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Climate-Tech Startups to Watch in 2022: BNEF Pioneers Winners

The winners of BloombergNEF's Pioneers award were announced on April 14. The annual competition searches for game-changing technologies or innovations, with the potential to accelerate global decarbonization and halt climate change. This note profiles each of this year's 12 winners, describing how the technologies work, the maturity of each company and the reasons behind BNEF's decision-making process.

- BNEF has run the Pioneers competition since 2010 and has awarded 129 companies as winners, including this year's Pioneers. Past winners have raised a cumulative total of $14.1 billion in funding, some 53% of which was raised post win. In 2022, BNEF received applications from 273 companies and projects from 27 countries.
- **Challenge 1 – Providing round-the-clock zero-emissions power:** The winners of this challenge are developing new technologies for energy storage (Nuvve's **vehicle-to-grid charging technology** and Energy Dome's **liquid CO_2 battery**), energy generation (Kairos Power's **molten-salt nuclear reactor**), and power grid monitoring (Reactive Technologies' **real-time inertia measurement system**).
- **Challenge 2 – Scaling long-term carbon removal:** The winners of challenge 2 are developing new technologies for carbon storage (Carbfix's **carbon mineralization** process), soil carbon sequestration (Climate Robotics' **mobile biochar production** unit), and direct air capture (Verdox's energy-efficient, **electrochemical capture** process).
- **Challenge 3: Decarbonizing aviation:** The winners of the aviation challenge are developing new technologies for power-to-fuels (Twelve's **CO2-to-fuels** electrolysis process), and hydrogen-powered flight (ZeroAvia's **hydrogen aircraft** designs).
- **Wildcards:** This year's wildcards are innovating in the important and diverse fields of batteries (Addionics' **3D electrode** design), air conditioning (Blue Frontier's **efficient and flexible air conditioning** unit), and point-source carbon capture (Carbon Clean's cost-effective, modular **carbon capture** equipment).

Figure 1: BNEF Pioneers 2022

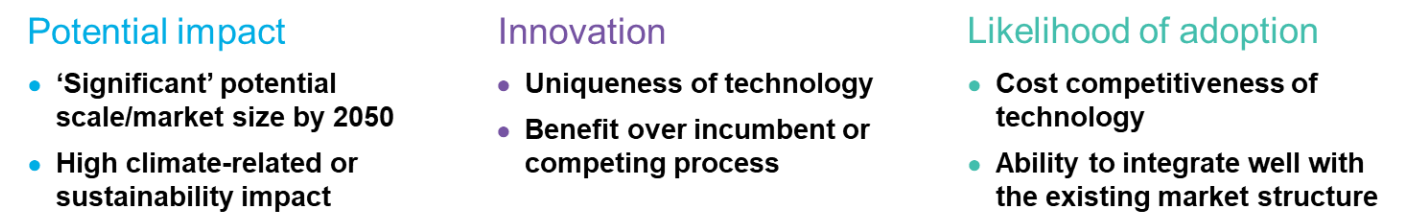
Source: BloombergNEF

1. How does BNEF choose its Pioneers?

Each year, BNEF awards the Pioneers prize to innovators addressing three pre-selected challenges, and also recognizes a few 'wildcard' winners, outside of these challenge categories. BNEF chooses its Pioneers in a four-step process:

1. **Choosing the challenges:** BNEF chooses its climate change challenge areas each year through discussions with each of our sector teams. The themes focus on topics where there is a lack of a clear technology solution to an urgent climate challenge. These technology gaps emerge from BNEF's long-term outlooks on energy, industry and transport such as the *New Energy Outlook* (web | terminal) and *Electric Vehicle Outlook* (web | terminal).
2. **Finding the applicants:** BNEF searches for potential applicants using its own startup databases and published research, as well as analyst knowledge. We solicit applications from our analysts, network of clients and research contacts. About half of the 250-300 applications that BNEF receives each year are solicited, while the other half come from our open application portal. Winners are often chosen from the pool of unsolicited applications.
3. **Choosing the finalists:** Each application is read and scored by a relevant sector analyst based on the dimensions of potential impact, innovation and likelihood of adoption (Figure 2). Top-scoring companies are put through as finalists. BNEF attempts to represent a diverse range of technologies with the finalists, rather than relying solely on quantitative scores.
4. **Choosing the winners:** BNEF conducts a full day of finalist judging, where an analyst champion pitches each finalist, using a prepared presentation and written profile. The judges are the BNEF management committee, which uses a voting and discussion process to determine the winners of the competition.

Figure 2: Scoring dimensions for BNEF Pioneers applicants

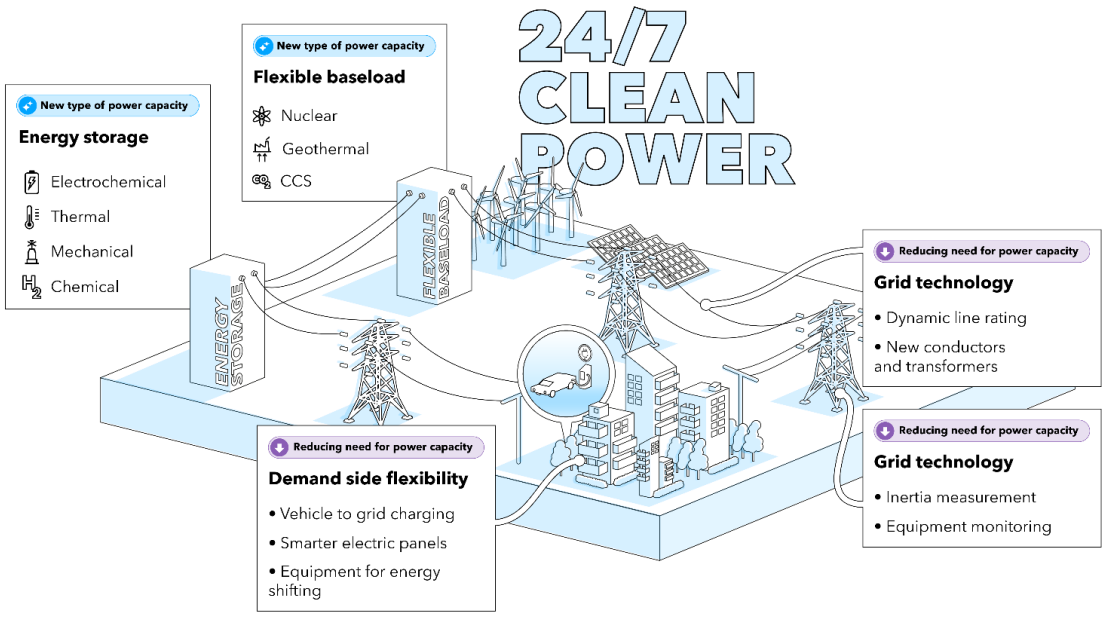


Source: BloombergNEF

2. Challenge 1: Providing round-the-clock zero-emissions power

Solar, wind and existing storage technologies can provide around three-quarters of our electricity needs in future, but to reach net-zero emissions requires other technologies to close the remaining gap. Eliminating the use of unabated fossil fuels, affordably, could require innovation in new and/or improved forms of net-zero baseload generation, storage and grid technologies (Figure 3). This chapter profiles the four Pioneers winners in this category.

Figure 3: Potential technologies for providing round-the-clock zero-emissions power



Source: BloombergNEF

2.1. Energy Dome

Table 1: Energy Dome company details

Name	HQ	Founded	Funding	Technology
Energy Dome	Italy	2019	$15 million	Liquid-CO_2-based long-duration energy storage

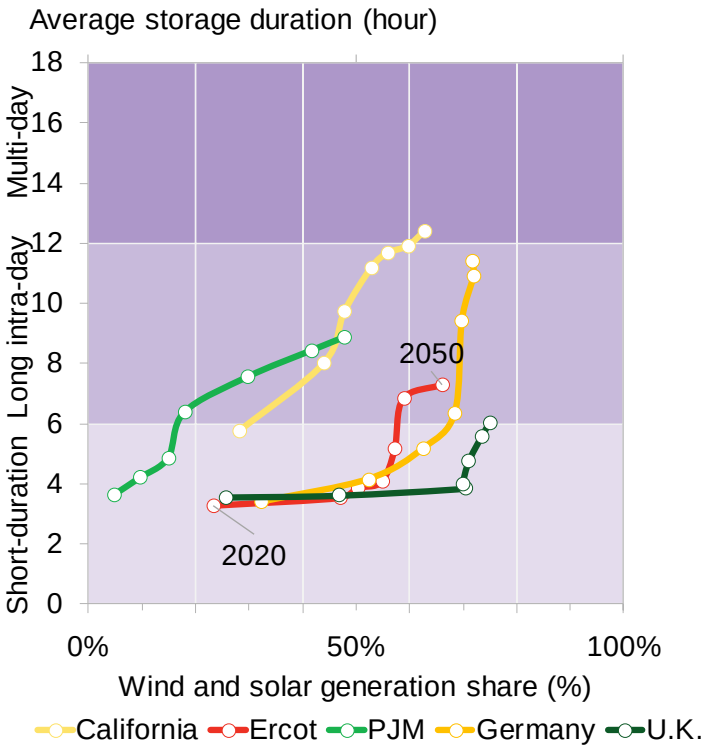
Source: BloombergNEF

Why is innovation needed in long-duration energy storage?

Energy storage systems will shift into the range of 4-12 hours in the coming decades

BNEF analysis on the cost declines of lithium-ion batteries shows that they will be a valuable tool in shifting renewable energy to hours when wind and solar generation are low. As renewable energy saturates the power system, however, energy storage systems will need to store energy for longer durations. They will cycle less often, but dispatch for a longer duration. This helps absorb more renewable surplus, reduce the use of fossil fuels and lower overall power system costs. BNEF research estimates that the average duration required of energy storage systems will shift into the range of 4-12 hours in the coming decades, with the exact figure depending on renewable power penetration (Figure 4) and the cost of long-duration storage products. While lithium-ion batteries are still falling in cost, they are unlikely to be the most cost-effective solution for storage systems of this duration.

Figure 4: Correlation between storage annual average discharge duration and renewable generation penetration, 2025-50, Economic Transition Scenario



Source: BloombergNEF. Note: we modeled the 8,760-hour least-cost power system using BloombergNEF proprietary NEFM model. Then we captured each storage dispatch duration over the entire year from 2020 to 2050, aggregated the data and conducted statistical analysis.

On March 11, 2022, Energy Dome announced its first commercial licensing agreement with Italian power engineering firm Ansaldo Energia

What is Energy Dome's technology?

Energy Dome's storage technology uses off-the-shelf components

Energy Dome's CO_2 battery uses electricity to compress CO_2 and store it as a liquid at ambient temperatures. The liquid CO_2 is stored in tanks at medium pressure to keep it in a liquid state. To discharge energy, the system releases liquid CO_2 from the pressure vessel, heats it with heat generated and stored during the charging (compression) stage, turning it back into a gaseous state, and that pressurized gas flows through a turbine, generating electricity with no atmospheric emissions. The CO_2 is returned to the storage dome where it will be repressurized when new energy is stored. Energy Dome's technology does not call for the development of new pieces of industrial kit and can be assembled from existing tried and tested components that are widely available from a global supply chain.

Why is Energy Dome a Pioneer?

Energy Dome's liquid-CO_2 storage technology has yet to be commercially demonstrated, but has many of the required characteristics to meet the role of 4-24 hour-duration storage. The company's CO_2 battery technology features high energy density (versus gravity-based or thermal storage), relatively high round-trip efficiency (>75%), flexible siting (versus pumped hydro, compressed air energy storage), synchronous inertia (versus electro-chemical batteries) and ambient temperature level liquification (versus liquid-air requiring operation at extreme cryogenic

temperature). All of which is achieved with a simple and reliable process comprised of well-known equipment.

How mature is Energy Dome?

Energy Dome was founded in 2019 and is about to test its first commercial-scale CO_2 battery, with successor deals of 20MW-100/200MWh that are expected to reach financial close in 2022. On March 11, 2022, Energy Dome announced the first commercial licensing agreement of its technology with Italian power engineering firm Ansaldo Energia.

Energy Dome has raised $15 million, $4 million in seed rounds and $11 million in a Series A in November 2021. Investors in the round include 360 Capital Partners, Barclays, Novum Capital as well as Third Derivative. The company has also taken part in several accelerator programs including Plug and Play's and Third Derivative's, and is also a Greentown Labs HQ Member.

The adoption of LDES technologies will be slow over the next 5-10 years, according to BNEF. This is because renewables penetration is not yet high enough to require such long storage durations. Nevertheless, Energy Dome is well poised to capitalize on demand for longer duration storage as it materializes, but must rely to some extent on new policies that reward assets providing long-term reserves and which meet resilience needs.

2.2. Kairos Power

Table 2: Kairos Power company details

Name	HQ	Founded	Funding	Technology
Kairos Power	U.S.	2016	NA	Molten-salt nuclear reactor

Source: BloombergNEF

Why is innovation needed in nuclear energy?

Studies have shown that it would be feasible to develop net-zero power systems that rely entirely on variable renewables such as wind and solar. However, a diverse portfolio of power generation resources will likely make the power system significantly cheaper. Long-duration energy storage technologies like those being developed by EnergyDome should be able to shift some variable renewables output, but it likely will not be cheap enough to displace all baseload generation. Zero-carbon baseload, such as nuclear, will also be a valuable tool in delivering a least-cost power system.

The safety of Kairos' reactor design eliminates the need for an expensive containment unit, lowering costs and reducing plant footprint.

Nuclear power is already a reliable and zero-carbon source of power but concerns around its cost and safety have caused the industry to stagnate. New innovations could overcome these challenges and gain public support for the technology. While nuclear fusion startups have received much investment attention recently (see: *Still Distant Fusion Emerging As a Net-Zero Option* (web | terminal)), there are also many innovations still to be made with nuclear fission.

What is Kairos Power's technology?

Kairos Power is developing an advanced 140MW_e fluoride salt-cooled high-temperature reactor. Its FLiBe molten-salt coolant is a mixture made from lithium fluoride and beryllium fluoride. Kairos' reactor is designed to be lower cost because of the inherent safety of its defining features. Its FLiBe coolant is able to operate under atmospheric pressure and the reactor uses TRISO (tri-

structural ISOtropic fuel). TRISO fuel particles are made of a uranium, carbon and oxygen kernel coated with multiple ceramic layers. This outer shell is extremely tough and provides robust containment for fission byproducts. The TRISO particles are then embedded in graphite and pressed into pebbles the size of ping-pong balls. TRISO fuel has a melting point higher than maximum reactor temperature, eliminating the possibility of core melt down.

Operating at low-pressure eliminates the need to construct an expensive reactor containment vessel, thereby reducing the cost and physical footprint of the plant. TRISO fuel is also proliferation-resistant due to the high burn-up of the fuel and consequent plutonium composition.

Why is Kairos Power a Pioneer?

Kairos does not anticipate commercial sales until 2030

Kairos Power is a leader in the development of next-generation fission reactors. The technology may generate fewer headlines than fusion, but is closer to commercialization and could deliver a cheaper and safer version of nuclear than exists today. Kairos is partnering with leading nuclear institutions and national laboratories in the U.S. that are supporting the development of its technology. The startup is among a select few advanced development reactor companies to receive government support. It has relationships with the Tennessee Valley Authority, Oak Ridge National Lab, Idaho National Laboratory, and the Electric Power Research Institute. Kairos has also been the recipient of funding from the U.S. DOE. Meanwhile, its executive suite is well-respected in the industry.

How mature is Kairos Power?

Following an extensive pre-application engagement with the U.S. Nuclear Regulatory Commission, Kairos is in the process of developing its Hermes 35MW_{th} pilot project, which will evolve into additional renditions prior to full-scale deployment of its commercial reactor. As a reactor-development company, Kairos does not anticipate commercial sales until 2030. While there is no publicly available funding data, the company is reportedly well-funded privately.

2.3. Nuvve

Table 3: Nuvve company details

Name	HQ	Founded	Market cap	Technology
Nuvve	U.S.	2010	$154 million	Vehicle-to-grid charging

Source: BloombergNEF

Why is innovation needed in vehicle-to-grid charging?

If China's EV fleet were capable of vehicle-to-grid charging in 2040, the total capacity would exceed the country's peak power demand

In the case where China's EV fleet were capable of vehicle-to-grid charging in 2040, the total capacity would exceed the country's peak power demand. This potential flexibility built into EV fleets presents one of the cheapest opportunities for preventing the buildout of expensive baseload generation and excess renewables capacity, in order to economically deliver 24/7 zero-emissions power. For more on V2G charging see: *Vehicle-to-Grid: Big Opportunities, Big Challenges* (web | terminal).

What is Nuvve's technology?

Nuvve offers three main pieces of technology differentiation. Firstly, it has developed virtual power plant (VPP) software for managing charging loads of EV fleets. Second, the company has created

communication protocols to allow chargers, EVs and the grid to talk to each other simultaneously. Previously, these components would not have been able to communicate. Finally, it has also developed bi-directional charging hardware in conjunction with third-party manufacturers that comes pre-loaded with its software platform.

Nuvve has multiple revenue streams. Its primary model is to use the VPPs created by its fleet customers to provide grid services such as frequency regulation, peak shaving and demand response. Another revenue stream is via its fleet-as-a-service model. With this model, Nuvve provides a fleet of electric vehicles, EV charging infrastructure, energy for the vehicles, energy management and maintenance to customers for a flat monthly fee.

Why is Nuvve a Pioneer?

Nuvve is a pioneer in V2G-charging technology. The company, founded in 2010, has developed both virtual power plant software and bi-directional charging hardware to manage the charging of EV fleets and amassed an impressive list of OEM, EVSE and technology partners and financiers, including BYD, EDF and Stonepeak Partners.

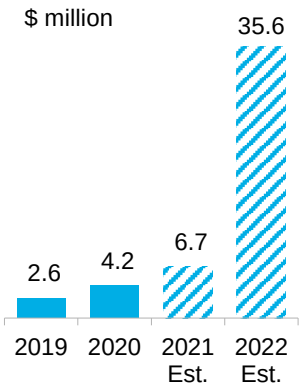
How mature is Nuvve?

For a technology that has yet to see much commercial traction, Nuvve has a lot of experience in the industry. The company was founded in 2010 as a spinout from the University of Delaware. It deployed V2G successfully across five continents, including successful commercial installations in Denmark and the U.S. The company was particularly busy in 2021:

- In March 2021, Nuvve went public via reverse merger, raising $62 million in cash proceeds from the deal at a valuation of $131 million.
- In August, Nuvve agreed to create a joint venture with Stonepeak Partners named Levo. This JV has $750 million available to finance EV fleets and charging infrastructure for fleet owners and operators.
- Also, in August, Blue Bird – a leading maker of school buses in the U.S. – said it would partner with Levo, using its financing capabilities to sell electric fleets through its distribution network. School buses are an ideal early target for V2G charging technology due to the long durations they are spent parked and unused.
- In October, Nuvve announced it would integrate its V2G technology into a mix of BYD battery-electric vehicles and finance the deployment of up to 5,000 medium- and heavy-duty EVs through Levo.
- In November, Nuvve and Blue Bird announced a first-of-its-kind V2G hub that would utilize 200 bidirectional DC fast chargers to create a VPP with up to 25MW of capacity.

Nuvve estimates that its revenues will amount to $6.7 million in 2021 (Figure 5). While its stock price has declined to $6.31 from a high on its debut of $22.27, the company spent most of the past year as one of the better performing EV charging companies to have gone public. This kind of price decline has been typical of most climate-related (as well as non-climate-related) reverse mergers this year. For more on transport related public markets deals see *Newly Listed EV Companies Raised $29 Billion in 2021* (web | terminal).

Figure 5: Nuvve revenues



Source: BloombergNEF

2.4. Reactive Technologies

Table 4: Reactive Technologies company details

Name	HQ	Founded	Funding	Technology
Reactive Technologies	U.K.	2010	$15 million	Grid inertia measurement

Source: BloombergNEF

Why is innovation needed in grid-inertia management?

A lack of inertia – rotational energy in turbines – increases the likelihood of blackouts

One major challenge in the transition to a zero-carbon power system is that inertia in the power system will decline as more fossil-fired thermal generation assets come offline. Inertia is the rotational energy stored in spinning power generators. Inertia is an essential tool in grid stability because any shifts in voltage or power supply are absorbed by the inertia of the system, preventing blackouts. A lack of grid inertia will lead to more blackouts.

What is Reactive Technologies' technology?

Reactive Technologies has developed both hardware and software to allow grid operators to measure inertia accurately and in real-time. The technology works by injecting power signals, called Grid-Sonar, into the grid and measuring any changes in frequency. The process relies on two pieces of Reactive hardware: an ultracapacitor, which sends the signals, and extensible measurement units (XMUs), which are sensors that measure frequency on the electrical grid and voltage on the power network. Reactive provides its inertia measurement technology to transmission and distribution system operators.

Reactive says that 10-30% of total inertia on the grid is at this distribution level, which is currently inaccessible

Reactive says that as well as allowing its customers to access accurate and real-time inertia measurements, it should also give them total visibility on the inertia that is available in the distribution grid – stored in equipment such as pumps and motors. Reactive says that 10-30% of total inertia on the grid is at the distribution level. This could provide a significant share of total inertia to the grid in scenarios where solar, wind and batteries make up >80% of generation.

Why is Reactive Technologies a Pioneer?

Currently, grid operators have very poor visibility on the level of inertia available to the power system. Meaning that they must act conservatively, keeping thermal power assets online and curtailing renewables. By knowing exactly how much inertia is on the grid, grid operators can reduce their demand for fossil fuel thermal power for frequency response and avoid renewables curtailment. Inertia management cannot deliver net-zero power by itself, but it will be a tool for making the most of existing assets with rotational energy, reducing the capacity of thermal assets.

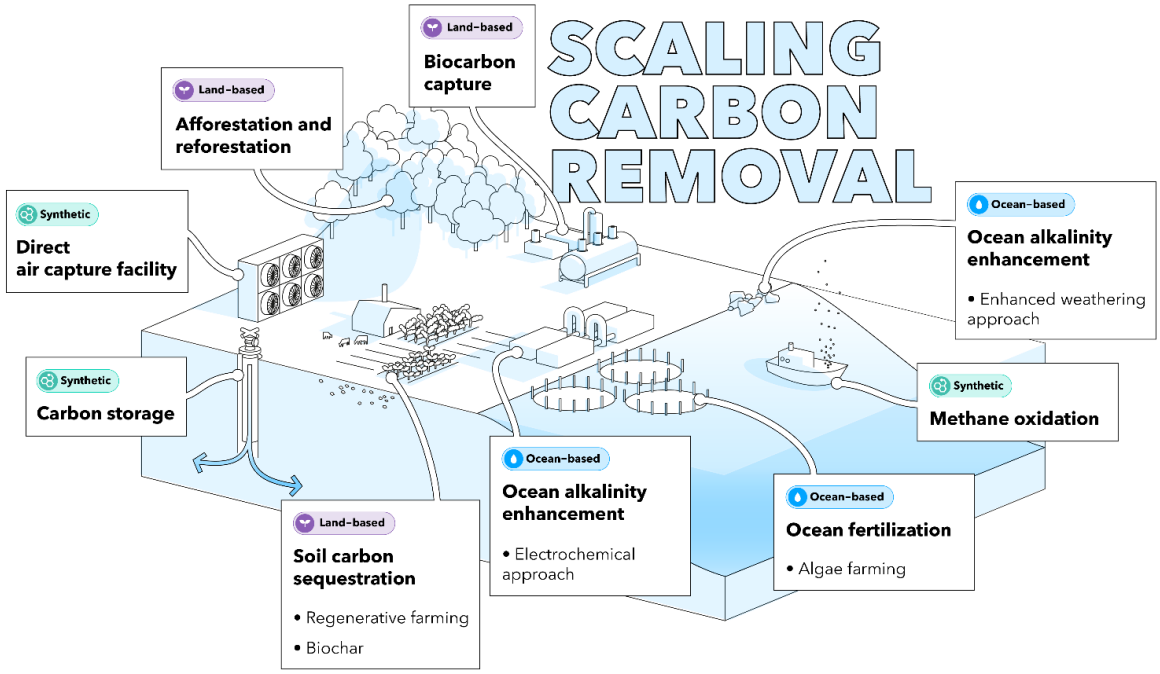
How mature is Reactive Technologies?

Reactive is in the early stages of developing its customer base but is quickly gaining momentum. The company is tackling an important challenge, and – unlike many technologies covered in this note – is cost-competitive under current market conditions. In October 2021, Reactive announced its largest project yet with the National Grid in the U.K. The company raised $15 million in August 2021 from investors including Breakthrough Energy Ventures, BGF and grid-equipment maker Eaton. Reactive is currently scaling up, setting up hubs in North America, Japan and elsewhere across the globe.

3. Challenge 2: Scaling long-term carbon removal technologies

Meeting net-zero targets will first and foremost require rapid, deep emissions reductions, but it is becoming clear that removing carbon from the atmosphere will also be needed to avoid warming above 1.5 degrees. Calculations of the extent of removal required vary significantly, but BNEF's Gray Climate Scenario requires 21.5 billion metric tons of carbon removal between 2023 and 2050, and Mark Carney has called for a $100 billion per year voluntary offset market. New innovations could include ways to improve existing nature-based carbon removal or finding ways to scale regenerative farming and ocean fertilization. Innovations for new technologies that offer measurable, scalable and long-term removal – such as direct air capture – must also be explored (Figure 6).

Figure 6: Potential technologies for scaling carbon removal



Source: BloombergNEF

3.1. Carbfix

Table 5: Carbfix company details

Name	HQ	Founded	Funding	Technology
Carbfix	Iceland	2007	Subsidiary of Reykjavik Energy	Carbon storage

Source: BloombergNEF

Why is innovation needed in carbon storage?

Currently, the most mature carbon-storage techniques inject CO_2 into deep saline aquifers or depleted oil and gas reservoirs where it is trapped underground by a caprock. CO_2 storage sites using these approaches in reality have a small risk of leakage, but the existence of such a risk lowers public acceptance and means that site monitoring is required. By adding alternative

storage techniques, storage could be applied in areas where it has not been previously considered. This increases the opportunities for pairing of sinks and sources, reduces transport costs, and adds to the potential CO_2 storage reservoirs worldwide.

What is Carbfix's product/technology?

Carbfix is a CO_2 storage company that imitates and accelerates the process that nature applies to regulate CO_2 levels in the atmosphere by storing CO_2 through carbon mineralization – i.e., turning carbon into stone for permanent storage. Its process dissolves CO_2 in water to produce a slightly acidic carbonic acid. This carbonic acid is then injected into underground cracks in basaltic rock formations. The carbonic acid reacts with free cations (e.g. Ca^{2+}, Mg^{2+}, Fe^{2}) in the rock formations causing it to turn into carbonate (i.e. stone). The process currently relies on the use of freshwater but the use of seawater is also being explored, and pilot injection of seawater-dissolved CO_2 is expected in 2022.

Carbfix has demonstrated that 95% of the CO_2 it injects into basaltic formations is mineralized within two years – eliminating the risk of any CO_2 leakage. The water injected into the subsurface is also slightly denser than the water naturally found in the formations, and is therefore likely to sink to the bottom rather than leak, in the event that it does not mineralize. Studies have shown Carbfix's solution to be safe.

Carbfix estimates that the storage potential of its process is 4,000GtCO_2 in Europe and in the U.S. is 7,500GtCO_2

Carbfix's technology is reliant upon volcanic rocks such as basalts. These rocks are abundant in regions with high-temperature geothermal energy resources, such as Iceland, East Africa and areas around the Pacific Ocean. These areas are also conveniently where geothermal energy – a low-carbon baseload source of power and heat that can be used to power direct-air capture plants – can be plentifully found. This means Carbfix's storage sites could be located relatively close to sources of zero-carbon baseload, and therefore direct air capture plants. Carbfix estimates that the storage potential of its process in Iceland is approximately 400 GtCO_2, while Europe could store 4,000 GtCO_2 and the U.S. 7,500 GtCO_2. This would be more than enough to serve the next century of carbon removal, even in high use-case scenarios.

Why is Carbfix a Pioneer?

Carbfix has emerged as an early leader in carbon mineralization, an interesting new approach to carbon storage. It has demonstrated the safety of its process and signed partnerships with several industry stakeholders. It is also innovating on the business model of storage with its Coda Terminal – showing what the future of a carbon-capture based economy might look like.

How mature is Carbfix?

Carbfix is founded on an academic collaboration dating back to 2007. Following the study of natural analogs for CO_2 mineral storage, extensive laboratory testing and modelling between 2007 and 2012, a series of injection experiments were carried out in the vicinity of the Hellisheidi power plant. After a successful verification of the injection system in late 2011, the pilot injection was begun in January 2012.

Since 2014, Carbfix has stored over 80,000 metric tons of CO_2 captured from a power plant in Iceland

Carbfix is a wholly owned subsidiary of Reykjavik Energy and has been financially supported by its parent company as well as various EU funds. Reykjavik Energy reported that, in 2021, Carbfix's revenues were largely derived from grants – noting a $4.5 million (3.9 million euros) grant from the EU's Innovation Fund in particular. While the company has yet to build any significant revenues, it has signed several partnerships granting its credibility in the carbon capture space:

- Since 2014, Carbfix has stored more than 80,000 metric tons of CO_2 captured from a power plant in Iceland. Carbfix is furthermore commissioning three pilot injections to develop different aspects of its technology in 2022.
- Carbfix is the storage partner for Climeworks' Orca project, the world's largest direct air plant, which has an annual capture capacity of 4,000 tCO_2.
- Rio Tinto has contracted Carbfix as a storage partner for the point-source carbon captured at its ISAL aluminum smelter in Iceland. Furthermore, the U.S. Department of Energy has awarded $2.2 million of funding to a Rio Tinto-led team, of which Carbfix is a part, to explore the CO_2 storage potential at a site based in Minnesota.
- Carbfix has signed an MoU with Aker Carbon Capture to offer their carbon capture and storage services as a combined package.

Carbfix's next major project is the development of its Coda Terminal. The Coda Terminal represents the first scale-up of the Carbfix technology at a large scale. Coda will be located in south-west Iceland and will be able to receive and inject 5,000 tCO_2/year from 2026, scaling up to 3 $MtCO_2$/year by 2031.

3.2. Verdox

Table 5: Verdox company details

Name	HQ	Founded	Funding	Technology
Verdox	U.S.	2019	$80 million	Direct air and point-source carbon capture

Source: BloombergNEF

Why is innovation needed in direct air carbon capture?

Direct air capture (DAC) is likely to be a core component of any emissions scenario that relies on negative emissions. While nature-based solutions could be cheaper by leveraging naturally occurring processes, there is more uncertainty regarding the ability to scale nature-based carbon removal to the gigaton-level without disrupting natural ecosystems. For more on direct-air capture see: *Material Tech Highlight: Direct Air Capture* (web | terminal).

What is Verdox's product/technology?

Verdox uses an electrochemical energy potential to absorb and strip CO_2 from its sorbent, rather than using temperature or pressure changes

A swing cycle in carbon capture refers to the process whereby CO_2 clings to a surface (adsorption) and is stripped from the surface (desorption). Traditional direct air capture processes use differences in temperature and pressure to induce a swing cycle on a particular sorbent. The combination of low temperature and high pressure cause CO_2 to cling to a surface, whereas high temperature and low pressure strip CO_2 from the surface. Creating these temperature and pressure differentials is the reason for why direct air capture has large energy demands – and often requires temperatures in excess of 900°C.

Verdox is trying to reduce the energy intensity of carbon capture by relying on an "electro-swing" cycle, rather than one based on temperature and pressure. Verdox has created an electrochemical cell where, by altering the voltage across the electrodes, one side of the cell gains an affinity for CO_2, causing CO_2 to cling to the electrode. It can then similarly "discharge" the CO_2 once the electrode is saturated. As well as being up to 70% less energy-intensive, this

electro-swing cycle is fully electrified – compared with some processes that rely on burning natural gas to generate high temperatures in the regeneration of sorbents.

Why is Verdox a BNEF Pioneer?

Verdox is a leader in developing a type of DAC process – based on electrochemistry – that could undercut the cost of current DAC leaders by reducing the need for energy, particularly heat, in the capture process. The technology also has applications in point-source capture for flue gases with low levels of CO_2 concentration, such as aluminum.

How mature is Verdox?

Verdox raised $80 million in 2021

Verdox is at an early stage of company development. The journal article upon which its process is based was only published in October 2019 and the company was founded shortly thereafter. Momentum is gathering fast, however, with the announcement of an $80 million round of financing in 2021. Investors include Breakthrough Energy Ventures, Prelude Ventures and Lowercarbon Capital. It has also in the past been awarded grants from ARPA-E.

In February 2022, Norsk Hydro – Europe's largest aluminum maker – announced that it had invested $20 million in Verdox. Norsk Hydro said in its announcement that it had examined 50 carbon-capture technologies for their potential to decarbonize aluminum production and stated that Verdox's technology was particularly suitable for the low concentration CO_2 produced by its aluminum smelters (1% concentration in smelters versus 4% in power plants). The company said Verdox's point-capture solution would ensure the competitiveness of its existing smelters, while meeting its climate ambitions.

3.3. Climate Robotics

Table 6: Climate Robotics company details

Name	HQ	Founded	Funding	Technology
Climate Robotics	U.S.	2020	$4.7 million	Nature-based carbon removal (biochar)

Source: BloombergNEF

Why is innovation needed in nature-based carbon capture?

Nature-based offsets are currently cheap but are difficult to verify and have low levels of permanence

Nature-based carbon offsets are currently the cheapest way to offset carbon emissions and they dominate the supply of voluntary carbon markets. Nature-based offsets are, however, largely based on afforestation and reforestation. The carbon stored in these projects has a low level of permanence and is difficult to verify. Natural ecosystems could prove a valuable tool in delivering low-cost carbon removal, but improvements are needed. For more on the potential of nature-based carbon removal solutions see: *The Land and Ocean's Role in Atmospheric Carbon Removal* (web | terminal).

What is Climate Robotics' product/technology?

Climate Robotics is developing a system that collects agricultural waste and pyrolyzes it to produce biochar (Figure 7). Had the agricultural waste been left to decay, carbon stored in the biomass would be released into the atmosphere. Biochar, produced via pyrolysis, is a much more stable form of carbon and does not release carbon into the air. By depositing the biochar on the soil, which enhances soil health, bio-based carbon will remain sequestered in the soil for

hundreds to thousands of years[1]. It is important to overcome this hurdle of 100 years of storage permanence, because if removals are not stored for this duration, then they will need to be recaptured within the next century while the world may still be warming.

Climate Robotics' biochar will sequester biogenic carbon in the soil for centuries

Climate Robotics deposits biochar into the top 10 centimetres of soil, meaning that the process can be repeated on a seasonal basis as the land is tilled. The world's soils are a viable sink for removing gigatons of carbon, but they will saturate within decades if utilized. Climate Robotics points to research that says its process can be used for at least 40-60 years on an acre of land without having a negative impact on soil quality – although this assumes higher rates of biochar application than most studies examining the practice. Solutions that can draw down carbon for decades can play an important role in negative emissions scenarios. By the time these carbon sinks saturate, the economy should have transitioned to net zero.

Figure 7: Climate Robotics system

Source: Climate Robotics

Why is Climate Robotics a Pioneer?

Onsite biomass pyrolysis could eliminate 80% of the cost compared with centralized plants

Climate Robotics has developed a process to store carbon in soils for hundreds to thousands of years. Its technology addresses shortcomings that have historically held back the biomass processing industry. A huge challenge in the processing of biomass is the cost of transporting it to central locations for processing. BNEF research estimates that harvesting and transport costs account for about 80% of waste biomass feedstock costs. Centralized plants that rely on waste biomass as a core input to their process can also suffer from lock-in once a plant is constructed. Surrounding suppliers can increase their prices easily as the centralized plant relies upon them for supply. In contrast, Climate Robotics' process of harvesting waste and producing biochar onsite at farms eliminates the transport costs associated with collecting waste biomass for pyrolysis, as well as the costs of distributing biochar for use.

How mature is Climate Robotics?

Like most nature-based offset providers selling offsets with durability of greater than 100 years, Climate Robotics is at a very early stage. The company was founded in 2020 and Pitchbook reports that it has raised $4.7 million to date. The vast majority of this was raised in a $4.4 million seed round, with investment from Congruent Ventures, Zag Capital and Graph Ventures. Climate Robotics also received an undisclosed investment from Exelon as part of the company's Climate Change Investment Initiative. Its only publicly announced project is a contract with Microsoft – a

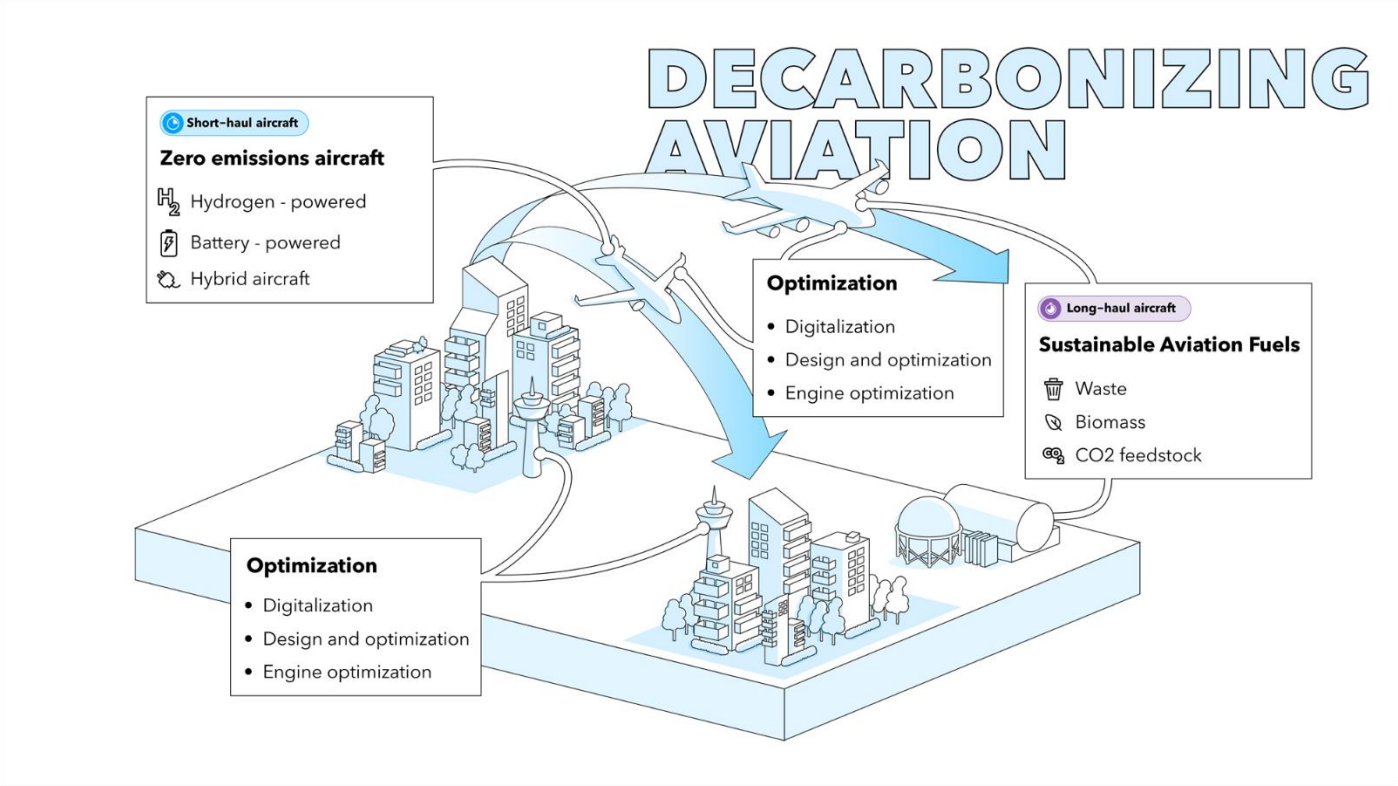
[1] Climate Robotics' process is not, strictly speaking, a carbon-removal or negative emissions technology. Rather it prevents emissions that would have occurred in the natural decay of biomass. This is functionally the same as removing carbon.

leader in corporate offset procurement – to remove 1,000 tCO_2 at a contracted durability of 200 years. The project will operate in Texas and sequester 2.2 tCO_2/acre annually.

4. Challenge 3: Decarbonizing aviation

Commercial aviation accounts for 2% of annual global CO_2 emissions and airplane contrails contribute toward global warming. As air travel becomes more affordable for an increasing share of the world's population, demand for air miles is set to triple between 2019 and 2050. Innovation is needed to develop commercially viable sustainable aviation technologies. While there is some promise in electrifying short-haul flights, and some use cases for biofuels and hydrogen, none of these have scaled up. New innovations could include advances in these technologies, as well as new engine and component design, flight efficiency and traffic control improvements (Figure 8).

Figure 8: Potential technologies for decarbonizing aviation



Source: BloombergNEF

1.1. Twelve

Table 6: Twelve company details

Name	HQ	Founded	Funding	Technology
Twelve	U.S.	2015	$58.8 million	Carbon utilization (jet fuel)

Source: BloombergNEF

Why is innovation needed in sustainable aviation fuels?

More than 80% of emissions come from flight routes exceeding 1,000km. Sustainable fuels are the only viable low-carbon option for these routes in the near term.

There are three main technology routes to address emissions from flight: battery-powered planes, hydrogen-powered planes and drop-in sustainable aviation fuels (SAFs) derived either from biomass or CO_2. Of these options, SAFs are the only viable carbon-neutral route for long-haul aviation in the near term. More than 80% of emissions come from flight routes exceeding 1,000 km. Bio-based SAFs currently supply almost the entire SAF market, but there are concerns around the potential land-use implications of relying on biomass as the only solution. Cost-competitive CO_2-derived fuels could therefore be a valuable asset in decarbonizing the aviation sector. For more on SAF see: *Sustainable Aviation Fuel (Part 1): Pathways to Production* (web | terminal).

What is Twelve's technology?

Twelve – formerly known as Opus 12 – has developed a polymer-electrolyte membrane (PEM) CO_2 electrolyzer that uses CO_2, water and electricity as inputs and produces carbon monoxide (CO) and syngas as outputs, with oxygen as the only byproduct. The company's IP lies in the electrolyzer's catalysts. Twelve is differentiated from other CO_2-to-fuels technology companies because its process is fully electrified and does not require high temperatures to generate a reverse water gas shift reaction (Figure 9 and Figure 10). Twelve's CO and syngas products can be turned into a drop-in jet fuel called E-Jet(R), which when burned, does produce emissions but reduces overall lifecycle emissions by up to 90% compared with fossil-based kerosene, according to analysis by Twelve and its third-party auditors.

Figure 9: Typical CO_2-to-fuels process

$$\textbf{RWGS: } CO_2 + H_2 \rightarrow CO + H_20$$
$$\textbf{FTS: } nCO + (2n+1)H_2 \rightarrow C_nH_{2n+2} + nH_20$$

Figure 10: Twelve CO_2-to-fuels process

$$\textbf{CO}_2\textbf{ Electrolysis: } CO_2 + H_20 \rightarrow CO + H_2 + O_2$$
$$\textbf{FTS: } nCO + (2n+1)H_2 \rightarrow C_nH_{2n+2} + nH_20$$

Source: BloombergNEF. Note RWGS (Reverse water gas shift), FTS (Fischer-Tropsch synthesis). The FTS reaction is what converts CO and hydrogen to fuels.

Why is Twelve a Pioneer?

Twelve's CO_2 electrolysis is fully electrified and does not require high temperatures, unlike its competitors

Twelve has developed the world's first commercial PEM CO_2 electrolyzer. This is an attractive alternative to an energy-intensive and high-temperature chemical reaction (known as the reverse water gas shift) that other companies are investigating to split CO_2 and create new products. This technology is useful for the utilization of CO_2 in many sectors – Twelve will first focus on the CO market, which spans chemicals, materials and fuels – and it could be an important step in making power-to-fuels for the aviation industry more commercially competitive.

How mature is Twelve?

Twelve was founded in 2015 and has received consistent, small rounds of funding from grants and accelerators. In 2021, the company raised a $57 million Series A. Twelve does not produce jet fuel itself, but rather its process produces CO and syngas, so it has focused on developing a wide range of customers. Its process has been used to create more materials from CO_2 in partnership with clothing companies and automakers such as Pangaia and Mercedes-Benz. In the fuel space, it has made two important partnerships. In 2021, it partnered with the U.S. Air Force to produce the world's first jet fuel made via CO_2 electrolysis, and test that it is drop-in ready. In March 2022, it partnered with Lanzatech – a BNEF Pioneer winner in 2012 – to convert CO

produced from Twelve's electrolysis into ethanol using Lanzatech's reactor technology, which can then be used to make jet fuel.

4.1. Zero Avia

Table 7: ZeroAvia company details

Name	HQ	Founded	Funding	Technology
ZeroAvia	U.S.	2018	$114 million	Hydrogen-powered aircraft

Source: BloombergNEF

Why is innovation needed in hydrogen-powered flight?

ZeroAvia uses a hydrogen fuel cell to power an electric motor that turns a propeller. It does not combust hydrogen.

Hydrogen has the potential to become the zero-carbon fuel that powers many hard-to-abate sectors such as iron and steel, petrochemicals and heavy-duty transport (including air travel). The fledgling clean hydrogen sector grew beyond expectations in 2021. State funding reached billions of dollars, electrolyzer sales doubled, as did the number of countries with hydrogen strategies.

There are still, however, technical and economic hurdles for using hydrogen as an aviation fuel. Green hydrogen is still not cost competitive with jet fuel. In addition, hydrogen-propulsion systems are far heavier than jet engines, and while hydrogen is energy dense in terms of the energy stored per unit weight, its volumetric energy density (energy stored per liter of space that it takes up) is very low. This low volumetric energy density will require the development of entirely new aircraft with much larger fuel storage tanks.

What is ZeroAvia's technology?

ZeroAvia is developing hydrogen-powered drive trains for aircraft. It uses fuel cells to convert chemical energy from hydrogen into electrical energy that will power an electric motor turning a propeller (rather than combusting hydrogen like jet fuel). ZeroAvia says its aircraft will reduce lifecycle emissions of aircraft by more than 90% compared with fossil fuel turbines. The company's IP is built around how it integrates various components to build a full drive train, as well as innovation around significant components alongside partners. It is not currently developing its own fuel cell stacks or electric motors. While integration and end-to-end system design may sound simpler than the development of new motors or fuel cell stacks, BNEF sees integrators as important sources of innovation in both hydrogen- and battery-powered aircraft.

Why is ZeroAvia a Pioneer?

United Airlines announced a conditional purchase of 100 retrofitted aircraft for its regional travel routes by 2028

Hydrogen-powered aircraft are still years from certification and commercial applications, yet ZeroAvia has emerged as a clear leader in the industry. ZeroAvia has already performed a test flight using a hydrogen-fuel-cell to power a commercial-grade aircraft. While this test was in a small six-seater plane, it is the only company known by BNEF to have successfully flown a hydrogen fuel-cell plane of that size. ZeroAvia has managed to bring together a full ecosystem of partners in components for hydrogen-powered aircraft. This alone is a key differentiator in the business of assembling components to build hydrogen-powered drive trains.

How mature is ZeroAvia?

ZeroAvia was founded in 2017. The company has raised $120 million in funding. Strategic investors, including Alaska Air Group, United Airlines and Shell, bought a corporate minority in the

company for $35 million in December 2021. With this investment, United Airlines announced a conditional purchase of 100 retrofitted aircraft for its regional travel routes by 2028. ZeroAvia expects to have a 10-20 seat, <500-mile range plane by 2024; a 50-80 seat, >500-mile range plane by 2026; and a regional jet of more than 100 seats and >1,000 miles range by 2030 (Figure 11).

Figure 11: ZeroAvia product timeline

Source: ZeroAvia

5. Wildcards

This year's BNEF Pioneers wildcards are innovating in the field of batteries, point-source carbon capture and air conditioning.

5.1. Addionics

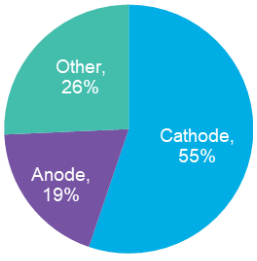
Table 8: Addionics company details

Name	HQ	Founded	Funding	Technology
Addionics	Israel	2018	$40 million	Battery electrodes

Source: BloombergNEF

Why is innovation needed in lithium-ion batteries?

Figure 12: Costs of cell manufacturing, 2021 (NMC, 10% Si anode, South Korea, 10GWh)



Source: BloombergNEF

The average cost of lithium-ion batteries has fallen 89% since 2010, yet they are yet to reach the $100/kWh barrier that will make EVs cost competitive with internal combustion engine vehicles on an upfront basis[2]. Further innovation on batteries is needed to drive down average costs and to also improve battery performance. Higher energy density and extended battery lifetime will further encourage the adoption of EVs. For more on next generation lithium-ion technologies see: *Company Profiles: 2020 Battery Startups* (web | terminal).

What is Addionics' technology?

Addionics has patented a 3D current collector design for electrodes that is compatible with any battery chemistry (including silicon and solid-state). Electrodes today are dense metal foils where the active material is sprayed on top in a thin layer. Addionics' porous 3D structure allows for the active material to be integrated throughout the electrode at higher loads, which leads to improvements in key battery performance metrics. The electrode can 'drop in' to existing assembly lines of battery cells. At a large scale, Addionics says its electrodes can reduce battery costs up to 10% per kWh due to higher energy density and longer lifetime. The cathode and

[2] BloombergNEF's 2021 battery price survey found that the volume-weighted average price for a lithium-ion battery pack, across all sectors, is $132/kWh in 2021 (web | terminal).

anode of an NMC battery typically account for about 74.3% of a cell's manufacturing cost (Figure 12).

Why is Addionics a Pioneer?

Addionics has developed an innovation to drive lithium-ion down the learning curve. Its 3D electrodes have been shown to achieve batteries with higher capacity, reduced charging time, extended lifetime, and enhanced safety – all without increasing costs. This innovation is particularly promising because it can be applied to any battery chemistry and could be commercialized faster than most new battery technologies because the innovation is based on physics (electrode design) rather than new chemistry innovations, which often require many more years of optimization.

How mature is Addionics?

Addionics has yet to commercialize the production of its electrodes. In January 2022, it announced that it had raised a $27 million Series A after its initial years were funded by various accelerators and incubators, bringing the company's total funding to $40 million. Addionics is leveraging this funding to expand the team, accelerate product development, and lay the groundwork for commercialization with the support of its partners, which include automakers and tier 1 suppliers.

5.2. Blue Frontier

Table 9: Blue Frontier company details

Name	HQ	Founded	Funding	Technology
Blue Frontier	U.S.	2017	$1.75 million	Air conditioning

Source: BloombergNEF

Why is innovation needed in air conditioning?

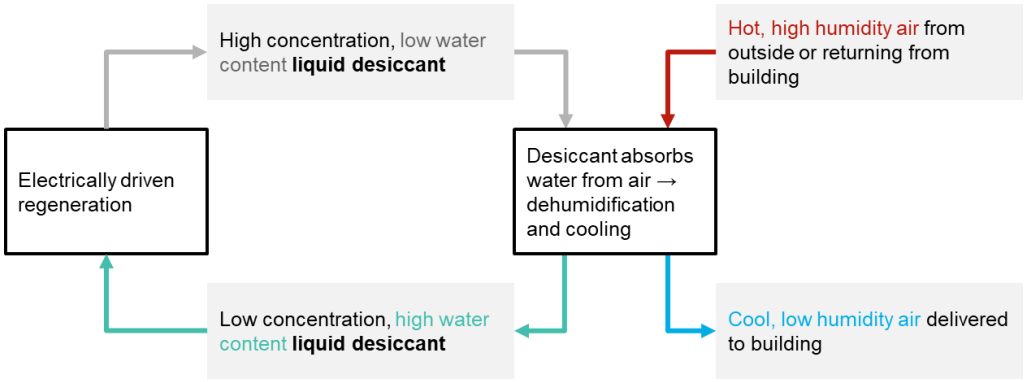
Residential and commercial air conditioning (AC) consume about 1,932TWh of electricity worldwide, accounting for almost 9% of global electricity demand. BNEF estimates that this will increase by 143% to 2050. This is due to a growing global population, rising income and declining AC prices. Besides total demand, extensive ownership of air conditioners also affects daily and seasonal electricity load profiles and peak demand, with most new demand growth concentrated during the hottest parts of the year. More efficient, flexible air-conditioning technology will reduce energy demand and grid stress. For more on AC demand see: *Air Conditioning Heats up Electricity Demand* (web | terminal).

What is Blue Frontier's technology?

BNEF estimates that air-conditioning demand will increase by 143% to 2050

Blue Frontier has built a new kind of AC that relies on a drying agent (desiccant) rather than a refrigerant. The unit uses a liquid desiccant to reduce the humidity of indoor air by absorbing water and drying the air, which is then subsequently cooled to the required temperature and humidity via indirect evaporative cooling. The desiccant is then regenerated with heat so that it can absorb more humidity (Figure 13). Desiccant regeneration is the energy-intensive step. Since this step does not occur at the same time as dehumidification, the technology allows load shifting as energy need not be consumed during peak power demand. This is different from traditional AC.

Figure 13: Simplified description of Blue Frontier's process



Source: BloombergNEF, Blue Frontier. Note: Steps do not occur concurrently unlike traditional AC technologies, which use refrigerants instead of a desiccant.

Why is Blue Frontier a Pioneer?

Blue Frontier is aiming to conduct field demonstrations of its technology in 2022 and bring initial units to market in 2023-2024

Blue Frontier's technology reduces energy consumption for air conditioning by up to 80% and also allows AC units to shift power demand across the length of a day. This would help reduce peak energy demand, preventing the need for expensive grid buildouts in regions with large AC demand. Blue Frontier's system also eliminates AC's reliance on refrigerants, which manufacturers are keen to replace due to their high global warming potential.

How mature is Blue Frontier?

While dehumidification may seem like a mature technology, Blue Frontier's liquid-desiccant AC unit is still in the pilot stages of development. It was tested with the U.S. DOE and is undergoing further testing at the National Renewable Energy Laboratory. The company participated in Wells Fargo's Innovation Incubator and received seed funding from VoLo Earth Ventures, Twynam, Third-Derivative and F&F. Blue Frontier aims to conduct field demonstrations of its technology in 2022 funded by utilities and to bring initial units to market in 2023-2024, before scaling by the end of the decade. The company is targeting commercial buildings in the U.S. as its first customer base.

5.3. Carbon Clean

Table 10: Carbon Clean company details

Name	HQ	Founded	Funding	Technology
Carbon Clean	U.K.	2009	$48 million	Point-source carbon capture

Source: BloombergNEF

Why is innovation needed in point-source carbon capture?

Carbon capture and storage (CCS) is a core component of many industries' future decarbonization pathways. BNEF emissions scenarios that rely heavily on CCS estimate that 2 $GtCO_2$ per annum of point-source capture could be needed to meet climate targets. BNEF analysis has shown that, depending on storage facilities, CCS may be the cheapest low-carbon

production process for high-value chemicals. And while cement decarbonization strategies have yet to take shape, the emissions generated from chemical reactions in cement production almost guarantee CCS will be needed, as fuel switching can only address half the sector's emissions. There is significant potential for CCS, but widespread deployment of carbon capture technology has been slow to take off, mainly due to cost concerns and onsite space restrictions. For more on point-source carbon capture see: *2021 CCUS Market Outlook* (web | terminal).

What is Carbon Clean's technology?

Carbon Clean's technology, CycloneCC, is a combination of two proven carbon-capture technologies – rotating packed beds and the company's proprietary amine-promoted buffer salt solvent (APBS-CDRMax) – that together improve the absorption process of carbon from flue gas. The solvent has been formulated to provide a high-performance CO_2 capture using fast-reacting amines and high-capacity salts. The rotating packed beds, meanwhile, use centrifugal force to enhance the contact of the CO_2-rich flue gas with the solvent, further improving the efficiency of the capture process.

Carbon Clean's use of process intensification means that the carbon capture equipment is 10 times smaller than incumbent technologies, reducing the cost of the equipment by up to 50% and making it easier to retrofit in existing plants. Carbon Clean's equipment is prefabricated, modular and reduces installation times to eight weeks to reduce plant disruption.

Why is Carbon Clean a Pioneer?

Carbon Clean was established 13 years ago and announced its new product, CycloneCC, in October 2021. CycloneCC will deliver carbon capture at an average cost of \$30/tCO_2. This price is well below current industry standards of \$60/tCO_2. The price of carbon in the EU has exceeded \$30/tCO_2e since December 2020, suggesting that CCS technologies that can be delivered this cheaply could make industrial processes more cost competitive in Europe. Carbon Clean has also amassed an impressive list of partners including CEMEX, Veolia, Tata, Holcim and Chevron.

Carbon Clean has over a decade of experience in the CCS industry and announced its new CycloneCC product in October 2021

How mature is Carbon Clean?

Carbon Clean was founded in 2009 and its technology has been used at more than 44 sites around the world, including plants in the U.K., U.S., Japan, Germany, India, Norway and the Netherlands. The company has received funding and grant support from the British and U.S. governments, and \$48 million in private capital from strategic investors including CEMEX, Equinor Ventures and Chevron Technology Ventures.

CycloneCC has been successfully pilot-tested at one metric ton of CO_2 per day and is currently being commercialized at 10tpd and 100tpd with select partners, including CEMEX and Veolia, for market roll-out in 2023.

Current CycloneCC projects and partnerships include:

- **CEMEX:** Carbon Clean is working on a FEED study for CEMEX's Rüdersdorf plant in Germany. The initial project aims to capture 100tpd before increasing to an additional 300tpd.
- **Chevron:** Chevron and Carbon Clean are seeking to develop a 120tpd carbon capture pilot using CycloneCC technology on a gas turbine in San Joaquin Valley, California.
- **Veolia:** Carbon Clean is working on a trial of its technology for Veolia's waste-to-energy facilities in the U.K.

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