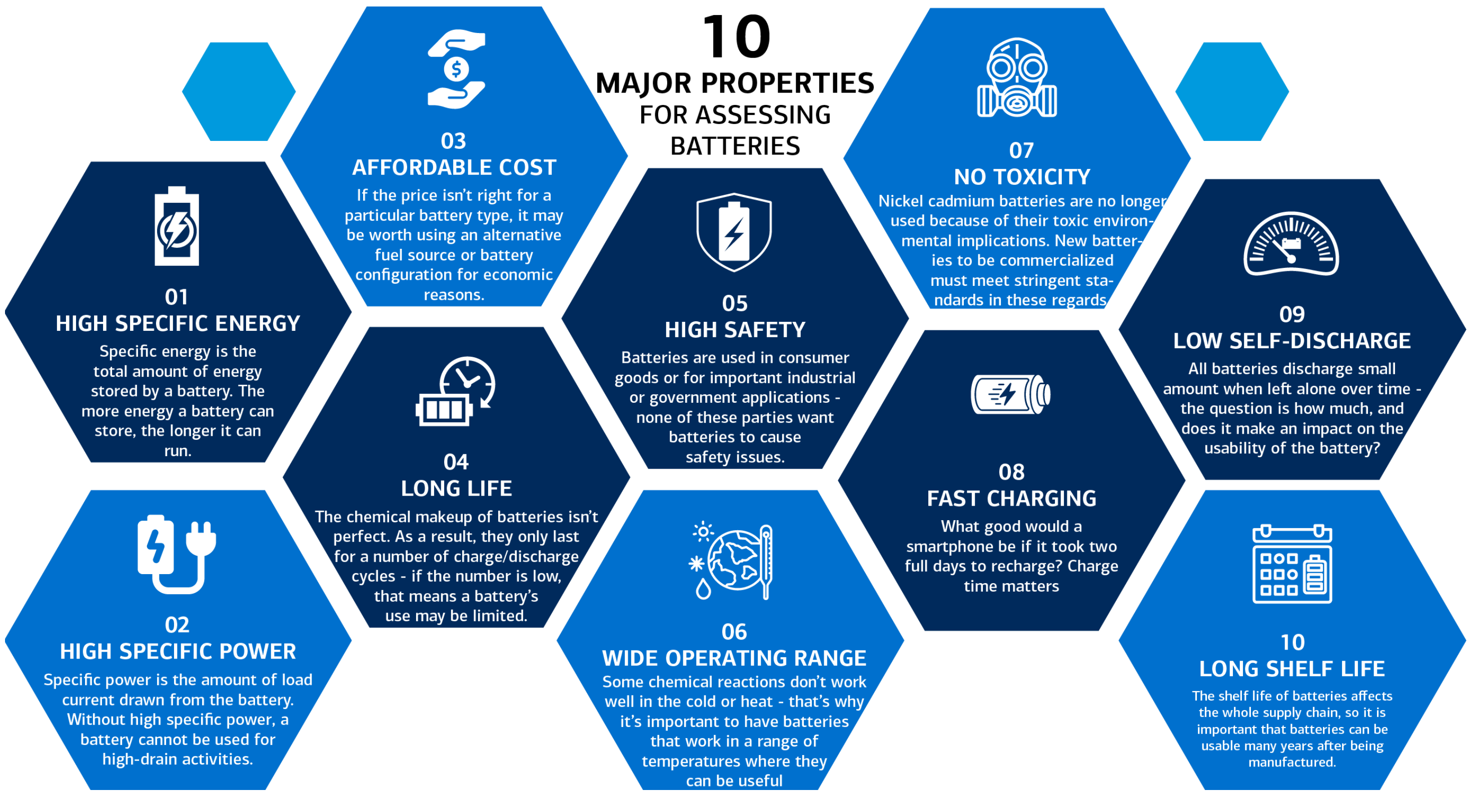
What is the “ideal” battery? Safe, cheap, and durable

Batteries are assessed on 10 key properties, in particular comparing the energy they can contain and how fast they can charge/release it, under what conditions (such as temperature or charging speed), and the relative cost and safety of doing so. The durability of the battery in terms of cycle/calendar life is also considered and varies depending on the chemistry and how the battery is used. A grid-level energy storage system needs to last longer than a battery in an EV, for example, but may not require such quick recharging capability or size/weight efficiency. Thus, a series of trade-offs are involved depending on the required functionality.

Exhibit 159: Battery attributes vary based on cost, safety, energy, durability, and charging. Innovation can influence them all

Battery chemistry and engineering influence 10 key properties to assess a battery's utility, from the energy it can provide under what conditions to its usable lifespan



Source: Visual Capitalist

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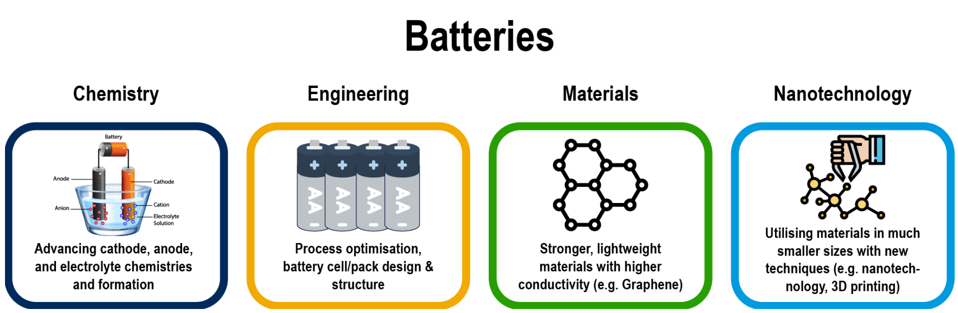
Next Gen batteries 101

While battery usage has increased dramatically in recent years, the basic four components of an anode, cathode, electrolyte and separator have remained constant since the first battery was created in 1799 by Alessandro Volta (the Voltaic pile). Three converging trends are enabling next-generation batteries: chemistry, engineering, and material science improvements. These are underpinned by increased funding and urgency, with batteries seen as a tool to mitigate climate change and as a cleaner power source to fossil fuels.

Exhibit 160: Battery Breakthroughs enabled by chemistry, engineering, material science improvements

Advancing chemistry mix of battery components, engineering of cells/packs, and utilizing materials in smaller sizes and greater consistency are key enablers of next generation batteries



Source: Bofa Global Research

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- **Chemistry:** the chemistry of each battery component continues to evolve, targeting improved performance on the above attributes. Each battery type uses different chemistry and materials depending on the desired properties and the conditions under which they will be used. Key trends under development include 1) increasing nickel content (at the expense of cobalt) in cathodes, 2) replacing graphite with silicon or lithium metal anodes, and 3) replacing liquid electrolyte with a solid alternative.

- **Engineering**: industrialising batteries with advancing engineering techniques is leading to improvements in battery cells, modules and packs. Embedding them within the structure of objects, for example, can increase efficiency and lower cost.

- **Materials:** manufacturers are now using stronger lightweight materials that have been previously unsuccessful industrially such as graphene, deploying new techniques such as nanotechnology to use the materials in new ways with more consistency, and experimenting with much smaller particle sizes (e.g. silicon nanowires, 3D printing techniques enabling thinner coating).

Future Batteries: Improving Cost, Performance, use cases

A combination of battery innovations are increasing their utility and applicability to new use cases, most in consumer electronics and mobility in the short term, but into higher power longer duration needs as the technologies mature and become more competitive with fossil energy alternatives. We highlight the key next gen battery technologies as:

- **Advanced Lithium ion** chemistries: increasing Nickel content in cathodes, replacing graphite with silicon in anodes, and “self-healing” technologies could enable a combination of increased energy density, fast charging, and longer durability of batteries. Nanotechnology and manufacturing advances could enable this.

- **Material switching**: replacing rarer/costlier materials such as lithium with relatively more abundant sodium/aluminium, or sulfur all offer potential for reducing cost; challenges remain on conductivity and density of the alternatives.

- **Solid State batteries**: replacing liquid electrolyte with a solid alternative, and lithium metal anodes (rather than graphite) could increase energy density and safety considerably, but challenges remain on cycle life and obtaining the materials at scale

- **Batteries as structures**: innovations to embed batteries within the structure of objects, e.g. battery packs rather than modules in the short term, and into the body of cars/planes/phones in the longer term could be enabled by using materials with conductivity and rigidity (e.g. carbon fibre)

- **Supercapacitors for “super batteries**”: advances in supercapacitors from using new materials such as graphene could make them effective alongside batteries in the short term to increase their performance and extend their usable life, and potentially competitive alternatives to batteries in the longer term.

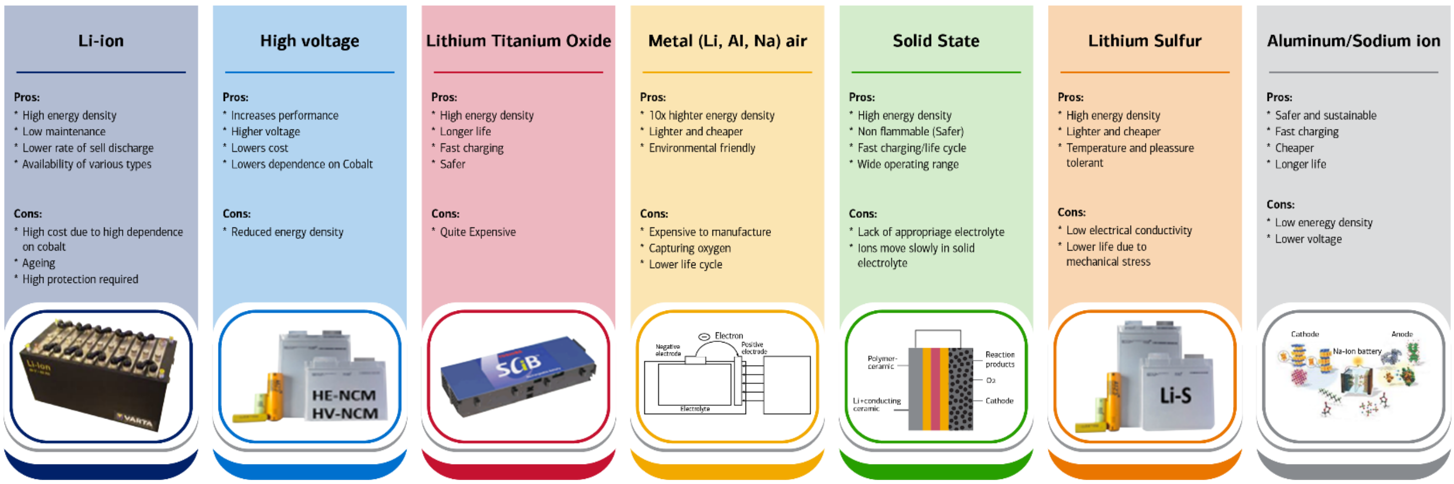
- **Future Energy Storage batteries:** as battery life, performance and cost continues to improve, a combination of technologies can extend their use into energy storage. Repurposing current lithium ion batteries for second life purposes as they’re retired from their primary use could enable new services such as vehicle to grid and powering homes. More larger scale grid balancing and long duration technologies such as flow batteries and high temperature batteries could offer power generation and storage alternatives to fossil energy in the long term as they mature.

Evolution of EV battery technologies

The accelerating transition to Electric Vehicles is a key driver in improving battery technology. The alternatives shown in below Exhibit 161 make use of different chemistries at varying stages of development, each having unique opportunities and current drawbacks to commercialization. Rather than a single chemistry emerging as the future "winner", it is likely that each can serve different use cases and customers depending on the requirements of future batteries and the costs required to achieve them.

Exhibit 161: Nextgen EV battery technology: several alternatives already exist and continue to evolve

An increasing number of chemistries are under development, each with different benefits & challenges and at varying stages of commercialisation. Li-ion (and higher voltage, lithium titanium oxide variants) are being commercialized, with metal air, solid state, lithium sulfur and sodium ion all at earlier stages of development



Source: Bofa Global Research

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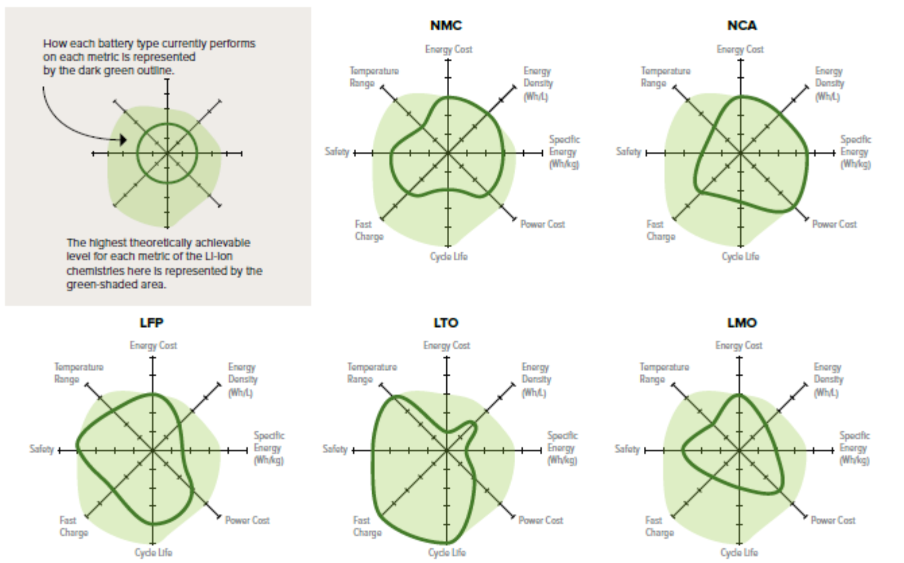
Not all lithium-ion tech is created equal

Unlike solar energy, for example, where the technology is fairly concentrated, batteries can use a wide variety of chemistries. Most of the variance to date has been based on the cathode materials used. The exhibit below shows the core 5 groups of lithium ion chemistries deployed, namely Nickel Manganese Cobalt (NMC), Nickel Cobalt Aluminium (NCA), Lithium Manganese Oxide (LMO), Lithium Titanate Oxide (LTO) and Lithium iron Phosphate (LFP). There are multiple derivatives of each based on the concentration of materials used. Their performance characteristics vary. Each chemistry has a series of trade-offs and limitations with regards to performance, considering energy, power, temperature range, safety, charging and cycle life.

No silver bullet with current Li-ion; trade-offs are required

As the below Exhibit shows, an NMC/NCA battery can provide the highest specific energy/density, but for a lower cycle life or temperature operating range than LFP or LTO batteries, for example. Chemistry choice is also influenced by the availability of raw materials, their cost, and ease of manufacturing, leading to varying strategies from manufacturers depending on what they're developing – optimizing for longer ranges with NMC vs entry-level batteries with LFP chemistries, for example.

Exhibit 162: Battery performance attributes vary by achievable energy, cost and cycle life
Conventional lithium ion technologies continue to improve, but each chemistry has limitations. NMC/NCA have a higher energy density, but LFP/LTO improved safety and durability, for example



Source: Rocky Mountain Institute

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Advancing lithium ion: high nickel cathodes and silicon anodes

Further increases in the energy density of lithium ion technologies beyond pack/module efficiency require improvements in the chemistry. Current state-of-the-art lithium ion batteries have seen continued iterations of cathode active materials (CAM) successfully commercialized, but anodes and electrolyte formation have stayed largely graphite- and liquid-based, respectively. Innovations are underway to address this, however, particularly with silicon or lithium metal-based anodes initially. Solid-state electrolytes thereafter could enable a doubling of energy density if they can be successfully manufactured.

The approaches to this have varied depending on the battery component:

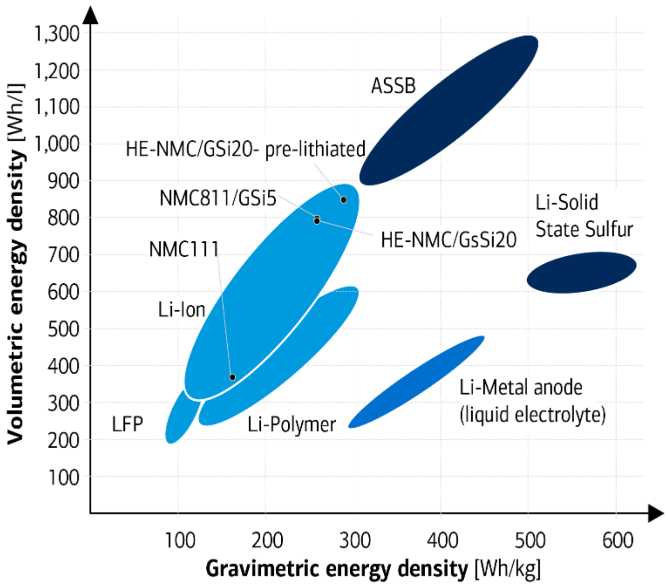
- Cathodes: the first such improvements have focused on the cathode active materials. Innovation has focused on increasing nickel content, reducing cobalt, and merging chemistries between NCA/NCM to increase energy density (NCMA).

- Anodes: replacing graphite with increasing silicon content, the key innovation being to enable this without swelling, via advanced particle design and 3D formation (e.g. Sila Nanotechnologies and Enovix). Combining these technologies could see energy density increase by ~20% vs current state-of-the-art high nickel cathodes (NCM811).

- Electrolyte: substituting current liquid electrolytes for gel polymer and solid (sulphide or oxide) alternatives can increase achievable energy density in the same volume (2-3x vs current lithium ion). It also improves safety, by removing a flammable liquid. However, commercializing a material that is as conductive as liquid alternatives and compatible with the vastly growing lithium ion manufacturing capacity is the key challenge, as is achieving fast charging and sufficient number of charging cycles.

Exhibit 163: Comparison of battery energy densities

Current Li-ion with nickel rich cathodes can reach >600Wh/l, with new chemistry potentially increasing >800Wh/l with silicon anode



Source: Roland Berger

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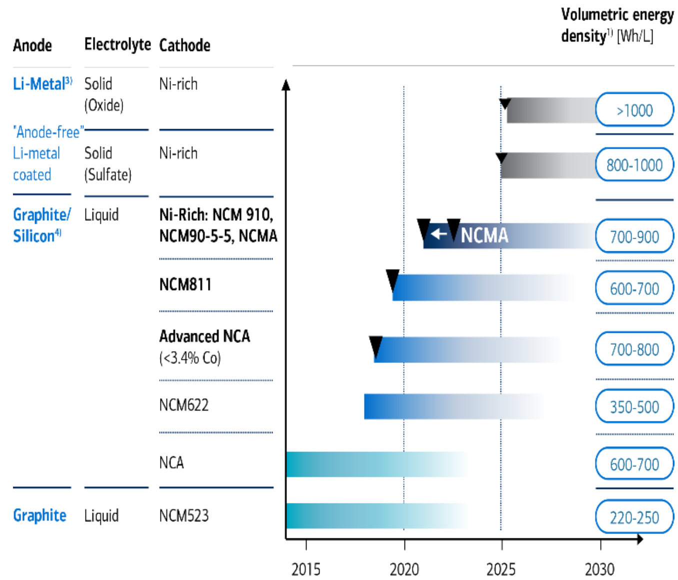
Exhibit 164: Solid-state batteries could double energy density

While Li-ion batteries are reaching their technological limit, solid-state batteries could improve density by omitting anode active material



Source: Roland Berger

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Self-healing long-life technology: the million-mile EV battery breakthrough

Innovation continues to target elongating battery life, particularly important for high-mileage transportation needs and long-duration energy storage projects that could use batteries. Recent breakthroughs claim to have achieved chemistry improvements, enabling EV batteries to be used for >1m miles. Automakers Tesla and GM say they tested their development in 2020, and battery maker CATL claims to have already created and be in a position to produce a battery capable of lasting >1.2m miles over 16 years, at a cost premium of 10% to current batteries. It used "self-healing long-life technology" that controls the consumption and decay of lithium applied to all battery components to prevent chemical activity when the battery is not being utilised, extending battery life. Bionic electrolyte technology enables electrode protecting films improving cycling and storage performance for example, and could be applied to both NMC and LFP chemistries per CATL.

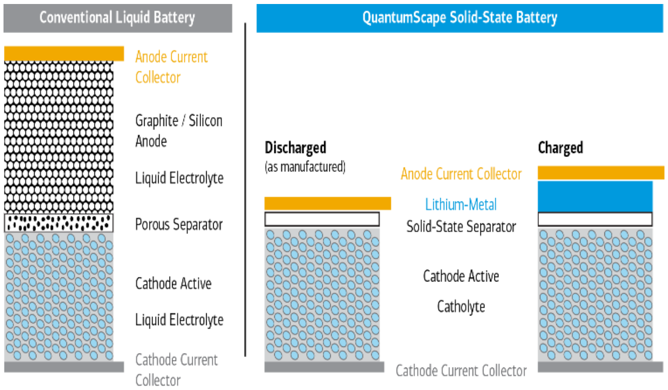
Current EV battery warranties cover 100-150,000 miles over 8 years by comparison. Such batteries could outlast the vehicles if used for private cars, after which they could be deployed in second-life energy storage applications or for another vehicle. Alternatively they could be used for far higher utilization applications such as taxis or grid balancing technologies like Vehicle to Grid (V2G).

Beyond lithium ion: solid-state batteries

To achieve energy densities beyond this point could require solid-state batteries. Their key difference rests in the use of a solid instead of liquid electrolyte. This brings a number of key benefits: 1) it reduces space required (thus increasing energy density), 2) it removes potentially flammable liquid, improving safety, and 3) it removes the need for pack cooling as a result (reducing cost). Key obstacles remain to commercialization, however, notably the formation of dendrites (needle shape formations) when charging that can pierce and short the cells, the relatively lower conductivity of solid electrolytes to date requiring advanced materials not commercially available, specialist production lines (e.g. dry/pressurized, varying compatibility with the increasing lithium ion manufacturing capacity), and lower cycle life or charging performance. Despite these challenges, potentially considerable energy density that could be realised.

Exhibit 165: Ceramic separator enabling lithium metal anodes

Quantumscape announced its solid-state batteries using ceramic separators would be on the market in cars by 2024



Source: Quantumscape

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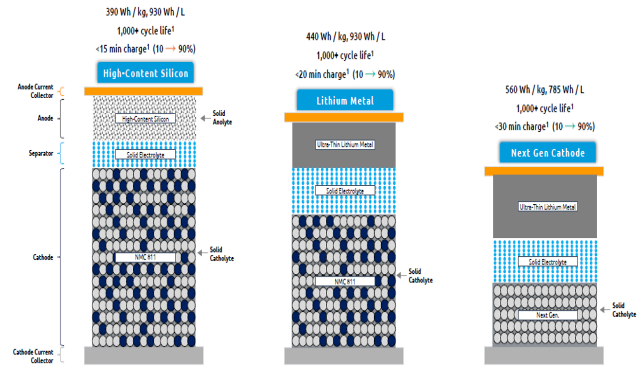
Exhibit 166: Solid Power: platform approach to solid state

Solid Power is developing high-content silicon anodes for initial compatibility with solid-state electrolyte – expected to be at validation stage by 2023. Next Gen cathodes could enable higher energy density for lower mass, but are still at R&D stage



Source: Solid Power

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"We don't think that any cell producer or carmaker is not looking at solid state batteries right now....The technology is just too hot to ignore it" *Christoph Neef, senior scientist at Fraunhofer Institute for Systems and Innovation Research, May 2021*

Lithium sulfur batteries

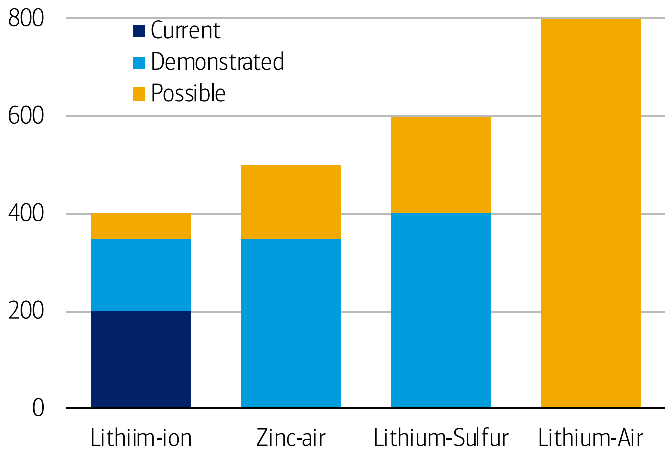
Lithium sulfur batteries have a lithium anode and a sulfur carbon cathode, and could provide high energy density at lower cost. The low atomic weight of lithium and moderate weight of sulfur make the Li-S batteries relatively lighter too. Li-S batteries could succeed Li-ion batteries because of their high energy density and reduced cost due to the use of sulfur (instead of cobalt). The Li-S batteries could also be coupled with solar panels to increase their recyclability. Currently, NASA has invested in solid-state Li-S batteries to power space exploration. On the downside, Li-S batteries have low electrical conductivity, thereby requiring extra conductive agents, which could increase the weight and stress on the battery pack. Current prototypes have lower cycle life as a result: thus far, charging a Li-S battery causes a build-up of chemical deposits that degrade the cell and shorten the lifespan.

Metal air batteries: getting batteries close to hydrocarbon energy density?

Metal air batteries have a pure metal anode (lithium, aluminium, zinc or sodium) and an ambient air cathode (mostly oxygen). They have a power density close to that of gasoline. It is a type of fuel cell battery that utilizes oxidation of a metal at the anode and reduction of oxygen at the cathode to produce electricity. Pairing metal and oxygen (from the air) can theoretically lead to electrochemical cells with the highest specific energy. Research projects such as Argonne National Laboratory suggest 5x more energy can be achieved than for a Li-ion battery, thus it is one of the most sought-after battery breakthroughs. The metal-air battery is expected to be light in weight as the cathode that weighs the most is made up of air. However, there are many challenges such as capturing enough volume and purity of oxygen from air, battery recyclability and lifecycle. Being able to create the complex packaging and air breathing interfaces in the cell required to enable them to recharge is also a key challenge. Improvements in zinc-air and lithium plating could mitigate this, but commercialization will also depend on significant cathode improvements.

Exhibit 167: Next Gen battery energy density outlook

Alternative battery chemistries to lithium ion could double achievable gravimetric energy density with further breakthroughs



Source: Rocky Mountain Institute, denotes Wh/KG energy density

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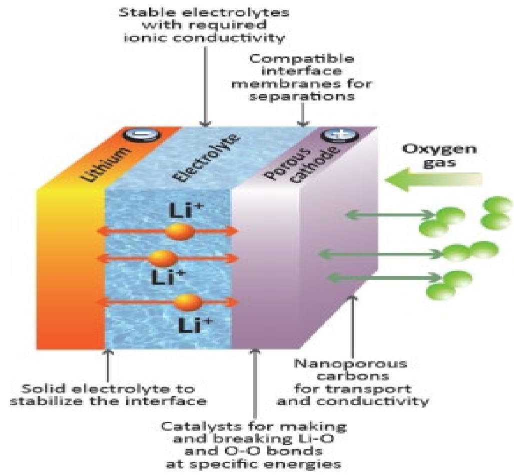
Exhibit 168: Lithium air batteries

Replacing current lithium ion cathodes with a porous alternative that can use oxygen as the reactant can theoretically achieve 4-5 the energy capacity at lower cost. Power output, safety and cycle life are key challenges



Source: Ecologic Institute

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Sodium/aluminium ion batteries: switching to abundant/cheaper raw materials

Alternatives to lithium ions can be used in batteries as the charge carriers, such as sodium or aluminium. While lithium offers higher energy density, the use of such alternatives lowers cost, increases safety as they are less flammable, and lowers dependence on relatively precious metals such as lithium/cobalt found in current Li-ion chemistries. Sodium is much more abundant, for example. Chinese battery manufacturer CATL recently launched a sodium-ion battery prototype (July 2021), achieving energy densities of up to 160 Wh/kg – relatively lower than current Li-ion but capable of faster charging of up to 80% capacity in 15 minutes, and performing better in lower temperatures.

Beyond chemistry: structural & material breakthroughs

Cell to pack and cell to chassis: the end of the battery pack?

Alongside cell chemistry improvements are methods to integrate battery cells directly into battery packs to increase energy efficiency and lower costs. Cell to pack technologies can eliminate or simplify battery module structures. Usually battery cells are clustered into modules, and then a cluster of modules is installed into a larger battery pack. Removing the module can save space/weight and thus allow for more energy in the same space. Tesla and CATL announced plans to deploy this in 2021, and BYD is already doing so with Blade batteries. According to CATL this can increase gravimetric energy density by 101-15% and volumetric energy density by 15-20% for the same battery system. It also reduces the number of parts in a battery pack by 40% and increases production efficiency by 50%.

The key rationale behind this is improving energy density in the short term, but the trajectory of the technology is evolving towards cell-to-chassis / cell-to body techniques that also eliminate the need for dedicated battery packs, instead integrating cells within the structure of objects such as a vehicle chassis. Tesla demonstrated this at its 2020 battery day and CATL aims to commercialize this before 2030. If achieved, not only could this enable higher energy density, but it could begin to enable performance feedback loops within EVs by reducing weight, thereby the volume of energy required to travel the same distance, and therefore cost. This could accelerate the crossover point for cost parity of heavier vehicles in particular by reducing the battery size/costs they would require to electrify.

Massless energy storage: integrating batteries into structures

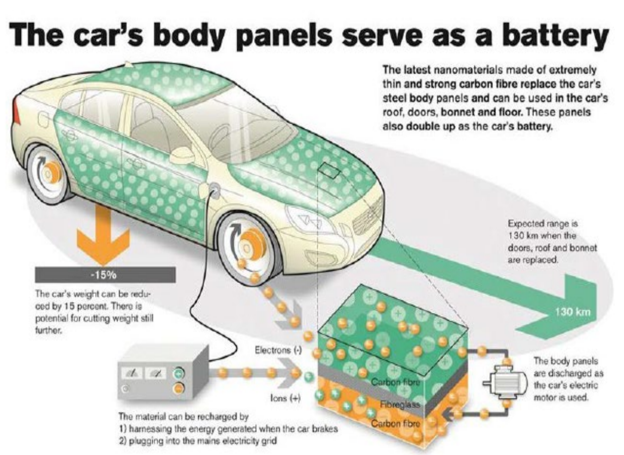
Further development of the technology to integrate batteries into the structure of objects is paving the way for "massless" energy storage in vehicles and other technologies. Current batteries account for a large proportion of vehicle weight without fulfilling any load-bearing function – the batteries in a Tesla Model S for example weigh >500kg, a quarter of the total vehicle weight. Integrating batteries into the structure of objects could remove that incremental weight of batteries (hence the term "massless" energy storage), having the effect of 1) reducing the volume of stored energy required to power the vehicle, and 2) reducing the raw material resource intensity of the vehicles.

- **What is it?** Integrating a battery within the structure of an object, using materials that perform both energy storage and load-bearing capability.

- **How does it work?** Using materials that can offer both rigidity and conductivity such as carbon fibre as an anode and/or cathode, ultra-thin separators and electrolytes that can perform mechanically and electrochemically.

- **When might it be commercialized?** While testing of the technology has been ongoing since 2007 (initially by the US Army Research Laboratory), challenges remain in achieving the required performance to compete with current technologies in terms of energy density. Recent research by Chalmers University (March) demonstrated a structural battery with energy density of 24 Wh/KG (~20% of current lithium ion batteries) but with potential to increase to 75 Wh/kg with the use of further innovation and new materials. Thus initial applications could be suited to consumer electronics, and scaled up for transportation and aerospace use thereafter.

Exhibit 169: The car's body panels could serve as a battery
Using thin lightweight materials safe enough to be incorporated into the structure of vehicles could enable the body of a car to double up as its battery



Source: Rocky Mountain Institute

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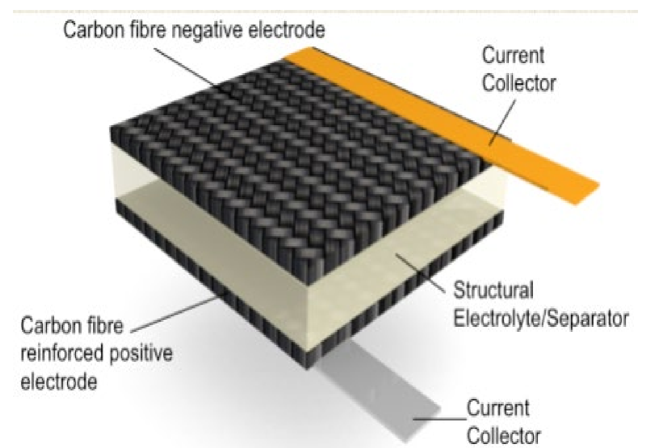
Exhibit 170: "Massless" energy storage breakthrough
Chalmers University of Technology demonstrated a structural battery in 2021 with an energy density of 24 Wh/kg using carbon fibre as a cathode, LFP coated aluminium foil anode and a fibreglass electrolyte separator



Source: Chalmers University of Technology

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> "Previous attempts to make structural batteries have resulted in cells with either good mechanical properties, or good electrical properties. Using carbon fibre, we have succeeded in designing a structural battery with both competitive energy storage capacity and rigidity … The next generation structural battery has fantastic potential. If you look at consumer technology, it could be possible within a few years to manufacture smartphones, laptops or electric bicycles that weigh half as much as today and are much more compact, and in the longer term is conceivable that electric cars, planes and satellites will be designed with and powered by structural batteries", *Leif Asp, Professor at Chalmers University of Technology*.

NanoTechnology for extreme fast charging (XFC)

Varying anode chemistry can also enable extreme fast charging (XFC). Current (graphite) anodes are stable at normal charging rates but face high electrical resistance – fast charging can cause dendrites on the anode surface, damaging the cells. Replacement with materials such as silicon/tin can alleviate that, allowing faster conductivity. However, nanotechnology and new materials are required to enable the use of smaller-sized particles. These can give more area to penetrate the active material, and lower resistance and heat.

Storedot is a start-up targeting the use of such technology with the goal of fast-charging smartphones and EVs capable of charging in 60 seconds and 5 minutes, respectively. They demonstrated the capability on an electric scooter in 2019, which fully charged in 5 minutes. While initial trials continue successfully in research labs, the key challenges for commercializing XFC are: 1) procurement of the required materials at scale given the infancy of supply chains, 2) the technical ability to manufacture them at scale, and 3) the functionality of the cells: ensuring safety by reducing heat/resistance, and elongating the cycle life of batteries under such charging conditions.

> "Today the supply chain of nano materials for metalloids, is basically non-existent. There's no real production in large volume of nano particles of metaloids, such as silicon. We have established a group where we can buy very cost-effective silicon, which is very cheap, grind it and mill it to a consistent 400-, 500-, or 600-nanometer sized particle that would enable us to achieve the fast charge", *Doron Myersdorf, CEO StoreDot Jul 2020 per ASME* .

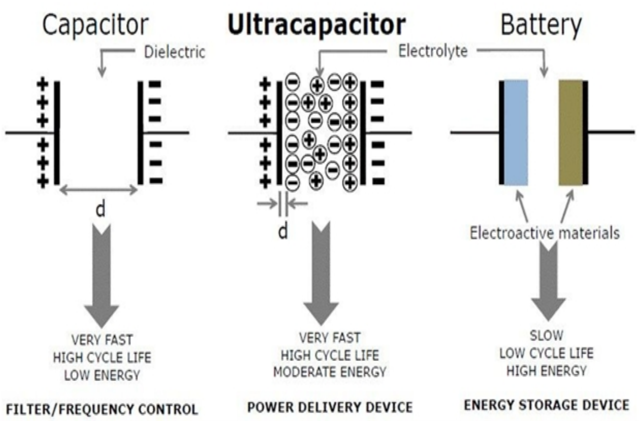
Supercapacitors: future of hybrid energy systems?

Like batteries, capacitors store electricity but do so statically rather than chemically. While they are far less energy-dense than current batteries, they can charge/discharge far more quickly, and last much longer. They are ideal for small bursts of power. For longer-duration power or energy, they are not as competitive as batteries. R&D and material science innovation could bridge some of the gap, and enable the use of "supercapacitors" instead of, or in parallel to, batteries. While the supercapacitor market was worth $3bn in 2019, it could grow to $17bn by 2027 according to Allied Market Research.

A capacitor has two conductive surfaces (plates) separated by a relatively thick dielectric separator. Supercapacitors instead have plates coated in an electrolyte separated by an ultra-thin insulator. The use of graphene as this coating can enhance energy storage capacity by vastly increasing surface area. University College London and the Chinese Academy of Sciences demonstrated that flexible graphene supercapacitors can store 10x more energy than existing supercapacitors in a 2020 proof of concept, claiming the highest reported energy density for supercapacitors to date at >88Wh/l. This is still only 10% of the energy storage capability of advanced lithium ion, however. It would need to increase much more significantly to offer a viable replacement for transportation unless consumers are willing to accept far lower ranges for faster charging.

The supercapacitors deployed in transportation thus far tend to be in hybrid systems in parallel with a combustion engine or battery. Lamborghini's Scion, for example, uses one for short initial bursts of acceleration, and recharges via a regenerative braking system. Using supercapacitors alongside lithium ion batteries could double or triple the life of batteries (source: NaWa Technologies), given the supercapacitor could take care of acceleration and energy recovery, the stressful part of a battery's life. Other potential benefits to use alongside EVs include: 1) the longer cycle life potential (up to 1m vs 3,000-5,000 of batteries per NaWa Technologies), 2) potential to decrease the battery size/weight by adding an alternative power source (by up to 1/3 without loss of range), and 3) the lack of rare minerals, making them attractive to use in parallel with battery systems.

Exhibit 171: Differences between capacitors, supercapacitors, batteries
While supercapacitors can store less energy than batteries, their ultra-fast charge/discharge could work in parallel with existing battery systems to elongate their usable life and reduce degradation



Source: Engineering.com

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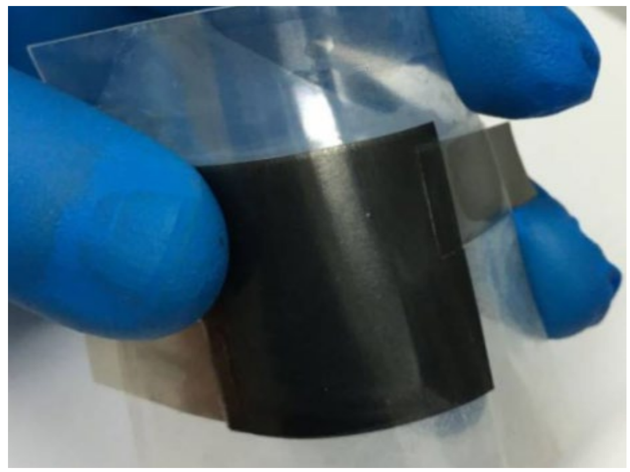
Exhibit 172: Graphene supercapacitors for increased energy storage
Supercapacitor research has shown that using graphene-coated materials can increase energy density 10x vs current supercapacitors



Source: University College London

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"Supercapacitors don't store as much energy, but their response is instantaneous. So, a supercapacitor could handle acceleration and energy recovery under braking — taking care of the stressful part of a battery's life – possibly doubling or tripling a battery's life expectancy", *Ulrik Grape, CEO NaWa Technologies*

Future Energy Storage Batteries: go with the Flow, and high temperature

Flow batteries use externally stored fluids to generate electricity as they flow past each other. Vandium redox flow batteries are the most common: an electrolyte of vanadium and sulfuric acid flows over carbon polymer electrodes. They can be expanded to scale using larger tanks, but have a relatively poor energy to volume ratio and are heavy, thus used for stationary applications. Their reducing cost and durability though means they can outcompete lithium ion in some cases for long lifetime use cases, and are being considered for new applications like fast EV charging – drawing power from the flow battery rather than the grid, saving sometimes costly grid upgrades.

High temperature batteries such as liquid metal could also provide low cost, long duration grid balancing, with components such as the electrolyte only becoming active at high temperatures, reducing degradation. They could provide energy shifting/peaking capacity safer (owing to non-conductivity/flammability at room temperature), cheaper (using less expensive materials: 1/3 of the cost of NMC li-ion technologies per Ambri) and more durable than alternatives such as lithium ion.

Challenges: technical, geopolitical, and materials-related

While most companies are working on optimizing the chemistry mix in Next Gen batteries, beyond that several recurring technical, materials, and geopolitical-related challenges still hold back commercialization of many battery breakthroughs.

1. **Technical & Engineering**: being able to replicate advanced chemistry and manufacture at scale is a key challenge limiting Next Gen batteries beyond lab testing, sometimes requiring optimized conditions such as dry rooms / pressurized cells.

2. **Materials**: most battery breakthroughs require a new way of utilizing, manufacturing or interacting with materials not yet commercialized in batteries. While they offer potential, extracting and/or deploying these at scale in the required formation poses challenges. These could be mitigated with advanced hardware such as 3D printing to interact with them more efficiently or at much thinner layering/coating.

3. **Geopolitical**: battery chemistry and industrialization are increasingly impacted by geopolitics. Metals required for batteries are concentrated in geographical regions (e.g. cobalt in Congo, lithium in Chile). Nations are setting diverging policy that could mandate that batteries must use locally sourced/recycled materials to avoid tariffs (e.g. the EU's Battery directive) and reduce the carbon footprint, or could even influence their extraction altogether (e.g. deep sea mining).

OceanTech: blue economy powering our aquafuture

What is it? Advanced technology industry focused on products that work in or use the ocean.

The answer to: 'How do we increase sustainability of the ocean economy while harnessing its benefits?'

Did you know? Ocean covers 71% of the planet's surface and contains 97% of the planet's water, yet more than 95% of the underwater world remains unexplored

By 2030: The global ocean economy could reach a gross value of around US$3tn (roughly equivalent to the size of the German economy in 2010)

Market size: US$1.5tn in 2010 growing to US$3tn by 2030E

Sectors affected: Agriculture, future food, oil & gas, renewables, waste, water, big data & AI, biotechnology, safety and mining

How much can the ocean economy grow by 2030?

The ocean economy's output in 2010 (base year for the calculations) is estimated at US$1.5tn or approximately 2.5% of world gross value added (GVA) which is roughly equivalent to the size of the Canadian economy that same year. However, by 2030, the global ocean economy could reach gross value-added of around US$3tn (roughly equivalent to the size of the German economy in 2010), following the business-as-usual scenario. The value-added of some ocean industries is set to grow faster than the world economy: for example, marine aquaculture, capture fisheries, fish processing, offshore wind, and port activities. Employment in ocean-based industries is set to be more than 40mn by 2030 (roughly the size of Germany's labour force) with especially rapid employment growth occurring in marine aquaculture, fish processing, offshore wind and port activities. This makes it almost inevitable that pressures on the ocean's natural assets will increase, as demand continues to grow on marine sources of food, energy, minerals, leisure pursuits and so on (OECD 2016).

Exhibit 173: The ocean economy includes established and emerging industries

Aquaculture, renewable energy, seabed mining, biotechnology etc are some of the emerging ocean technologies

Established	Emerging
Capture fisheries	Marine aquaculture
Seafood processing	Deep and ultra-deep water oil and gas
Shipping	Offshore wind energy
Ports	Onshore renewable energy
Shipbuilding and repair	Marine and seabed mining
Offshore oil and gas (shallow water)	Maritime safety and surveillance
Marine manufacturing and construction	Marine biotechnology
Maritime and coastal tourism	High-tech marine products and services
Marine business services	Others
Marine R&D and education	
Dredging	

Source: OECD (2016), The Ocean Economy in 2030

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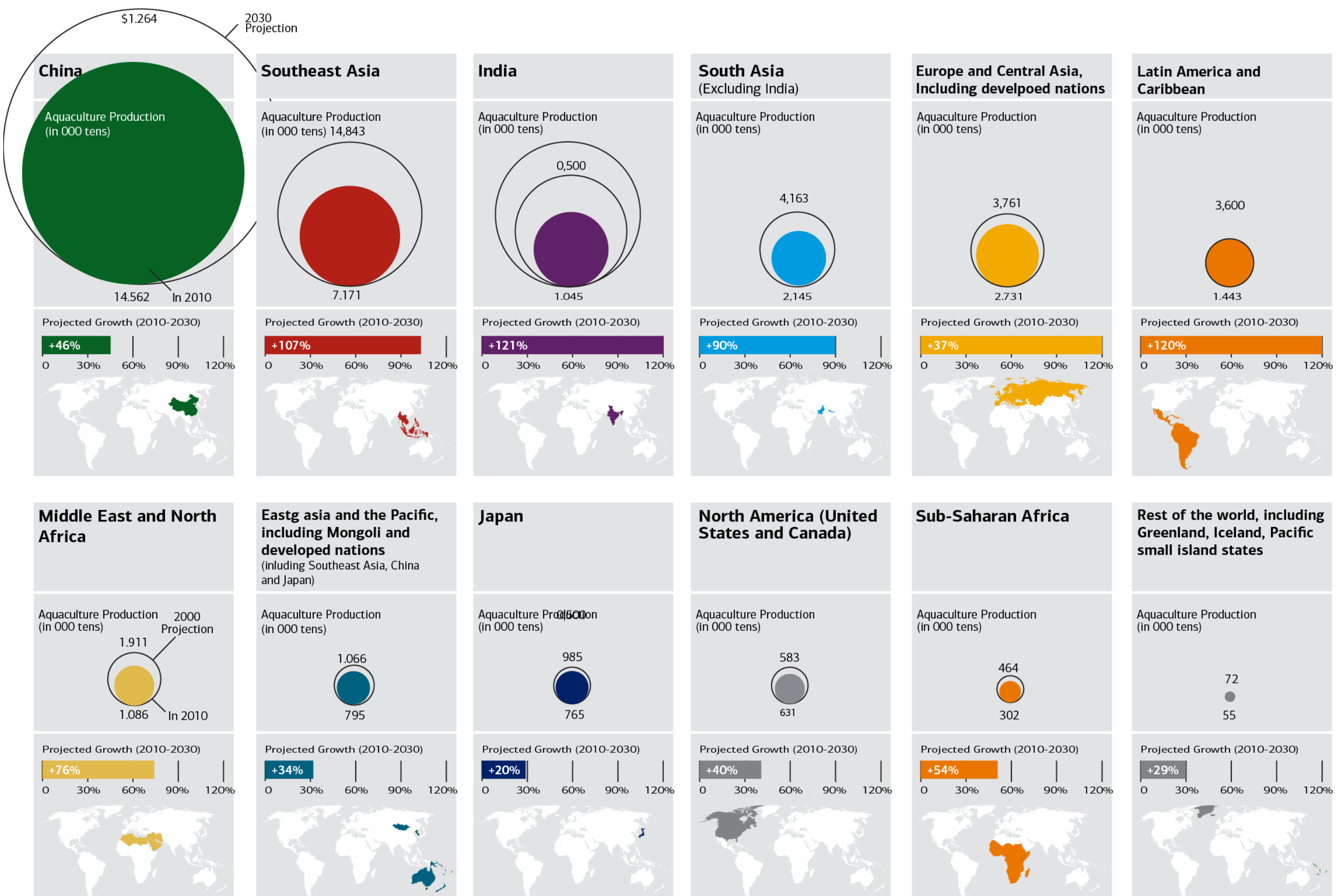
Marine aquaculture: seafood for the future

> The world's fish consumption is predicted to increase by ~20% by 2030 (FAO, 2020)

Marine aquaculture (also referred to as mariculture) is the farming – the seeding, breeding, raising and harvesting – of ocean species including fish, mollusks, crustaceans, and aquatic plants. This practise can take place onshore with tanks and ponds, or in the open ocean with cages and longlines along the seafloor or suspended in the water column. Most aquaculture is produced in fresh-water systems, but farming in the marine environment is becoming a more attractive option as competition for land and fresh water resources increases.

> Aquaculture is now the fastest-growing form of food production on the planet, growing at an annual rate of 6% (Nature Conservancy, 2017)

Exhibit 174: Aquaculture production and projected growth from 2010-30
India is expected to have the highest projected growth at +121% from 2010-30



Source: World Bank, Fish to 2030 (2013)

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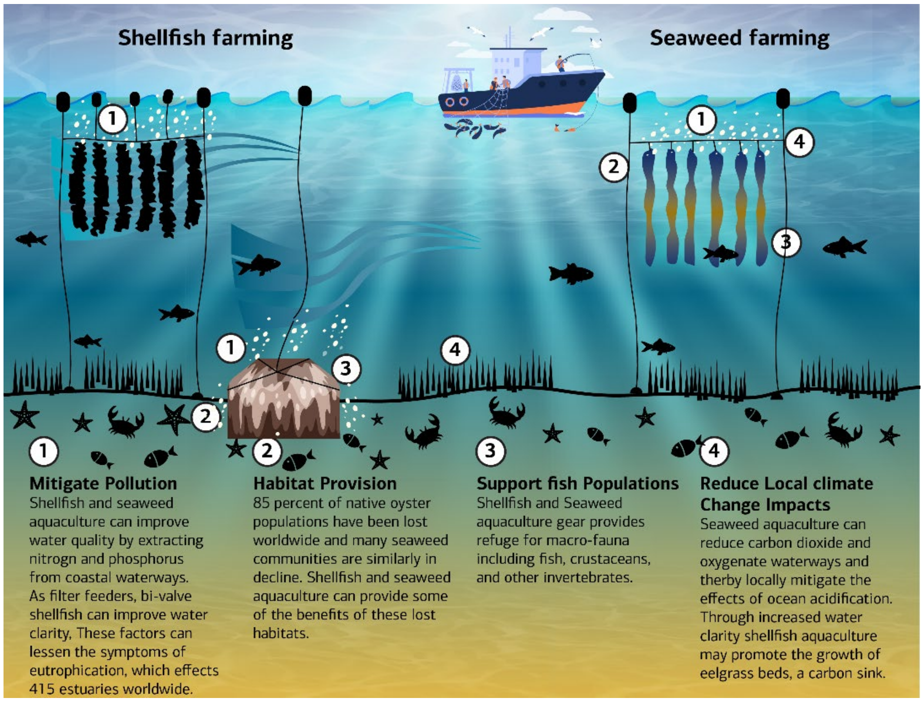
Ecosystem benefits of aquaculture

Coastal ecosystems are threatened by coastal pollution, loss of habitat and overfishing. When done in the right way and in the right places, commercial aquaculture can accelerate ecosystem recovery in addition to providing sustainable seafood and green jobs in coastal communities.

Exhibit 175: Ecosystem benefits through shellfish and seaweed farming
Mitigate pollution, Habitat provision, Support Fish populations, Reduce local climate change impacts



Source: Nature Conservancy 2017

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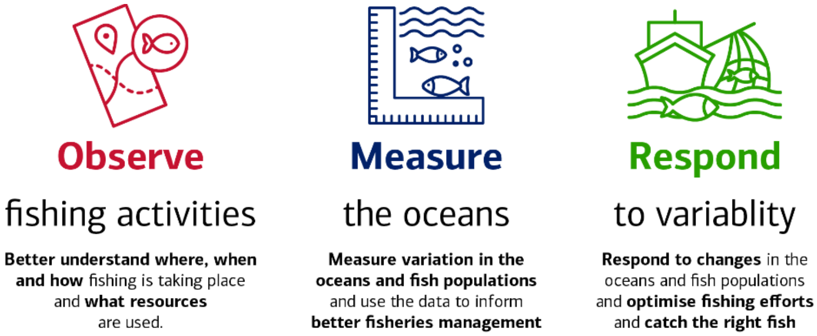
Precision fishing: using advanced analytics to balance fishery interests with environmental concerns

> Implementation of precision fishing would significantly reduce unnecessary wastage of 9.1mn tonnes of fish per year (FAO, 2018)

Precision fishing can be defined as the use of advanced tools and technologies to optimize fishing operations and management (Costello, 2016). This form of high-tech fishing enables us to harvest only what we need from the oceans, thereby reducing our negative impact on them. With improved management, the ocean could sustainably provide 6x more food than it currently does. Precision fishing can help support these efforts, so we can have our fish and eat them too.

Exhibit 176: What is precision fishing?

Using technology to observe, measure and respond to variability in commercial fish populations



Source: SafetyNet Technologies

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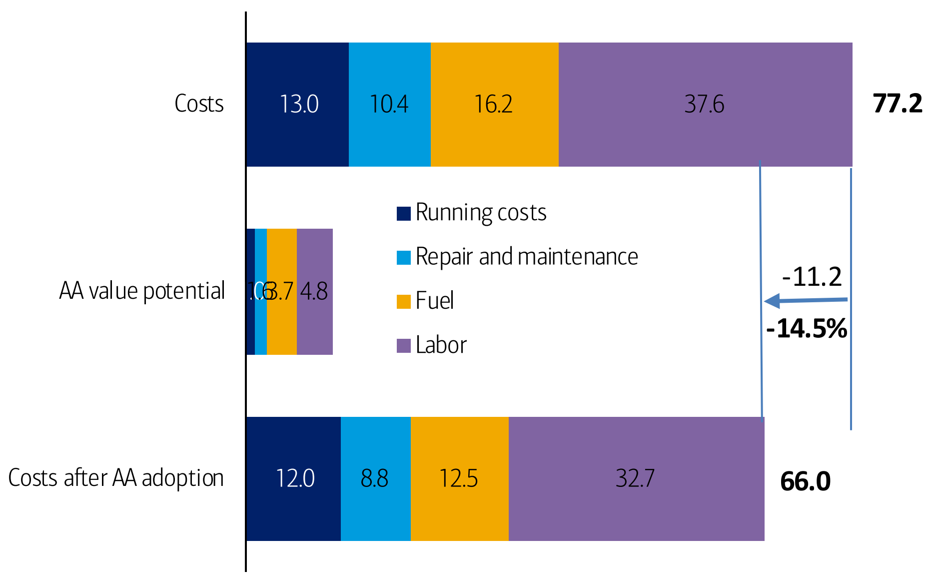
The growth of Advanced Analytics – the use of sophisticated methods to collect, process and interpret big data – could promote the development of precision fishing. If large-scale fishing companies around the world move to this model, they could decrease their annual operating costs by about US$11bn, and customers would benefit from lower prices for fish and seafood (McKinsey 2019). Precision fishing techniques can also contribute to improved management of ocean resources, which could increase industry profits by as much as US$53bn by 2050 while simultaneously raising the total fish biomass to at least twice the current level (McKinsey 2020).

Exhibit 177: Advanced analytics could save more than US$11bn of costs for large-scale fishing companies worldwide

Operational variable costs and reduction potential from advanced analytics (AA), $ billion



Source: McKinsey 2019

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The path forward requires sustainability

Marine aquaculture, accounting for almost half of global aquaculture production, will play a critical role in securing supplies of food for a global population that will likely exceed 9bn by 2050. However, climate change and other environmental constraints will undoubtedly challenge growth of marine aquaculture. Temperature and sea-level rises, shifts in precipitation, freshening from glacier melt, changing ocean productivity and circulation patterns, increasing occurrence of extreme climatic events, eutrophication, and ocean acidification (OA) are some of the stressors that will influence the potential of marine aquaculture production (FAO, 2018b; IPCC, 2019). It will therefore be critical to anticipate new opportunities and challenges in marine aquaculture production.

Ocean energy: the next big thing

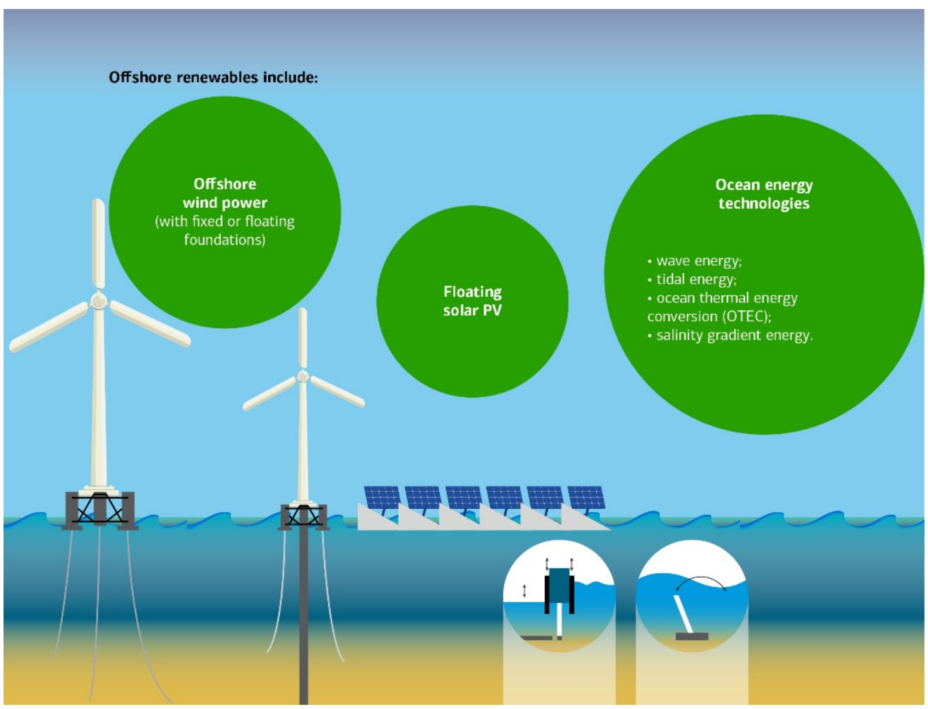
> Ocean energy can provide 10% of Europe's current electricity needs by 2050, which is enough to power 94mn households per year (Ocean Energy Europe)

Oceans are the world's largest untapped source of energy. Ocean energy refers to all forms of renewable energy derived from the sea. Tides, waves and currents can be used to produce electricity. Although still at the research and development stage and not yet commercially available, promising ocean technologies include:

- **Wave energy**: converters capture the energy contained in ocean waves and use it to generate electricity
- **Tidal energy**: produced either by tidal-range technologies using a barrage (a dam or other barrier) to harvest power between high and low tide; tidal-current or tidal-stream technologies; or hybrid applications
- **Salinity gradiant energy**: arising from differing salt concentrations, as occurs where a river empties into an ocean
- **Ocean thermal energy conversion**: generates power from the temperature difference between warm surface seawater and cold seawater at a depth of 800–1,000 meters

Exhibit 178: Offshore renewables include Offshore wind power, Floating solar PV and Ocean energy technologies

Ocean energy technologies comprises Wave energy, Tidal energy, OTEC and Salinity gradient energy



Source: IRENA 2020

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Offshore renewables can help to fulfil the **UN SDGs** by 2030:

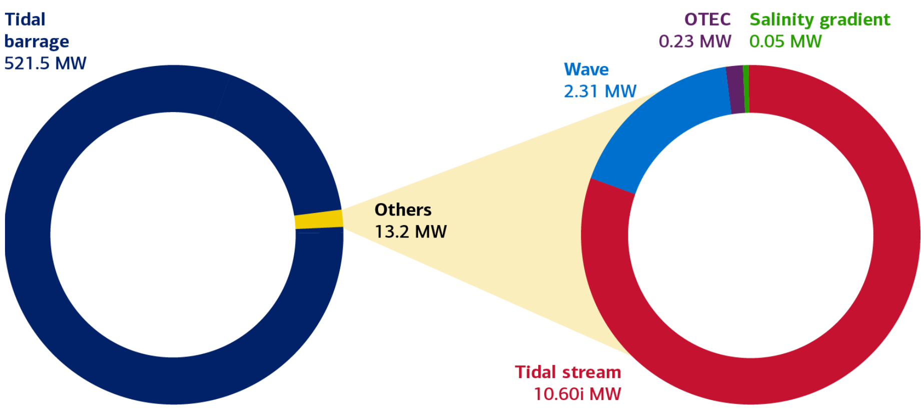
- **SDG 7** aims to ensure affordable, reliable, sustainable and modern energy access for everyone
- **SDG 14** calls for conservation and sustainable use of oceans, seas and marine resources

Ocean energy potential

The cumulative installed capacity for ocean energy technologies worldwide currently amounts to 535 megawatts (MW), which is negligible in comparison to the global installed capacity for all renewables (around 2600 gigawatts, GW). Tidal barrage technology dominates the world's ocean energy output mainly via three large projects in Canada, France and South Korea. However, the newly installed capacity, and ocean energy's expected trend, is moving towards other technologies, such as tidal stream, followed by wave energy and ocean thermal energy conversion (OTEC).

Exhibit 179: Global ocean energy, 2020

Tidal barrage technology dominates the world's ocean energy output with 521.5 MW of 535 MW



Source: IRENA ocean energy database

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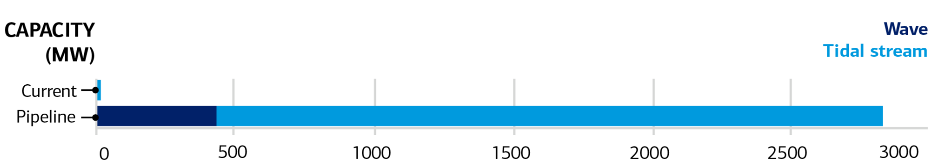
Tidal stream and wave projects currently being developed (excluding tidal range technology), if realised, would account for almost 3GW of additional capacity worldwide. Most of this capacity exists in Europe (55%), followed by Asia and the Pacific (28%) and the Middle East and Africa (13%), with the remaining share being split between North America (2%) and South and Central America (2%).

Exhibit 180: Ocean energy projects worldwide: Current capacity versus expected pipeline

Tidal stream and wave projects, if realized, would account for almost 3 GW of additional capacity worldwide



Source: IRENA ocean energy database

Note: Excluding tidal range technologies

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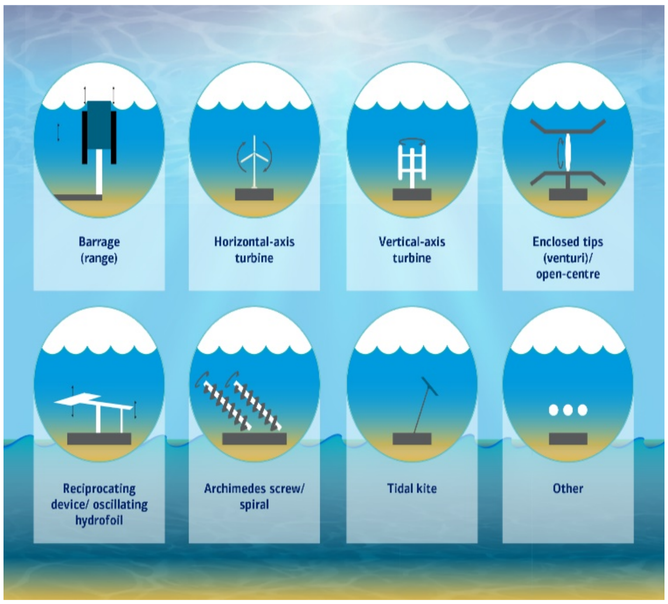
Ocean energy could reach 10GW of installed capacity by 2030, according to IRENA's projections

While ocean energy is globally distributed, European countries such as Finland, France, Ireland, Italy, Portugal, Spain, Sweden and the United Kingdom, along with Australia, Canada and the United States, have been at the forefront of the market, with the largest number of projects tested, deployed and planned, as well as most project developers and device manufacturers.

Exhibit 181: Tidal energy technologies
Examples of current prototypes



Source: IRENA 2014, ENEC, World Energy Council 2016

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Exhibit 182: Wave energy technologies
Examples of current prototypes

Source: IRENA 2014, ENEC, World Energy Council 2016

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Action on ocean renewables

Europe aims at retaining its leadership in ocean energy development, maximizing the benefits for the region through the recent offshore renewable strategy, a key element of the European Green Deal and part of the COVID-19 recovery package. The marine renewables industry will need to scale up 5x by 2030 and 25x by 2050 to support the Green Deal's objectives. Offshore renewable technologies, though not yet cost-competitive with fossil fuels or more mature renewables, are set to become less costly over time, particularly as increasing deployment creates economies of scale. Offshore renewables could be further promoted through engagement with the Group of 20 and through preparation of the agenda for the next major global climate conference, the 26th Conference of Parties to the United Nations Framework Convention on Climate Change (COP 26).

Ocean sensing and imaging – the advent of a new era?

New smart sensors, processes and techniques are generating significant improvements in sensitivity, accuracy, stability and resistance to harsh ocean conditions. Since the 1990s, there has been steady progress in automated sensing of key physical features such as current, salinity and temperature, and the last decade has seen advances in the form of novel in-situ sensors capable of monitoring some biochemical and biological features such as nitrates, methane and micro-nutrients. However, as we illustrate below, the road ahead is still long, specifically when it comes to biological and ecosystem-related sensors.

Exhibit 183: Essential Ocean Variables (EOVs) in physics, biochemistry, biology and ecosystems, and technological readiness levels

Blue represents mature technological readiness; Orange represents pilot technological readiness; Red represents concept technological readiness

Physics	Biogeochemistry	Biology and ecosystems
Sea state	Dissolved oxygen	Phytoplankton biomass and productivity
Ocean surface vector stress	Inorganic macro nutrients	Harmful algal bloom incidence
Sea ice	Carbonate system	Zooplankton diversity
Sea surface height	Transient tracers	Fish abundance and distribution
Sea surface temperature	Suspended particulates	Apex predator abundance and distribution
Subsurface temperature	Nitrous oxide	Live coral cover
Surface currents	Carbon isotope	Sea grass cover
Subsurface currents	Dissolved organic carbon	Mangrove cover
Sea surface salinity		Macroalgual canopy cover
Subsurface salinity		
Heat flux/radiation		

Source: Delory 2019

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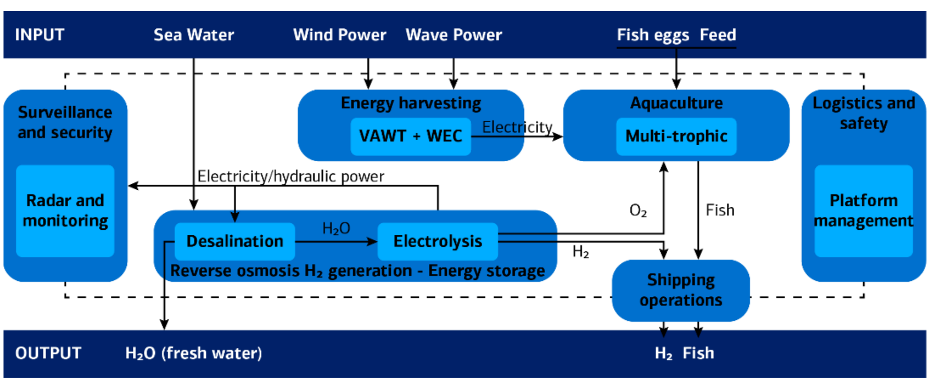
Multiple-use platforms: system integration of different ocean-based technologies

The concept of common-use or multiple-use ocean platforms is generating considerable interest in ocean engineering and ocean management. The core of the idea is system integration to build on capturing synergies offered by use of different ocean-based technologies – renewable energy (wind, wave etc), marine aquaculture, maritime transport and logistics, marine research, biotechnology – deployed on the same site. The European Union has set in motion several such multi-platform projects, which include TROPOS, H2OCEAN, MERMAID, ORECCA, and MARINA. Below is a diagrammatic representation of the process implementation of H2OCEAN, providing insights into the complexities of the concepts underlying such integrated platforms. Multi-functional platforms will also need to be developed in a number of specific under-sea activities. There will be much more integrated work required across various disciplines in future.

Exhibit 184: H2OCEAN multi-use platform process

Different ocean-based technologies like renewable energy, aquaculture, biotechnology etc deployed on the same site



Source: Koundouri 2014

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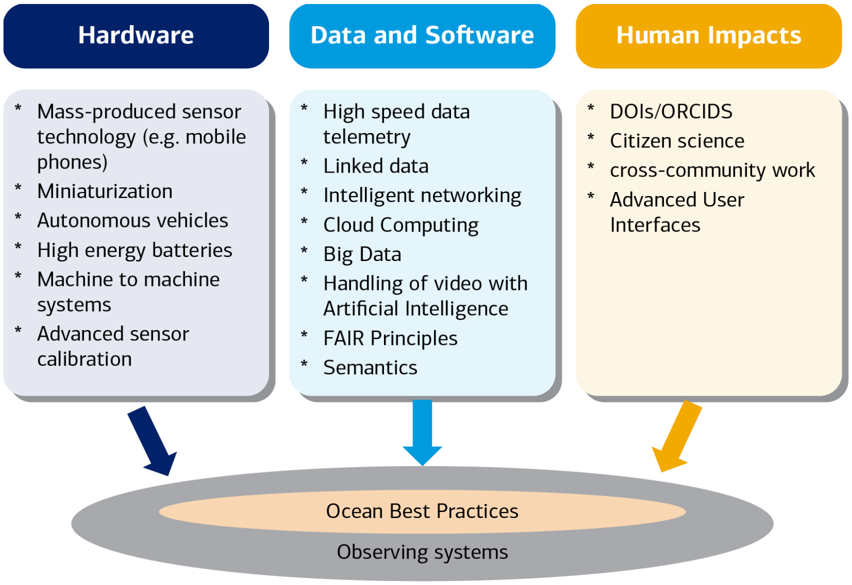
OBPS: focal point for ocean data community

Ocean Best Practices (OBPS) is an open access, permanent, digital repository of community best practises in ocean-related sciences and applications maintained by the International Oceanographic Data and Information Exchange (IODE) of the UNESCO-IOC as an IOC (IODE, GOOS) project. Many new technologies are emerging and becoming more mainstream (e.g. cloud computing, AI, machine autonomy, high-speed data telemetry etc). This will necessitate a new generation of documented methods and processes, as value-chain components become ever-more interlinked, marine-related disciplines and data types become more integrated, and remote and autonomously configurable sensor-to-sensor systems call for more advanced quality control processes (Pearlman *et al*, 2019). Such an expansion of technologies and services will need to go hand in hand with an expanded set of best practises, which in turn will need to be guided by international consensus, opening up further opportunities for a more active role of the OBPS.

Exhibit 185: Advances in the next decade will enhance ocean observing and impact best practices evolution

Advances through Hardware, Data & Software and Human impacts



Source: Pearlman 2019

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Tech companies making waves in ocean technology

- **Google's X** sub-division which focuses on ambitious so-called "moonshot" projects, has announced a new ambitious fish-tracking project called **Tidal** to help save the environment and feed the world. This latest project revolves around an underwater camera system and machine perception tools to track fish behaviour over time. Google hopes that these insights will help the fishing industry track the health and stocks of fish. There's precious little from Google on how Tidal will actually be implemented.

- **Microsoft** has partnered with the Center for the Fourth Industrial Revolution and the Ocean (C4IR Ocean) to develop technology-based systems to improve ocean health, as part of C4IR Ocean's mission to promote a sustainable ocean

- **Shone** collects data via sensors, cameras, radar and GPS to analyse ships' surroundings by retrofitting manned ships with autonomous capabilities. This helps to predict the behaviour of other ocean users and pre-empt any problems that could arise during the journey. Shipping leader CMA GCM uses Shone technology to aid with navigation and gather data from its fleet

- **Resolute Marine has created Wave$_2$O**, which uses several wave energy converters to pressurise seawater and pump it to an onshore desalination plant. The system uses ocean energy to provide clean drinking water from the sea in areas where standard seawater desalination plants are too costly or time consuming to build. One advantage to the system is that it can be installed within a matter of days.

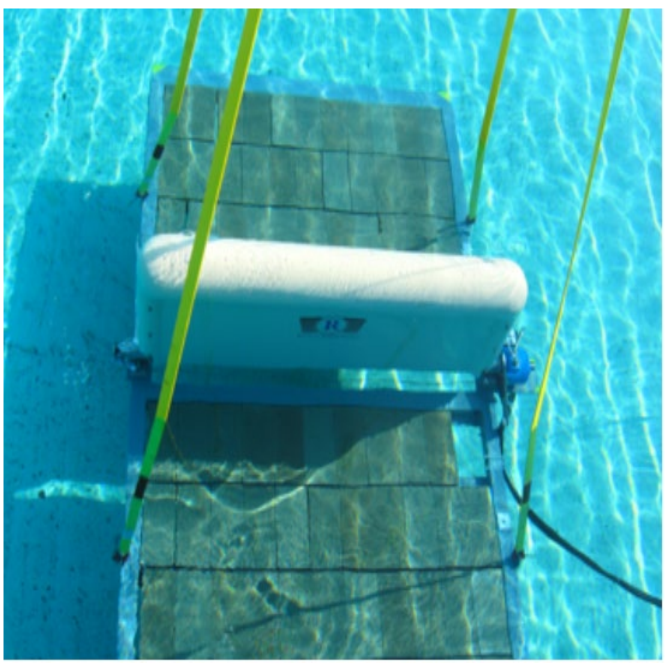
- **AquaBotix** has developed a portable Unmanned Surface Vehicle (USV) called **SwarmDriver** for monitoring, research, defence, and surveillance. The vehicles can swarm in groups of 40 or more, and dive to depths of 50 metres. The USVs can communicate and make autonomous decisions, just like an aerial drone swarm. AquaBotix entered a special purpose cooperative research and development agreement (CRADA) with the US Navy in 2018.

- **OceanServer**, a subsidiary of global aerospace and defence technology company L3Harris, has designed and manufactured the first 'family' of low-cost, lightweight AUVs called **Ivers**, which come in three iterations and are designed for coastal applications. The maximum depth of the Iver4 is 300 meters below surface level. There are currently more than 300 Iver models in operation, with applications in energy, intelligence, marine biology, research, search and rescue, and inspections

- **NOTPLA has developed Ooho!** a packaging option made from a seaweed-based material. Ooho! has been used by Selfridges, JustEat, and various events including the London Marathon as an alternative to plastic packaging. The material has impressive sustainability credentials, being fully biodegradable and even edible.

Exhibit 186: Wave$_2$O by Resolute Marine

Wave$_2$O system deployment typically employs several wave energy converters (WECs) that pressurize seawater which is piped ashore to directly drive a seawater reverse-osmosis (RO) desalination system



Source: Resolute Marine

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Exhibit 187: Iver4 900 UUV by OceanServer

Maximum depth of Iver4 is 300m below surface level

Source: L3Harris

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Looking forward: Encouraging balanced mix of sustainable ocean use and conservation

Despite uncertainties due to COVID-19, many of the major trends associated with ocean-based industries should continue. As the global population grows, longer-term demand for marine sources of food, energy, minerals and leisure pursuits is still likely to increase. The development of ocean-based industries should go hand in hand with preserving marine natural assets and ecosystem services.

Green Mining: decarbonization requires sustainable metals

Green mining: Sustainable, minimal impact mining (deep-sea mining, agromining, mining of desalination waste and other waste water)

The answer to: 'How do we make batteries greener?'

Did you know? Deep-sea mining could produce metals with 70% fewer CO2 emissions

By 2024: Commercial deep-sea mining is set to start

Market size: US$12.9bn by 2024E

Sectors affected: Metals & mining, offshore oil & gas, shipping, agriculture, EV battery production, commodities, space

The green revolution relies on metal: how do we prevent destruction of the environment to get there?

Shifting from a carbon-intensive economy means becoming a metal-intensive one. Electric vehicles, energy storage and other climate solutions have been dogged by accusations of unsustainability, particularly in relation to batteries as consumption of metals rises. Alternative sources to traditional mining, such as deep-sea mining, agromining and mining of desalination waste and other wastewater, could provide more sustainable solutions.

US$12.9bn green mining market by 2024

The green mining market size was estimated to be worth US$9bn in 2019 and is projected to reach US$12.9bn by 2024, increasing at a CAGR of 7.5% (source: MarketsandMarkets, Bloomberg).

How much metal is needed and what is the climate impact?

Exhibit 188: Applications helping to decarbonise the economy, along the commodities required

Aluminium, Nickel and Copper are the key metals for decarbonisation

	Power applications			Automotive	Others		
	Wind	Solar photovoltaic	Energy storage	BEV and FCEV	Electric motors	Carbon capture and storage	Light emitting diodes
Aluminium	X	X	X		X	X	X
Chromium	X					X	X
Cobalt			X	X		X	
Copper	X	X		X	X	X	X
Indium		X				X	X
Lead	X	X					X
Lithium				X			
Molybdenum	X	X				X	X
Neodymium (proxy for rare earths)	X			X			
Nickel	X	X	X	X		X	X
Platinum			X	X			
Silver		X		X			X
Steel	X						
Zinc		X					X

Source: World Bank, The Growing Role of Minerals and Metals for a Low Carbon Future, BofA Global Research

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Metals & mining's impact on climate and environment is of growing concern

As investors focus on ESG in the sector, the metals & mining industry has some key environmental and social issues to overcome it help the planet escape its dependency on carbon emissions.

- **Waste volumes** – To make enough metal to manufacture 1bn electric cars from traditional land mining, 64Gt of solid waste and 1.5GT of CO2 will need to be produced. In 2022, the volume of waste (tailings and rock waste) is expected to have already reached 234Gt (vs 37bn+ tonnes of CO2e waste entering the atmosphere from burning fossil fuels) as well as consuming 11% of energy use (source: ReportLinker 2018, IPCC 2018, The Metals Company). This is only set to grow as the ore grades decline (meaning fewer economic minerals/tonne of material) and demand for metals increases.

- **Destruction of biodiversity** – mining of some of the metals for electric vehicles, like cobalt, take place in some of the most biodiverse parts of the planet such as the Democratic Republic of Congo (DRC).

- **Social issues** – improperly governed supply chains have resulted in the use of child labor in some mines, while others can have negative impacts on local communities by contaminating local resources and groundwater.

Exhibit 189: The Environmental, social and economic impacts of producing 1bn EVs worth of metals

Nonliving resource impacts such as use and pollution of land, forests, water and soil would be substantial with land-ore mining

	Land
Climate change	
GWP - CO2 equivalent emissions, Gt	1.5
Stored carbon at risk, Gt	9.3
Non-living resources	
Ore use, Gt	25
Land use, km2	156,000
Incl. Forest use, km2	66,000
Seabed use	2,000
Water use	45
Primary and secondary energy extracted, PJ	24,500
Waste streams	
Solid waste, Gt	64
Terrestrial ecotoxicity, 1, 4-DCB equivalent Mt	33
Freshwater ecotoxicity, 1, 4-DCB equivalent Gt	21
Eutrophication potential, PO4 equivalent Mt	80
Human & wildlife health	
Human toxicity, 1, 4-DCB equivalent Mt	37,000
SOx and NOx emissions, Mt	180
Human lives at risk, number	1,800
Megafauna wildlife at risk, trillion organisms	47
Biomass at risk, Mt	568
Biodiversity loss risk	Present
Economic impact	
Nickel sulfate production cost, USD per tonne NI	14,500
Jobs created (non-artisanal, worker-years)	600,000

Source: LCA White Paper 'Where should metals for the Green Transition come from'

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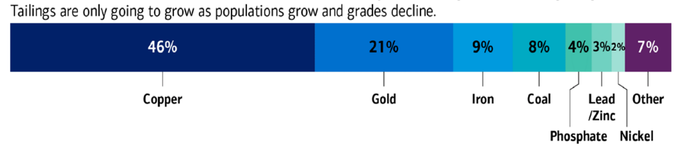
Exhibit 190: What metals contribute to tailings? 46% of tailings come from copper

Waste/tonne of metal produced is increasing as ore grade declines

CONTRIBUTION TO GLOBAL TAILINGS, BY COMMODITY

The volume of waste material produced per unit of commodity is increasing due to declining ore grade. Tailings are only going to grow as populations grow and grades decline.



Source: Global Tailings Review, ICMM, UNEP, PRI

Note: Tailing facility estimates come from using the reported number of facilities projected to global commodity production using USGS mineral commodity production estimates

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How could we source the necessary materials better?

To quench this ever-growing thirst for metals, scientists, start-ups, and governments have been exploring a variety of alternative solutions including deep-sea mining, agromining, and mining of various water sources:

- **Deep-sea mining** – collection of minerals from the floor of the ocean (most commonly in the form of nodules)

- **Agromining** – the cultivation of plants that grow with high concentrations of key metals (very early research phase)
- **Wastewater mining** – the mining of brinewater from desalination or wastewater to collect metals as well as direct lithium extraction
- **Asteroid mining** – capturing mining materials from asteroid belts in space

In addition, recycling of metals remains an underpenetrated space with volumes of e-waste continuing to accumulate, which is failing to be dealt with appropriately.

Exhibit 191: What could green mining look like?
Deep-sea mining, agromining, and wastewater/desalination mining and asteroid mining

Source: BofA Global Research

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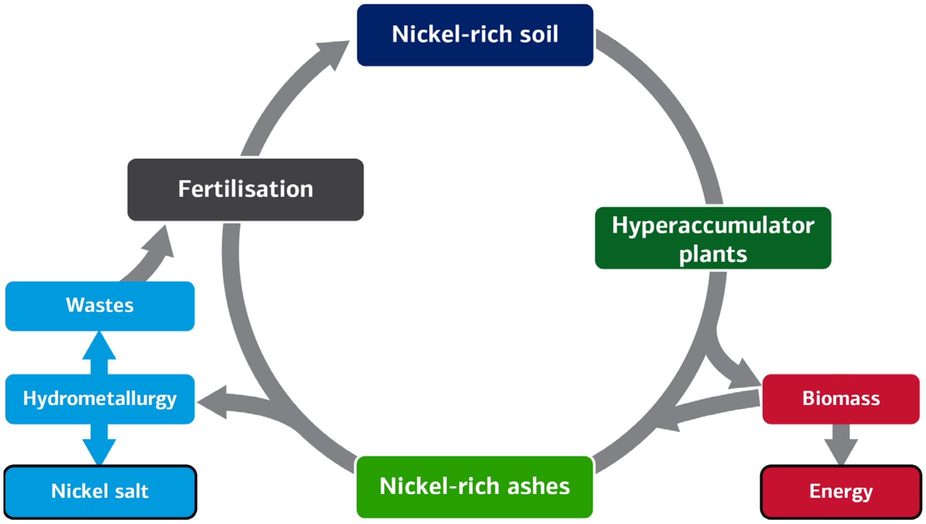
Agromining: can metal grow on trees?

Plants grow by taking in nutrients from the soil. However, certain plants take in higher concentrations of minerals than others. Some plants, known as hyperaccumulators that suck up high volumes of metals, such as cobalt, zinc and gold are now being investigated as a potential alternative source of metal. This form of mining is known as agromining or phytomining.

Exhibit 192: How does agromining work?
The process of agromining for nickel



Source: Life Agromine

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Hyperaccumulating plants provide the most potential for nickel

Dr van der Ent (a plant ecophysiologist and biogeochemist) estimates there are 300,000 known plant species on the planet. Of these, around 700 have some kind of hyperaccumulating property. Specifically, two-thirds are estimated to grow on nickel, with at least three species that have more than a 25% concentration of nickel in their sap.

Exhibit 193: Green sap plants could 'bleed' nickel
Phyllanthus balgooyi is one of the "hyperaccumulator" trees that absorb metallic elements

Source: ABC News

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What kind of land could host these hyperaccumulating plants?

Ultramafic sites: areas with soil enriched with metals such as nickel, chromium and cobalt while deficient in other necessary nutrients are unsuitable for traditional agriculture but could be used for agromining

Ultramafic soils that could support hyperaccumulator plans cover approximately 1% of land (source: Echevarria, 2018, Kidd et al Environmental Science, 2018). Specifically focusing on nickel, while concentration levels can range typically from 2-750mg/kg, certain soils can contain 3,600mg/kg+ of nickel if found above concentrated rocks (source: Sparks 2002, Kidd *et al* Environmental Science, 2018). This includes former mines that need rehabilitation and soils above sub or low-grade ores.

Examples of agromining practise occurring in Malaysia, Europe and China

While the idea is definitely in its early phase, a physical demonstration farm has been operating in Malaysia for the past 5 years. The farm has managed to harvest 200-300kg of nickel per hectare per year. Beyond Malaysia, a number of pilot test sites by Agronickel and LIFE-Agromine in Europe (Spain, Austria, Greece and Albania) are also yielding nickel crops, while investigating how to improve soil and crop efficiency.

> Europe has over 10,000km² of land of low fertility and productivity that is rich with metals that could be used for agromining

Use cases of agromining: rehabilitation, supplements, jobs in DMs

- **Helping rehabilitate areas where strip mining has occurred:** One of the use cases for this technology is in rehabilitating old nickel mines where strip mining has removed the original tropical habitat. Normally, rehabilitation of a region is a cost factor for mining companies. Instead using the region as a further source of sustainably grown metals could provide revenue for the rehabilitation process for lands as well as soil waste.

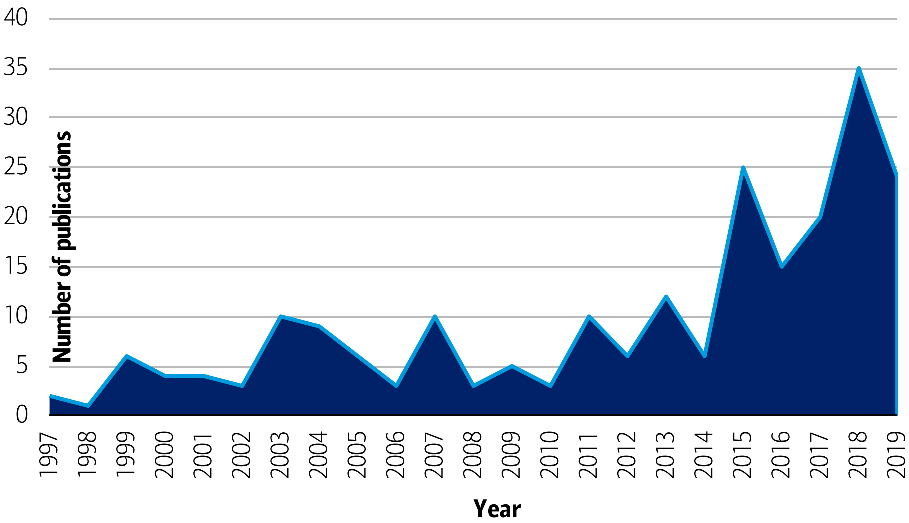
- **Supplements for deficient diets**: With unhealthy and deficient diets a major issue across the world, including deficiencies in zinc and selenium in developing markets, some of the harvested plants could be used as a supplement for humans.

- **New source of income:** In developing markets, with subsistence agricultural lifestyles, agromining could provide a new source of income for regions where traditional agriculture may not thrive and the ore is deemed sub- or low grade.

What still needs to be done before commercialization?

The technology remains the key hurdle for this emerging concept: researching optimal hyperaccumulating plants and optimizing cultivation to create economically viable yields. Fortunately, scientific research in the space has been expanding rapidly over the past 4-5 years with greater interest from the global community.

Exhibit 194: The number of publications on phytomining has taken off in recent years
Number of phytomining publications increased from an average of below 10 pre-2014 to over 20 for the past 3 years



Source: Li et al sustainability, 2020

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Wastewater mining: two birds with one stone?

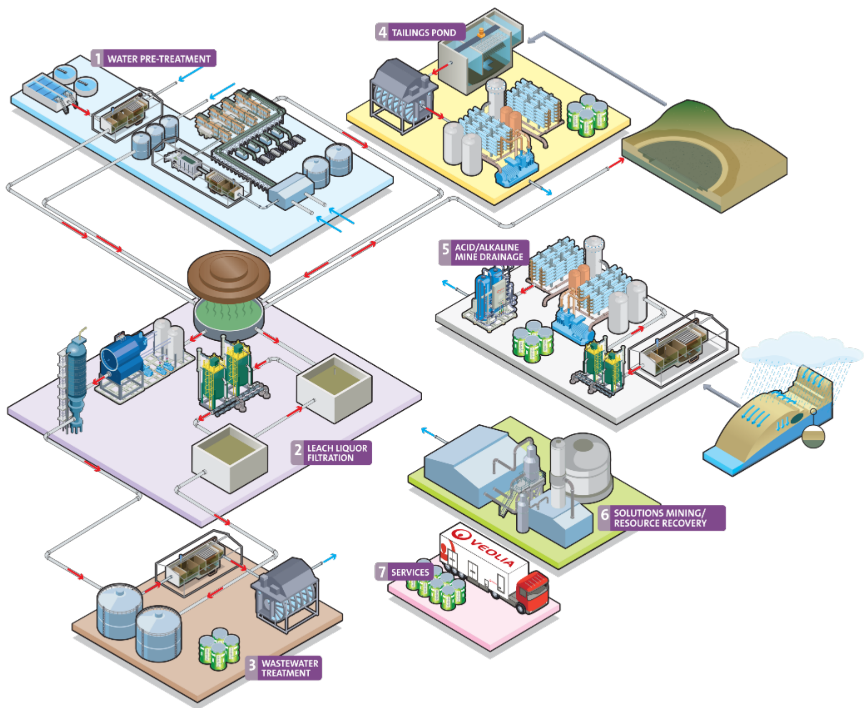
Valuable metals can be found in a number of liquid sources as well; in particular, tailing from mining sites, waste from desalination plants and even general wastewater. Simultaneously, clean and safe water and contamination of water supplies as resources in certain geographies are growing concerns for the planet. In fact, nearly 90% of sewage and 80% of general wastewater is released back into the environment untreated. Water mining could be a solution to these growing problems.

Desalination produces more brine than freshwater

> Desalination produces more toxic waste than clean water (141mn m³ of brine to 100mn m³ of desalinated water/day across the globe)

While countries have had to increase use of desalination to deal with increasingly extreme droughts and population water demands, the consequence has been significantly more toxic waste in the form of brine. The impact of the discharge of this brine into the sea has already had a visible impact on the ocean.

Exhibit 195: How would wastewater mining work?
From water pre-treatment to tailings pond to solutions mining and resource recovery



Source: Veolia

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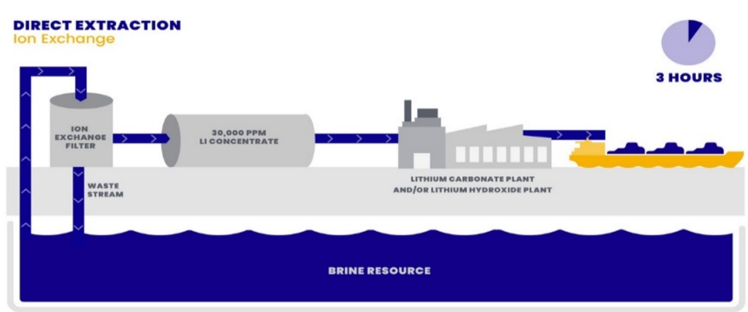
Lithium direct extraction

Conventional lithium extraction from brines involves salt-rich waters under salt lakes being pumped to the surface into large ponds, where solar evaporation reduces the liquid content. Typically, this process can take between 9 months and 2 years, with lithium recoveries usually below 50%. In contrast, an innovative solution developed by Lilac Solutions offers a fast-track production process, with lithium brines produced in under three hours with very high purity and with minimal environmental impact. Lab testing has shown that lithium concentrations of 30-60,000 mg/L lithium can be produced from brines of ~300 mg/L lithium in a few hours using the Lilac process (source: Lake Resources).

Exhibit 196: Lithium Direct Extraction
Extracting lithium from brine



Source: Lake Resources

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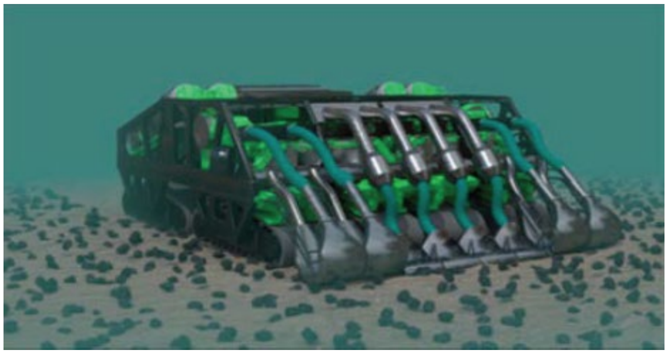
Deep-sea mining: can blue metal be green?

Deep-sea mining involves extraction of polymetallic nodules on the ocean floor up to 6000m below sea level. These nodules contain metals vital for EV batteries, including nickel, cobalt and rare earth metals at sufficient quantities to potentially disrupt certain metals' market post commercialization. In our original Eureka! Future Tech Primer, we provide an in-depth discussion on the technology, capacity and costing. Below, we take a look at recent developments.

Exhibit 197: Deep sea mining image of potential mining system
What does mining on the bottom of the ocean look like?



Source: The Metals Company

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Exhibit 198: Nodule field
Polymetallic nodules on the bottom of the ocean

Source: International Seabed Authority

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DeepGreen (The Metals Company) case study

Undersea Polymetallic nodules are probably the world's largest estimated source of battery metals. A single nodule is the equivalent to 4 battery metals in high concentrations. In addition, this low cost production would be equivalent to the second lowest cost nickel producer worldwide. Currently there are 3 license areas under control in the Pacific Ocean. 1.6bn tonnes of high grade material is sufficient to electrify the entire US car fleet. ESG footprint: "expected to be able to compress most of it". Zero solid waste, 90% less CO_2 eq. emissions (nodules vs. land ores). 1 Electric Vehicle accounts for 155 kg of metals but 58t of toxicity, 45t of water needed, 64t of solid waste generated and 13t of CO_2 eq. emissions.

Exhibit 199: A deep sea manganese nodule
The metal contains manganese, nickel, copper & cobalt, all key metals used in batteries.

Source: DeepGreen / The Metals Company

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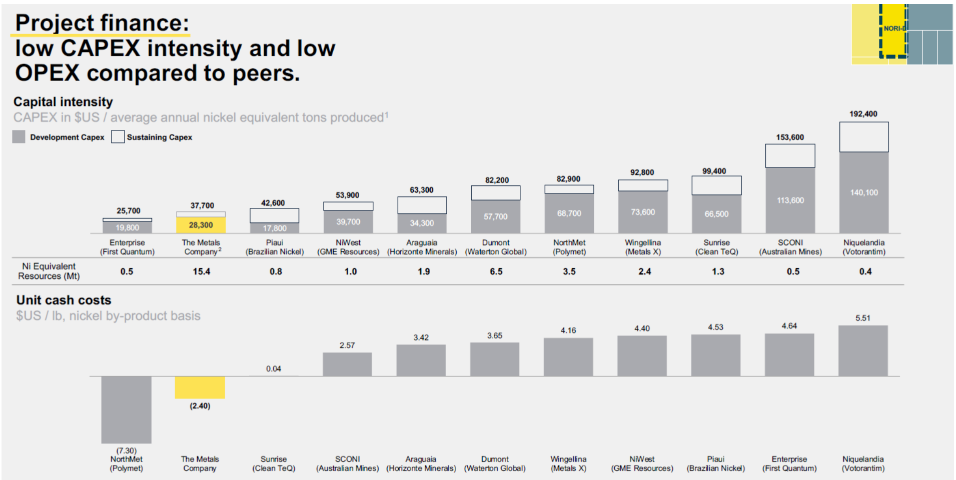
Location: one of the lowest biomass and carbon sequestration environments on the planet. Focusing only on nodules. No cobalt crusts or seafloor massive sulphides. Full portfolio: US$31.3bn NPV.

Exhibit 200: Low capex & low opex for The Metals Company?
The Metals Company unique resource means that it should have both low capex & low opex relative to other nickel projects.



Source: DeepGreen / The Metals Company

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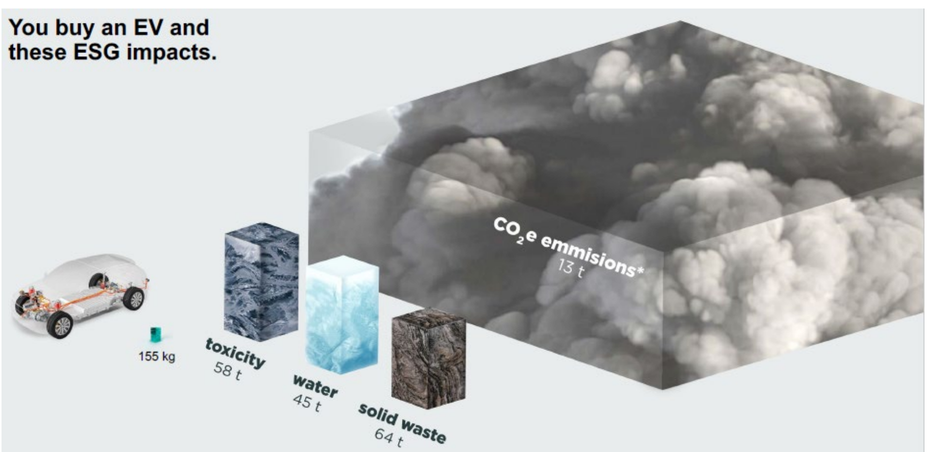
The timeline is much shorter for Bluefield (3 years) compared to Greenfield (5-7 years), with lower capex (US$28k/t vs US$60k/t), no land use or large infrastructure, and easier waste management.

Exhibit 201: Environmental impact of 155kg of metals in 1 Electric Vehicle
The Metals Company expects "to be able to compress most of it"



Source: DeepGreen / The Metals Company

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Environmental debate continues on drawing in consumer-facing companies

Various environmental organizations, such as Greenpeace, have highlighted and protested the potential costs of deep-sea mining. Concerns voiced by such organistaions include the disruption of unexplored habitats and the loss of biodiversity and species, most of which are undiscovered. In particular, companies such as BMW, Volvo, Google, and Samsung have voiced concerns about the uncertain impact of deep-sea mining committing to excluding deep-sea metals from supply chains until the impacts are fully understood. Deep-sea mining companies have instead highlighted the destructive impacts of current land-based mining.

Exhibit 202: How do the impacts of land and deep-sea mining stack up?

Comparison of environmental, social, and economic impacts of deep sea mining vs land based mining

	Land	Nodules	% change
Climate change			
GWP - CO2 equivalent emissions, Gt	1.5	0.4	-70%
Stored carbon at risk, Gt	9.3	0.6	-94%
Non-living resources			
Ore use, Gt	25	6	-75%
Land use, km2	156,000	9,800	-94%
Incl. Forest use, km2	66,000	5,200	-92%
Seabed use	2,000	508,000	+99.6%
Water use	45	5	-89%
Primary and secondary energy extracted, PJ	24,500	25,300	+3%
Waste streams			
Solid waste, Gt	64	0.0	-100%
Terrestrial ecotoxicity, 1, 4-DCB equivalent Mt	33	0.5	-98%
Freshwater ecotoxicity, 1, 4-DCB equivalent Gt	21	0.1	-99%
Eutrophication potential, PO4 equivalent Mt	80	0.6	-99%
Human & wildlife health			
Human toxicity, 1, 4-DCB equivalent Mt	37,000	286	-99%
SOx and NOx emissions, Mt	180	18	-90%
Human lives at risk, number	1,800	47	-97%
Megafauna wildlife at risk, trillion organisms	47	3	-93%
Biomass at risk, Mt	568	42	-93%
Biodiversity loss risk	Present	Present	
Economic impact			
Nickel sulfate production cost, USD per tonne NI	14,500	7,700	-47%
Jobs created (non-artisanal, worker-years)	600,000	150,000	-75%

Source: The Metals Company

Cradle-to-gate production of nickel sulfate, manganese sulfate, cobalt sulfate and copper cathode

Serving size billion of 1 electric cars

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Regulation publication delayed due to lockdown but expected in 2021/22

Deep-sea mining is likely the only industry to be regulated before it starts acting. Currently, exploration phases are occurring, while the International Seabed Authority develops the exploitation regulation for commercialization of the sea bed. Official publication was delayed from the anticipated July 2020 date due to the Covid lockdown. The Metals Company, which has a few exploration concessions, expects the exploration regulation to be published officially in 2021 or 2022.

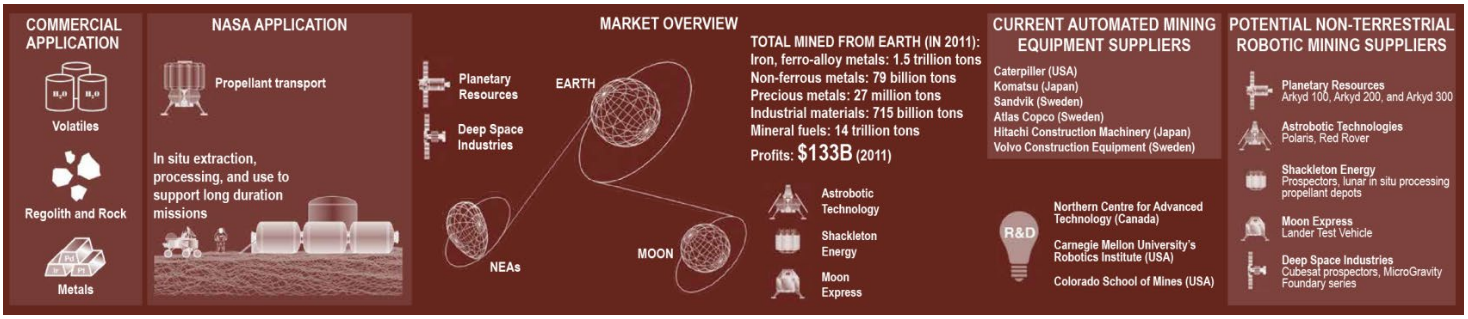
Asteroid mining: trillions of dollars in space

> **"The first trillionaire there will ever be is the person who exploits the natural resources on asteroids.** There's this vast universe of limitless energy and limitless resources. – Neil deGrasse Tyson, Astrophysicist

Robotic mining capabilities are critical to NASA's plans for long-duration space missions to asteroids, the Moon and Mars. NASA is developing robotic prospecting and mining capabilities for space exploration via a number of programs: including the Regolith Advanced Surface Systems Operations Robot (RASSOR), the Regolith and Environment Science and Oxygen and Lunar Volatile Extraction (RESOLVE), and the Moon Mars Analog Mission Activities (MMAMA). The Lunabotics Mining Competition is a university competition sponsored by NASA, Caterpillar, SpaceX, Newmont Mining Corporation and Honeybee Robotics. Competitors are tasked with designing and building an excavator that can mine and deposit a minimum of 10kg of simulated moon dust in 10 minutes. The adoption of automation in terrestrial mining has been slow due to technical issues. However, several large mining companies, e.g. Rio Tinto and BHP Billiton, are using autonomous or semi-autonomous equipment and remote virtual control room technologies that allow miners to operate equipment from thousands of miles away which, in principle, would also apply in space (source: NASA).

Exhibit 203: Robotic mining

NASA developing robotic prospecting and mining capabilities for space exploration via a number of programs including the RASSOR, RESOLVE and MMAMA



Source: NASA

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Furthermore, it isn't just companies that are getting involved in outer-space mining. According to consultancy Navitas, Middle Eastern states are developing space programs and investing in nascent private space commodity initiatives. These initiatives are aimed at giving them a foothold in building extra-terrestrial reserves of water – a substance likely to fuel travel within space – and other resources that could be used for in-space manufacturing. The UAE and Saudi Arabia have space programs, with the Saudis signing a pact with Russia in 2015 for cooperation on space exploration. Abu Dhabi is an investor in Richard Branson's space tourism venture, Virgin Galactic. In addition to money, the Middle East also has geography on its side with its proximity to the Equator. Navitas expects companies to launch satellites searching for rare gases and metals in asteroids within 5 years, with actual mining happening within 8 years (source: Bloomberg).

Asteroid Mining: US$700 "quintillion" in Mars/Jupiter asteroid belt

> **The mineral wealth of the asteroid belt would amount to US$100bn for *each* person on Earth**

Asteroids are leftover material from the early formation of the solar system or debris from the destruction of a planet. There are tens of thousands of asteroids circling the Sun. In our solar system, most are grouped inside the asteroid belt, between the orbits of Mars and Jupiter where there over 1m asteroids, with about 200 that are over 60 miles (100km) in diameter. Most asteroids fit into three basic categories (source NASA):

1. **C-Type** (carbonaceous) – more than 75% of known asteroids fit into this category. The composition of C-type asteroids is similar to that of the Sun without the hydrogen, helium and other volatiles.

2. **S-Type** (silicate) – about 17% of asteroids are this type. These contain deposits of **nickel**, **iron** and **magnesium**.

3. **M-Type** (metal-rich) – a small number of asteroids are this type, and they contain **nickel** and **iron**.

> **"3554 Amun" asteroid is thought to contain US$6tn worth of cobalt** and another US$8tn in iron and nickel – Professor John S. Lewis, "Mining the Sky" (1996)
>
> **NASA is looking to explore the "16 Psyche" asteroid** worth US$10,000 quadrillion or US$10 quintillion

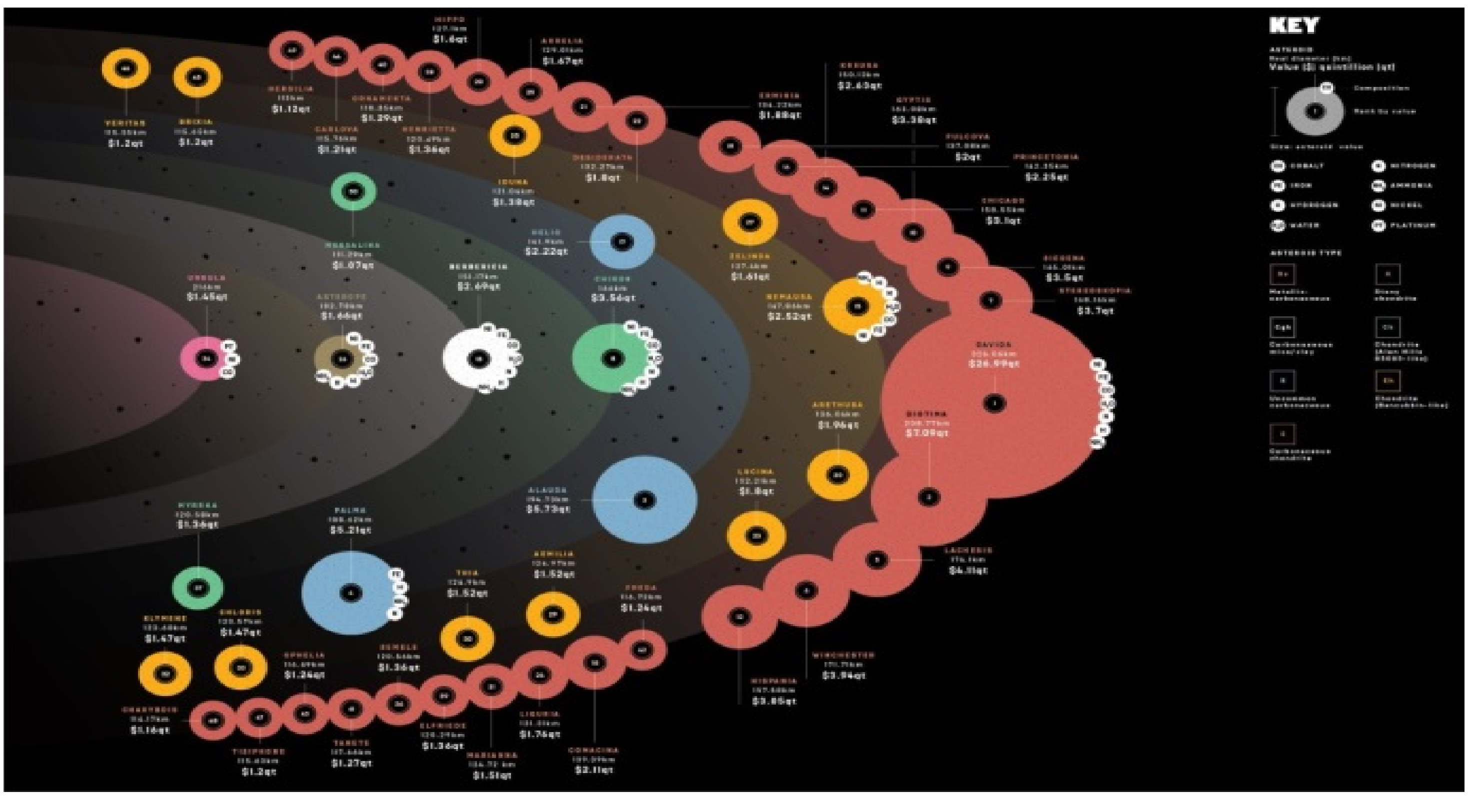
Asteroids contain water which could be the key to getting to Mars and deep-space exploration. Water is an invaluable commodity in space, given the potential difficulties of mining ice in Mars and/or bringing an asteroid back to Earth.

There are estimates that the minerals of the asteroid belt between Mars and Jupiter could be worth US$700 *quintillion* – which is US$100bn for *each* of the 7bn people on Earth at spot prices. John S. Lewis, author of "Mining the Sky", argues that an asteroid with a diameter of 1km would have a mass of about 2bn tons. There are perhaps 1mn asteroids of this size in the solar system. One of these asteroids, according to Lewis, would contain 30mn tons of nickel, 1.5mn tons of metal cobalt and 7,500 tons of platinum, with the platinum alone having a value of more than US$150bn (source: Lewis 1996, Biggs 2013, NASA).

However, asteroid mining is costly. NASA estimates it would cost US$1bn today to bring back 2oz of an asteroid – the weight of a tennis ball. On the other hand, a study at the Keck Institute for Space Studies (KISS) at Caltech estimates that one full cycle Asteroid Capture and Return mission, moving an asteroid weighing about 1.1mn pounds (500,000kg) to a high lunar orbit by 2025, would cost approximately US$2.6bn. An MIT study (Schuler, 2011) found that opening a mine and separation plant can cost up to US$1bn.

Exhibit 204: Potential value of the asteroid belt

Mars Jupiter asteroid belt is abundant in resource



Source: Visual Capitalist

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Planetary Resources –a stated goal to "expand Earth's natural resource base"

Planetary Resources is an American company with a stated goal to "expand Earth's natural resource base" by developing and deploying the technologies for asteroid mining. It is backed by Peter Diamandis, James Cameron, Larry Page, Eric Schmidt, Richard Branson and Tencent among other investors.

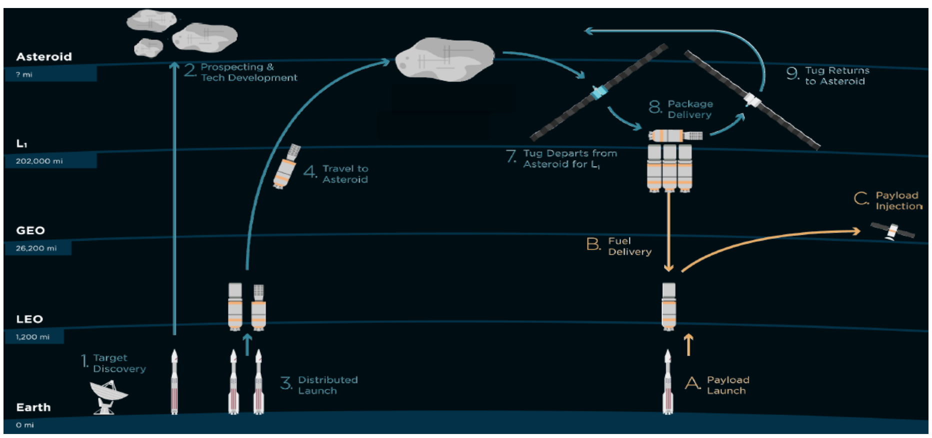
Luxembourg, home of the company's European headquarters, invested US$28mn in Planetary Resources in 2016 to conduct key research and development and international business activities in support of commercial asteroid prospecting. It is now hiring asteroid miners across Europe (source: Planetary Resources).

Deep Space Industries

Deep Space Industries (DSI) is another American privately held company with global operations in the space technology and resources sectors. The company is developing spacecraft technologies that are needed for asteroid mining, and is selling satellites that use these technologies. DSI is expecting to make in-space materials, extracted from asteroids, commercially available in the early 2020s, including space-based refuelling, power, asteroid processing and manufacturing.

According to the Artemis project paper, there are roughly 1,100,000 metric tonnes of lunar helium-3. To put this number into perspective, just 25 tonnes of the material could be enough to power the entire US for a year while a further 75 tonnes would power the remainder of the world for the same time.

Exhibit 205: How asteroid mining would work
Sending rocket with probes to mine asteroids



Source: Planetary Resources

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Capture Storage (CCS): fossil's last decarbonization earthshot

What is it? Carbon Capture and Storage (CCS) is a process to remove CO2 from the atmosphere

The answer to: Could this be the 'get out jail free card' for the fossil industry to decarbonize?

Did you know? The cost of capture typically accounts for around 80% of total costs

By 2030: ~US$25bn annual capex *or* US$100bn of cumulative investments

Market Potential: US$1tn cumulative investments by 2040/2050E

Sectors affected: Oil & gas, renewables, utilities, industrials and forestry

Carbon Capture and Storage (CCS) is a process to remove CO2 from the atmosphere. Industrial processes, such as power generation, cement and iron & steel manufacturing produce carbon dioxide through fuel combustion and/or the chemical reaction that takes place. However, other components of the gas are produced, namely nitrogen. Exerting a lot of energy to compress and store gas, which is primarily nitrogen, is not economically feasible on the basis of per ton of CO2 avoided. Therefore, carbon capture involves the separation of carbon dioxide to form a concentrated stream of CO2. This stream is then compressed, transported and stored.

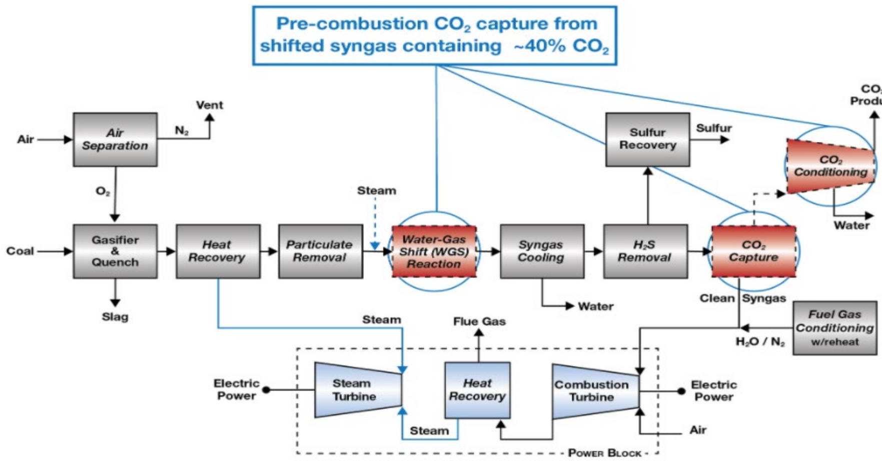
Capture

Carbon capture is categorized according to the type of capture process (post-combustion, pre-combustion, and oxy-combustion) and type of separation technology (absorption, adsorption, membranes and cryogenic distillation).

Pre-combustion

Pre-combustion refers to the removal of CO2 from fossil fuels before combustion.

Exhibit 206: Pre-combustion technical overview
Pre-combustion removes the CO2 from the fossil fuels before combustion



Source: NETL

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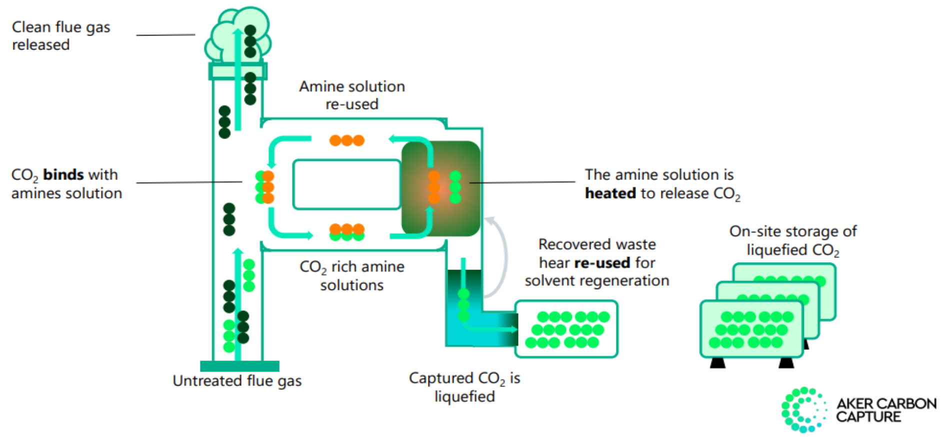
Post-combustion

Post-combustion capture refers to the separation of CO2 from the flue gas. The first step is to remove the impurities; for instance, a desulfurization unit can be used to remove sulphur. The flue gas is then treated, using technologies such as absorption, adsorption, membranes, and cryogenic separation, to produce a concentrated CO2 stream. The CO2 is compressed and cooled in liquid form. Post-combustion is the most widely used technology to date, with 40+ years of history.

Exhibit 207: Post-combustion technical overview

Post-combustion separates the CO2 from the flue gas after combustion has taken place



Source: Aker Carbon Capture

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Oxy-fuel

As fuel combusts with air, the flue gas is primarily a mixture of nitrogen and CO2. However, by just using oxygen (instead of air), the nitrogen is removed in the flue gas. The end product is flue gas with a very high concentration of CO2 (80-98% depending on the fuel) and water vapour. This makes it possible to separate or capture the CO2 from the flue gas purely by low-temperature dehydration and desulfurization processes. This process is technically feasible but consumes large amounts of oxygen coming from an energy-intensive air separation unit.

The separation technologies include…

The separation of CO2 can be accomplished through the application of four main CO2 capture technologies:

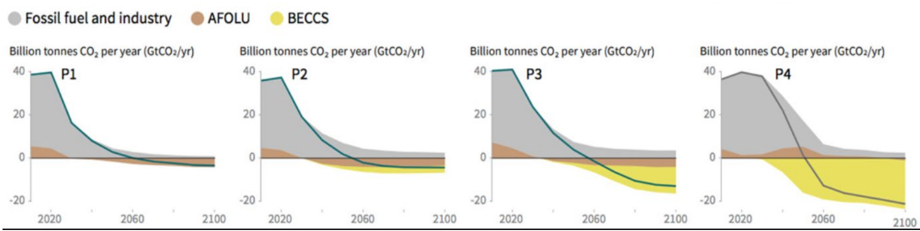
- **Absorption**, involves the physical absorption of CO2 into a solvent (the most mature technology that has been used for around 40 years with high CO2 capture rate, however, high energy intensity);
- **Adsorption**, involves the attachment of the CO2 to the surface of another material (may offer a lower cost alternative with greater flexibility in operating temperatures);
- **Membranes**, which selectively separate CO2 based on differences in solubility or diffusivity (low energy intensity, lower capex and simple O&M; however, low CO2 capture rate and lower CO2 concentration is required in flue gas);
- **Cryogenic** processes, which separates the CO2 by condensation (this physical process is suitable for treating flue gas streams with high CO2 concentrations).

Nascent technologies providing net-negative emissions

Despite current decarbonisation efforts, the IPCC has stated that negative emissions technologies will be required to meet CO2 levels consistent with 1.5 degrees Celsius of warming. Two identified negative emissions technologies include: biomass energy coupled with CO2 capture and storage (BECCS) and direct air capture (DAC):

Exhibit 208: Breakdown of contributions to global net CO2 emissions in four model pathways for 1.5 degrees Celsius

Net negative emissions will be required to meet global temperatures of 1.5 degrees Celsius



Source: IPCC

Note: P1 pathway: Assumed the world rapidly reduces fossil fuel emissions after 2020. P2: The world switches towards sustainable and healthy consumption patterns (limited amount of BECCS). P3: "Middle of the road scenario" – historical social and economic trends continue. P4: Resource and energy intensive scenario.

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Direct air capture (DAC) – the marginal carbon price?

Unlike CCS, which captures carbon emitted from a 'point source' industrial stream (i.e. flue gas), direct air capture aims to capture carbon directly from the earth's atmosphere. Large fans push air through a filter, which encounters a solvent and captures the CO2. The solvent is heated, which releases the CO2 to be stored. Due to the very low CO2 concentration of the earth's atmosphere (0.04%), the energy requirements are huge. Literature on direct air capture's unit costs vary significantly, but are as high as US$440/t. Five companies are currently working on DAC: Global Thermostat, Climeworks, Infinitree, Carbon Engineering and Skytree. Most recently, Oxy Low Carbon Ventures and Carbon Engineering have announced a joint venture to build the world's largest DAC facility capturing 1MtCO2/y, expected to be completed in 2023.

Bioenergy with CCS (BECCS) providing net negative optionality

Biomass feedstock takes in CO2 from the atmosphere through photosynthesis. The biomass is then transported to a conversion facility. The biomass is them combusted (to produce heat for use in electricity generation / industrial applications), or converted to biofuel (using digestion / fermentation processes). CO2 is produced during combustion / conversion; which if captured and stored has a net negative emissions footprint. As of 2019, five facilities around the world were using BECC's technologies, with another three in the pipeline. Again, however, a review of recent literature puts the cost of CO2 between US$15/t and US$400/t. Moreover, literature identifies that the limiting factor or BECCs is not the technology, but the supply of biomass.

Storage (and transportation)

After the CO2 is separated, it then needs to be transported…

After the CO2 is separated, it then needs to be transported to the location of storage. CO2 can be transported via pipeline, rail, truck and ship. Transport by pipeline is the most mature technology. For instance, there is an already extensive onshore CO2 pipeline in North America, with a combined length of more than 8000km. However, shipping offers flexibility. The key considerations for transportation are the distance between source and storage, volume of emissions and the potential to reuse existing infrastructure.

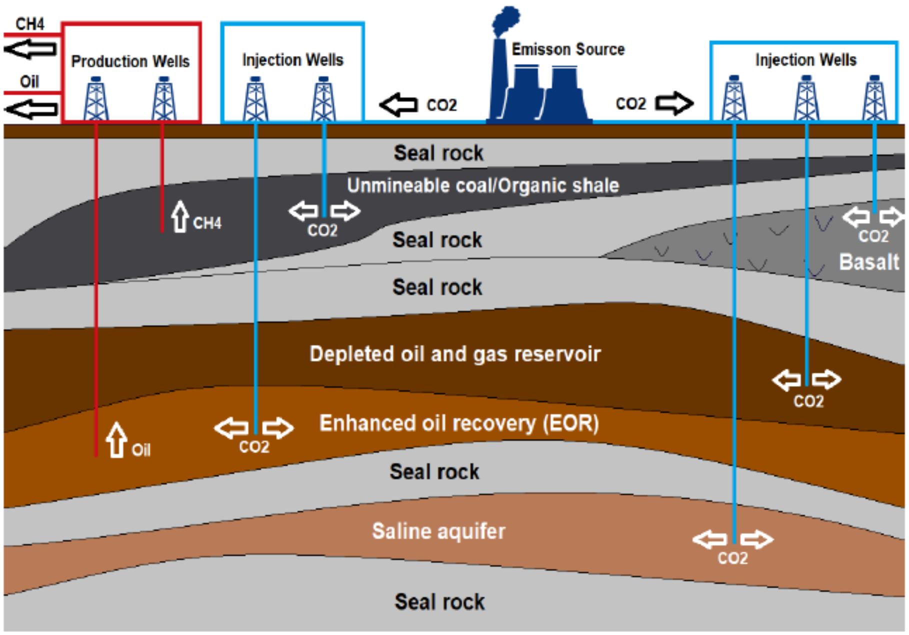
…to be stored in either a depleted oil and gas reservoir or deep saline formation

After the CO2 is separated into a high purity CO2 stream, it is then pressurised into a supercritical fluid and injected into storage. There are two core storage locations for

CO2: depleted/in use oil and gas reservoirs and deep saline formations. The benefit of using oil and gas reservoirs is that the cost of exploration is already a sunk cost. Moreover, using CO2 for enhanced oil recovery (EOR) can cover operational costs due to the potential revenue stream. Meanwhile, deep saline formations involve the injection of captured CO2 into a deep underground geological reservoir of porous rock, covered by an impermeable layer of rocks, which seals the reservoir and prevents the leakage of CO2. Despite the high potential, there is comparatively less knowledge about the CO2 storage features of saline aquifers compared with the other options.

Exhibit 209: Storage sites for CO2

CO2 can be stored in a range of geological sites; yet, saline aquifers and depleted oil and gas reservoirs offer the best permanence and scale



Source: WoodMackenzie

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Storage is unlikely to be a constraint: 8000Gt to 55000Gt

The overall technical storage capacity for storing CO2 underground worldwide is uncertain, particularly for saline aquifers. However, the potential is huge (8000Gt to 55000Gt) and hence is unlikely to be a bottleneck of CCUS adoption. The majority of the estimated CO2 storage capacity is onshore in deep saline aquifers and depleted oil and gas fields. Storage capacity is estimated to range from 6000Gt to 42000Gt for onshore sites. There is also significant capacity offshore, ranging from 2000Gt to 13000Gt.

Utilization: the 'U" in CCUS

The carbon captured can also be used as an input into a range of products and services. Today, around 230mt of CO2 is used globally each year. Consumers include the fertilizer industry (using CO2 as a raw material in urea manufacturing), oil and gas, food and beverages and others. In our view, the most promising area is enhanced oil recovery (EOR):

EOR is the injection of CO2 into nearly depleted petroleum reservoirs, which acts as a solvent that reduces the viscosity of the oil and allows enhanced oil recovery of the reservoir. Once the field is depleted, it can be utilized to store additional CO2 permanently. On average, each new tonne of CO2 used for EOR produces two additional barrels of oil. In 2014, EOR projects in the United States used CO2 to produce approximately 300,000kb/d —more than 2% of US oil production. According to NRG, crude oil prices in excess of US$60/bbl to US$65/bbl are required to cover the operating costs of the capture facilities. Finally, the Clean Air Task Force (CATF) has provided analysis that a barrel of EOR oil emits 37% less CO2 than conventional oil.

Appendix: Eureka 1.0 - what has changed?

Exhibit 210: The 15 technologies from Eureka 1.0
Only 6G features in both Eureka 1.0 and Eureka 2.0

COMPUTING	CLIMATE ACTION	COMMUNICATIONS	NEXT GEN MATERIALS	DISTANCE
Quantum Computing	Geoengineering	6G	Nanotechnology	Hyperloop
Technological Singularity	Nuclear fusion	Nanosatellites	Graphene	Space Tourism
Behavioural biometrics for security	Mass Vertical & Greenhouse Farming	LiFi	3D bioprinting	Deep sea mining

Source: BofA Global Research

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Exhibit 211: Eureka 1.0 – what has changed since 2019 and what lies ahead
Space Tourism is mainstreaming and has advanced the most; Quantum Computing potentially most exciting moonshot; No real world application breakthrough still in most of the moonshots

Type	Name of Technology	Recent Newsflow / Commentary	Why it hasn't worked / What has changed
Computing	Quantum Computing	Google have announced 'quantum supremacy' compared to IBM since 2019; IonQ became the first pure-play quantum computer company to go public via SPAC; D-Wave launched its 5000+ qubit advantage system	Still in infancy, but potentially most exciting moonshot for the future. Governments, private investors, big tech companies investing heavily in this space. But still easily 5-10 years away before delivering any sort of meaningful value
	Technological Singularity	Majority of 995 participants in a recent survey of AI researchers expected AI singularity before 2060	still remains a distant threat to humanity as AI has not outsmarted humans (yet)
	Behavioural biometrics for security	BioCatch has launched behavioral biometric solution in July'21 for compliance with the Strong Customer Authentication (SCA) requirement of Europe's Payment Services Directive 2 (PSD2) to help banks and financial institutions to improve compliant customer experiences	COVID has acted as a catalyst since 2019 with the introduction of vaccine passports, biometrics etc that has enhanced tracking of citizens
Climate Action	Geoengineering	Storegga and Carbon Engineering jointly announced that they have begun engineering and design of a DAC facility, proposed to be the first large-scale facility of its kind in Europe that will permanently remove between 500,000 and one million tonnes of carbon dioxide from the atmosphere annually.	carbon capture storage (CCS) sub theme has gained in traction as fossil industry's last chance saloon
	Nuclear fusion	US National Ignition Facility has taken a significant step towards Ignition, achieving a yield of more than 1.3 megajoules (MJ); Helion Energy became the first private company to achieve 100 million degrees Celsius fusion fuel temperature	still remains moonshot and energy source of the future with fully functioning reactor still years away
	Mass Vertical & Greenhouse Farming	AppHarvest and AeroFarms have publicly listed via SPAC since 2019 and other companies like Infarm, Plenty have made funding announcements	Moonshot in its infancy, but well placed to replace conventional production of food crops

Exhibit 211: Eureka 1.0 – what has changed since 2019 and what lies ahead

Space Tourism is mainstreaming and has advanced the most; Quantum Computing potentially most exciting moonshot; No real world application breakthrough still in most of the moonshots

Type	Name of Technology	Recent Newsflow / Commentary	Why it hasn't worked / What has changed
Communications	6G	Companies have increasingly published theoretical whitepapers on this technology (Samsung, Huawei etc) since 2019	6G will be the successor of 5G mobile technology to transmit mobile data and estimated to be commercially available before the end of this decade
	Nanosatellites	UK government has acquired OneWeb, SpaceX plans Starlink spinoff and has continued launches since 2019	Big future of Nanosatellites still to come with over 2500 nanosats forecasted to launch in six years from now
	LiFi	PureLiFi secured $4.2 million deal with the US Army Europe in Apr'21 to deliver secure wireless communications system, described as the first large-scale deployment of li-fi communication technology	no real world application breakthrough with this technology still disappointing
Next Gen Materials	Nanotechnology	Lipid nanoparticles, next generation liposomes that use nanotechnology, are vital components of the Pfizer/BioNTech and Moderna mRNA COVID-19 vaccines, playing key role in protecting and transporting the mRNA effectively to the right place in cells.	no real world application breakthrough with this technology still disappointing
	Graphene	Nanotech Energy became the first and only producer to break the 50% content barrier in Sep'20 by developing a process that produces 90% monolayer graphene. It is fast approaching 98% now.	no real world application breakthrough with this nextgen material still disappointing
	3D bioprinting	3D printing leader 'Stratasys' enhanced its digital anatomy 3D printer to bring ultra-realistic simulation and realism to functional bone models. Besides, broad spectrum of 3D-printed applications in the fight against COVID-19 included 3D-printed: respirators, ventilator valves, customized face masks, medical manikin, isolation wards, hands-free accessories such as door openers, sanitizers etc	few breakthroughs but economies of scale still haven't been reached
Distance	Hyperloop	Elon Musk Boring Company has created Las Vegas tunnel loop since 2019 and Virgin Hyperloop and Hyperloop TT have made announcements. First passenger test by Virgin Hyperloop in Nov'20 was an success and it intends to begin carrying passengers as early as 2027	Far away from reality with delayed completion timelines, projects still under feasibility study, safety concerns, working within governmental regulations, tube construction issues.
	Space Tourism	SPAC mergers becoming increasingly common: Virgin Orbit, to go public via SPAC merger around the end of 2021; Small launch firm Astra went public through a SPAC in June 2021, becoming the first company of its kind to do so.	Mainstreaming with billionaires Richard Branson and Jeff Bezos going to space within 10 days of each other in July 2021. More than 700 people have already signed up for commercial passenger flights that Virgin Galactic says will start in 2022.
	Deep sea mining	The Metals Company (DeepGreen) has publicly listed via SPAC since 2019	Not started yet. First commercial mining applications may be filed within two years. At the same time, concerns around incomplete regulations and unsettled science of mining's effects.

Source: BofA Global Research

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Disclosures

Important Disclosures

FUNDAMENTAL EQUITY OPINION KEY: Opinions include a Volatility Risk Rating, an Investment Rating and an Income Rating. *VOLATILITY RISK RATINGS*, indicators of potential price fluctuation, are: A - Low, B - Medium and C - High. *INVESTMENT RATINGS* reflect the analyst's assessment of both a stock's: absolute total return potential as well as its attractiveness for investment relative to other stocks within its *Coverage Cluster* (defined below). There are three investment ratings: 1 - Buy stocks are expected to have a total return of at least 10% and are the most attractive stocks in the coverage cluster; 2 - Neutral stocks are expected to remain flat or increase in value and are less attractive than Buy rated stocks and 3 - Underperform stocks are the least attractive stocks in a coverage cluster. Analysts assign investment ratings considering, among other things, the 0-12 month total return expectation for a stock and the firm's guidelines for ratings dispersions (shown in the table below). The current price objective for a stock should be referenced to better understand the total return expectation at any given time. The price objective reflects the analyst's view of the potential price appreciation (depreciation).

Investment rating	Total return expectation (within 12-month period of date of initial rating)	Ratings dispersion guidelines for coverage cluster*
Buy	≥ 10%	≤ 70%
Neutral	≥ 0%	≤ 30%
Underperform	N/A	≥ 20%

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