

**BUSINESS
FINLAND**

Emerging Climate Tech

A graphic illustration featuring a realistic globe of the Earth showing continents and clouds. Several vibrant green leaves are positioned behind the globe, partially overlapping it. A magnifying glass with a black handle and a silver frame is positioned to the right of the globe, with its lens focused on the Earth's surface.

Future Watch projects 2/2024

Data-Driven Tech Research for Business Finland by CATAPULT



Future Watch Emerging Climate Tech

Data-Driven Tech Research for Business Finland

This research focuses on climate technology advancements in manufacturing, mobility, and city environments.

The report explores both emerging and currently strengthening climate technologies globally and provides one tool to assess Finnish tech's global position and inform future innovation strategies.

The project is part of the pilot, where Business Finland explores new tools and methods for supporting customers with foresight #zero carbon mission #zero waste mission.

Table of Contents

PART 1

Research
Summary

PART 2

Big Picture &
Early Findings

PART 3

Emerging
Climate
Technology

PART 4

Concluding
Notes

Part 1

Research Summary

Quick Recap of the Focus



Emerging innovations in climate technology



Tech

No restrictions

Stage

Early-stage innovations

Geography

Global focus with special interest areas: India, China, the United States, Australia, Canada, South Korea, Japan, and the EU.

Focus



Climate technology advancements in manufacturing, mobility, and city environments.

Goal



This research explores both emerging and currently strengthening climate technologies globally to assess Finnish tech's global position and inform future innovation strategies.

Descriptive points



The project scope is set to technologies addressing the energy transition and emissions reduction.

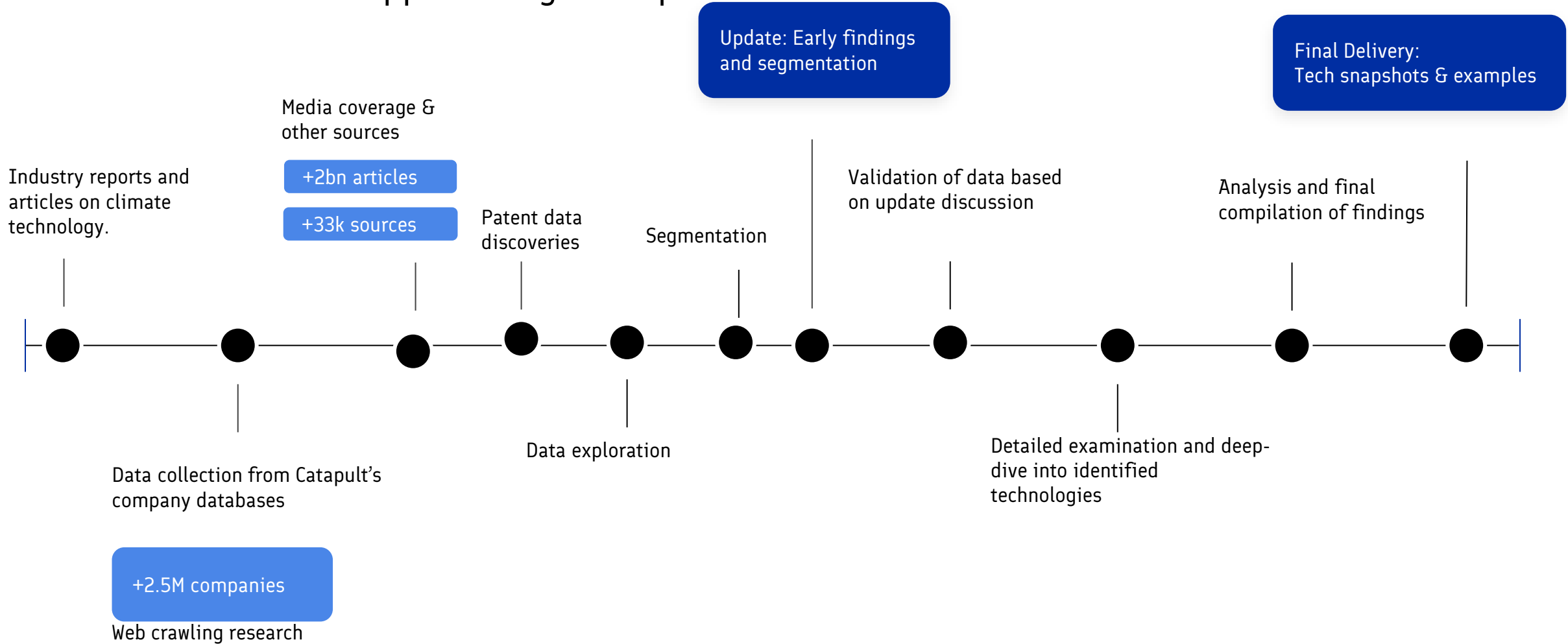
Examples of areas that are of special interest to Business Finland include:

- Regenerative and mitigative technologies
- Material innovations
- Novel use of buildings in energy storage and generation.

Business Finland is also interested in understanding technology dependencies required to bring these detected innovations to market.

Research Roadmap

How research team is approaching the topic?



Part 2

Big Picture & Early Findings

Big Picture Insights

Introduction

Next up



We'll start going through the early insights by looking at the key drivers of innovation and evolution of the climate technology sector at a general level.

This will enable us to paint the picture and understand which regions have been active and what types of technologies have been gaining attention in recent years.



Climate Technology Drivers

What is driving future innovation?

Regulation and policy

Compliance-based drivers, such as the EU ETS, tend to focus on the outcome rather than specific technologies making them suitable for a wide-range of climate tech.

Public funding

Incentive-based drivers, such as USA's IRA, are costly but offer open-ended support that can lead to faster adoption and accelerated development.

Consumer interest

Consumers are increasingly aware and interested in sustainability, expecting companies adhere to CSR guidelines.



Corporate net zero targets

Net-zero targets set by companies, either as single entities or in groups (e.g. FMC) drive the search for and adoption of low-carbon technologies.

Technological advances

New technologies like affordable IoT, AI, and ML are helping organisations to make informed decisions based on data resulting in improved operational efficiency.

Investor pressure

Investors are increasingly advocating companies to disclose their emissions, establish emissions targets and implement emission reduction plans.

Investment Activities

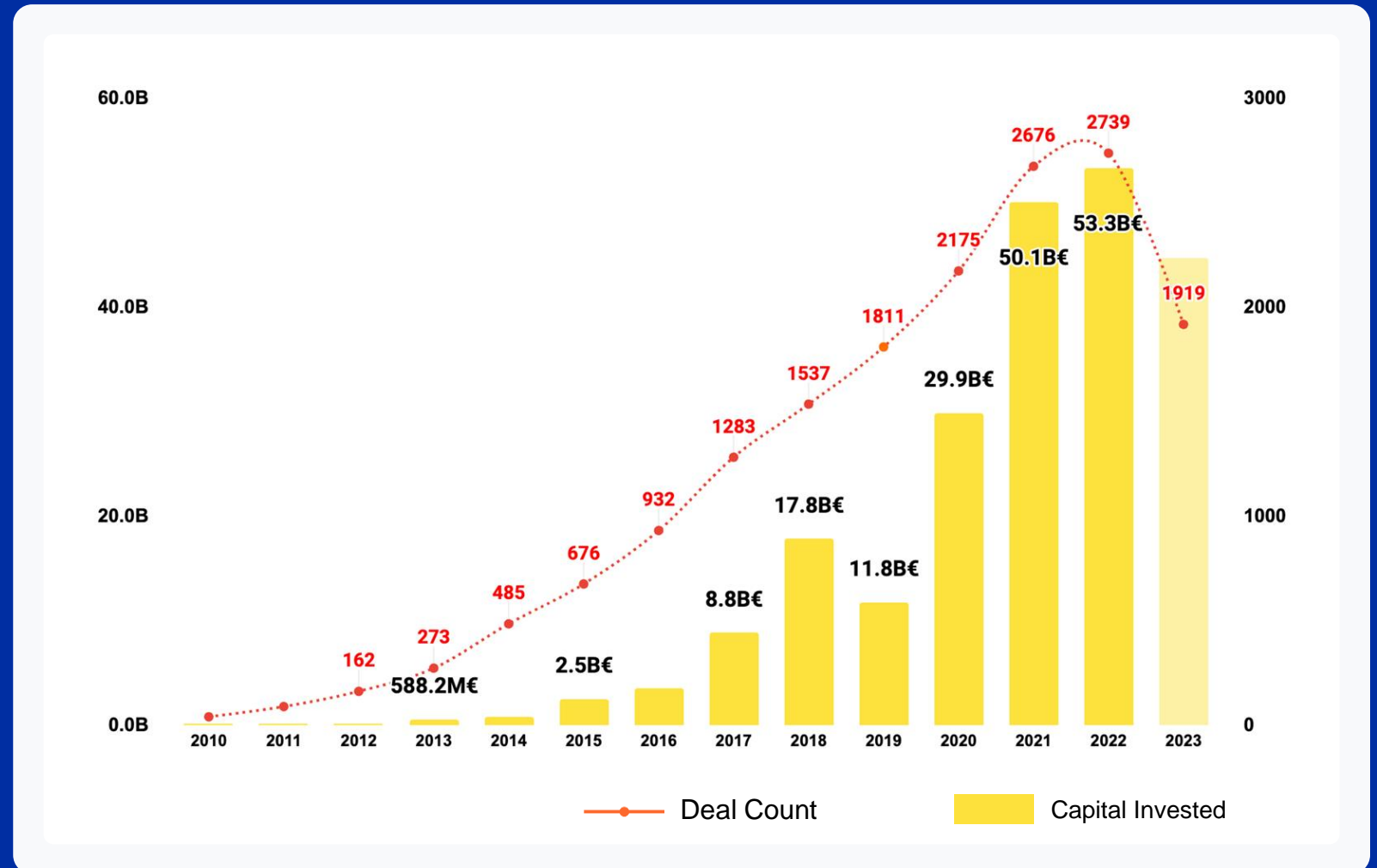
Quick overview of the investment going into climate technology

Insights

In 2023, funding for climate tech start-ups decreased to levels last seen two years ago.

The change and decline in climate tech investment is due to economic uncertainties, less capital availability.

Investments into climate technologies, however, did not decrease as much as the total venture and private equity investment over the same period of time (50.2% vs. 40.5%). This can be seen as a positive indication.

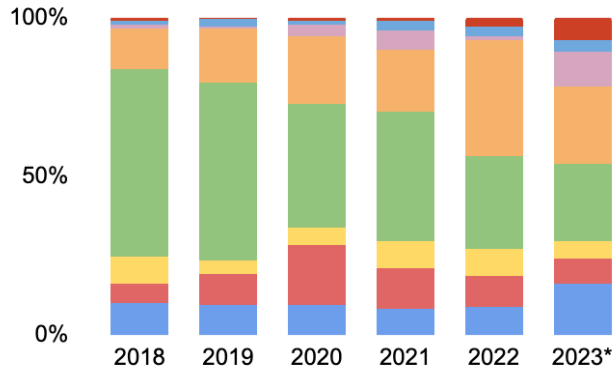


*Data from the capital invested into companies founded after 2010

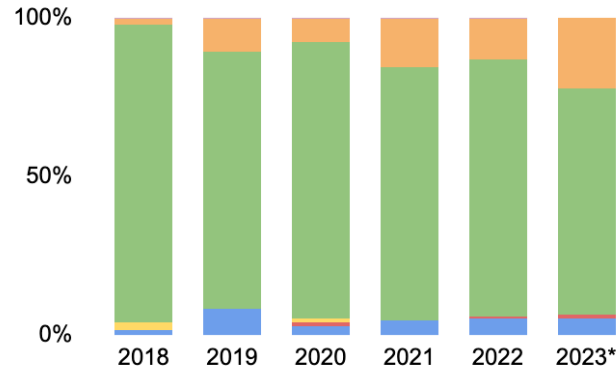
Investment Trends Across Regions



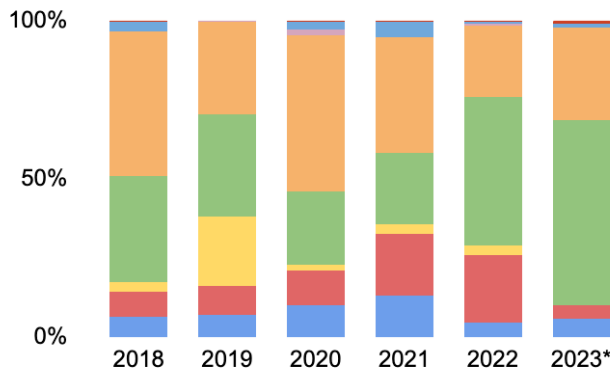
North America



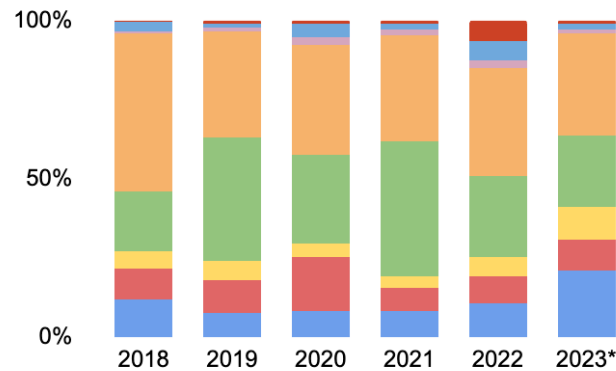
China



Asia-Pacific



Europe



Insights

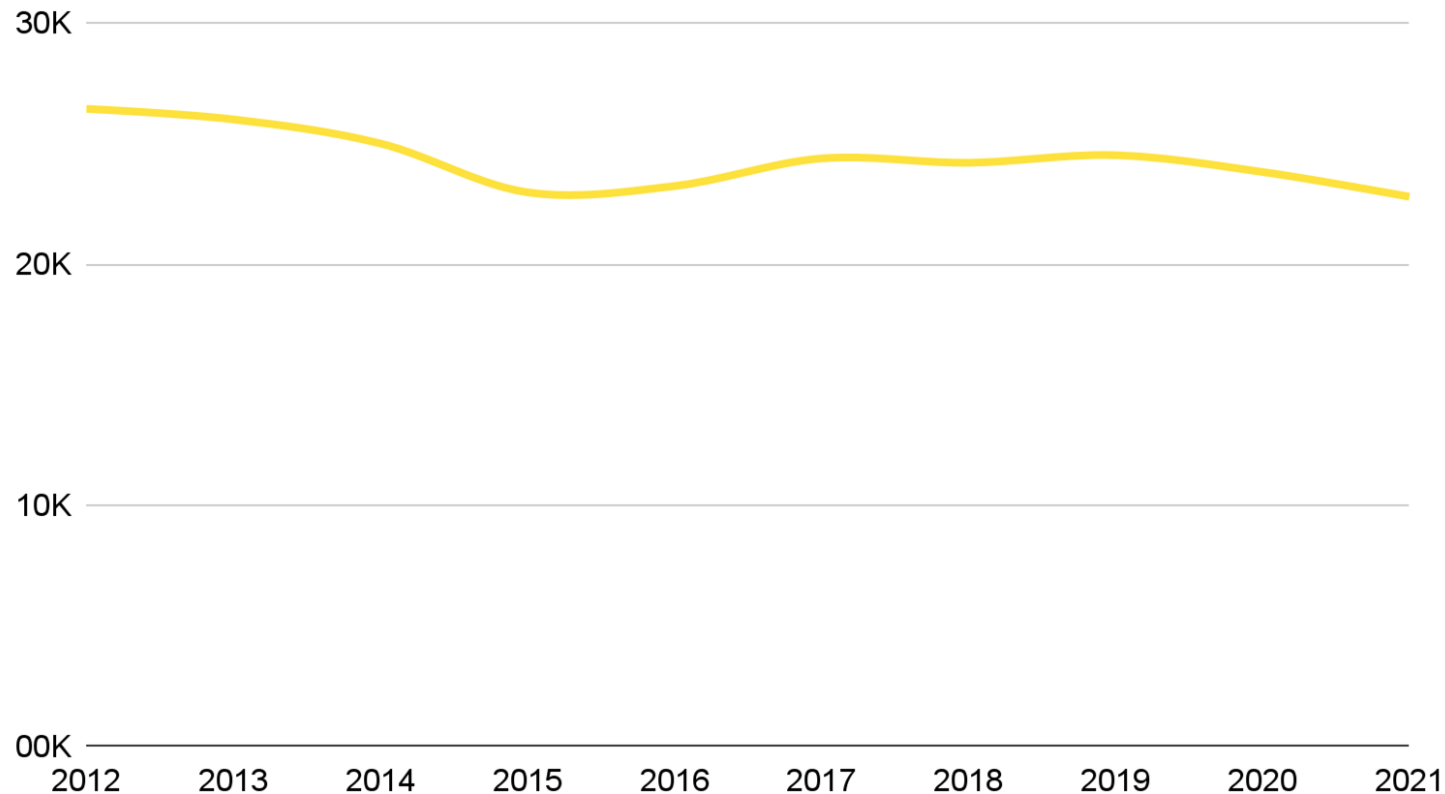
Funding relative to emissions reduction potential (ERP) is evolving. Five years ago, lower-ERP technologies like light-duty battery EVs and micromobility received more funding.

Solar and wind startups now get less investment due to technology maturity and investor interest in other climate solutions.

Currently, investors are prioritising investments focusing on higher-ERP technologies e.g. CCUS, hydrogen, and alternative fuels and foods.

Climate Technology Patents

2012-2021 showing a downward trend.



Insights

The number of patents filed in key countries over the past 10 years shows a slight downward trend.

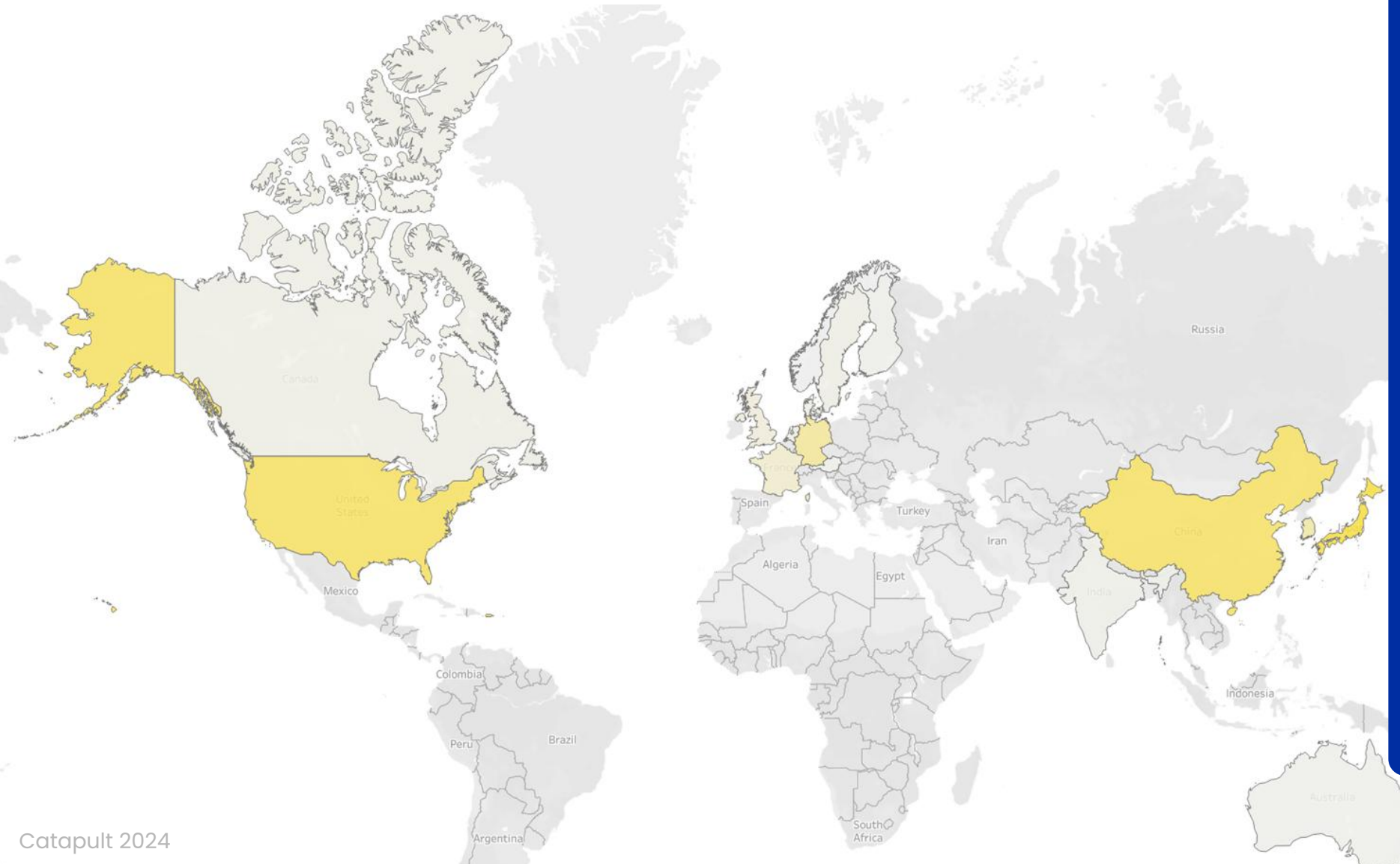
In the beginning of the observed period (2012) the total number of filed applications for patents related to climate technologies stood at 26,444. In 2021 the number of filed patents stood at 22,798.

The list of countries includes: United States, China, Japan, South Korea, Germany, France and United Kingdom.

Source: [OECDFinl](#)

Climate Technology Patents

Focusing in 2017-2021



Countries

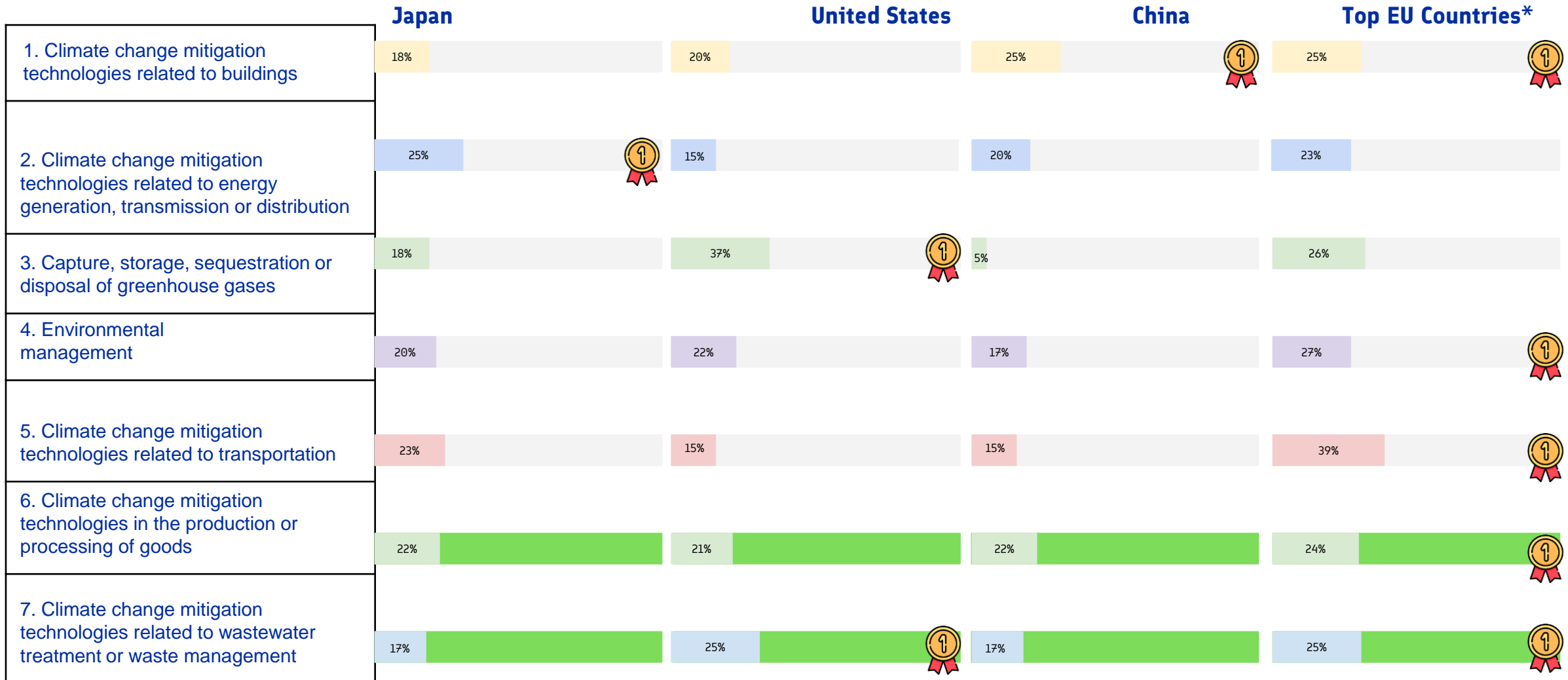
Japan	30,337
United States	25,042
China	24,640
Germany	15,927
South Korea	13,395
France	6,395
United Kingdom	4,003
Canada	2,315
Denmark	2,036
Netherlands	2,103
Sweden	1,950
India	1,703
Australia	1,454
Austria	1,428
Finland	1,178
Norway	627

Source: OECD

Climate Technology Patents



Patents Breakdown 2017-2021



BUSINESS FINLAND Patent Analysis

BUSINESS
FINLAND

A closer look at recent climate technology patent themes and trends



Carbon Capture

In carbon capture patenting, the US leads in application numbers, followed by China, Japan, the EPO, and Germany. Solvent and membrane technologies dominate patents, with the US, China, Korea, and Japan at the forefront of global grants. For more information, see the Global CCS Institute's [report](#).

Hydrogen

In hydrogen technology patents, the EU (28%) and Japan (24%) lead, with the US experiencing a decline. Germany, France, and the Netherlands spearhead Europe's growing leadership in electrolyser production. Data is based on [EPO findings](#).

Battery and clean energy

Based on [EPO data](#) from 2022, electrical machinery, apparatus and energy (+18.2%), a field that includes clean energy inventions and battery technology, grew fastest. In 2023, Asian applicants filed over two-thirds of energy storage patents at the EPO, while EPO member states contributed only 21% to battery-related applications.

Insights

The patent analysis reveals that advanced economies lead in green innovation, while developing nations are significantly behind.

The next wave of climate technology patenting is likely to involve higher ERP and enabling technologies technologies such as carbon capture, smart grids, hydrogen ecosystem or value chain, and fuel cells that can complement readily available clean technologies.

Next up



In the next section we'll take a look at the three technology segments identified from the data and look at what themes, technologies, and geographic areas are trending within each of the segments.

Based on the discussions on these initial observations, we'll target the research into more concrete emerging technologies for the final research delivery.



Market Segmentation



Introduction



1. Energy

Focus on energy management and storage, clean energy sources and electrification.



2. Carbon

Focus on opportunities enabled by carbon technologies and software solutions.



3. Resilient Landscapes

Focus on creating secure, responsive and adaptable environments.

Emerging Climate Tech Snapshot

Themes and technologies that stand out



Energy

Energy Storage

Alternative Fuels

Energy Generation

Electrification

Carbon

Carbon Capture

Carbon Compensation & Reporting

Carbon Utilisation

Net Positive & Regenerative Approaches

Resilient Landscapes

Environmental Monitoring & Response

Sustainable Cities

Climate-Adaptive Technology

Circularity



DETECTED THEMES

This segment highlights solutions targeting the decarbonisation of the energy sector. Technologies focus on reducing global dependence on fossil fuels by innovating alternative energy sources and storages. Major theme influencing the speed of the energy transition is digitalisation and developments enabled by it, especially in energy management and optimisation.

The early findings linked with energy have been divided into the following categories:

Energy Generation

Energy Storage

Alternative Fuels

Electrification



Energy Generation

A look at recent developments

Observations

In the aftermath of COP28's call to phase out fossil fuels, the energy generation industry is expecting an increased growth of solar and wind capacity creating both energy independence but also hardware dependencies. Innovative developments in geothermal, nuclear and hydrogen are expected to further expedite this transition. Challenges can be anticipated to rise from permitting and supply chain issues.

Geographic focus

Development activities appear to be most active in China, U.S., Japan, and European countries including UK, Germany and France.

Technologies

Concentrated solar power

Advanced SMRs

Energy harvesting

Fuel cells

Airborne wind energy

Renewable energy optimisation



Energy Storage

A look at recent developments



Observations

The increase in renewable energy utilisation drives the production of long-duration energy storage. Simultaneously, the ever-growing EV infrastructure requires also short-term solutions. While the current focus lies on enhancing energy consumption capacities to secure stable power system operations, the focus in the near future appears to be on the development of portable energy storage. Also, research into improving battery performance and lifespan by finding alternatives to lithium batteries is gaining attention.

Geographic focus

Research indicates the majority of developments taking place in the U.S., China, and the UK.

Technologies

Alternative battery materials

Alternative storages

Hydrogen storage

Distributed energy storage

Solid-state batteries

Second life batteries



Alternative Fuels

A look at recent developments



Observations

Development of clean, alternative fuels has been on the development map for relatively long but challenges in scalability and high production costs have hindered large-scale adoption. Green hydrogen-based fuels represent one of the leading alternatives while other more recent developments in low-carbon hydrocarbon fuels such as biofuels and synthetic fuels are also emerging as viable options. Benefits of these include drop-in replacements without major hardware modifications.

Geographic focus

Much of the developments in alternatives are taking place in North America, Brazil, and Asian countries including China and India.

Technologies

Green methanol

Biofuels

Green hydrogen

Waste to fuel

Synthetic fuels

Air to fuel



Electrification

A look at recent developments



Observations

Demand for clean electricity is set to grow significantly with major sectors such as transportation, building, and industrial segments undergoing rapid electrification. The ongoing “electrification of everything” is further driven by developments in energy management and optimisation supported by AI and smart grids. Along with digitalisation, decentralisation is a key theme under electrification.

Geographic focus

Innovation activities are particularly active in UK and Germany as well as the U.S.

Technologies

Smart Grid

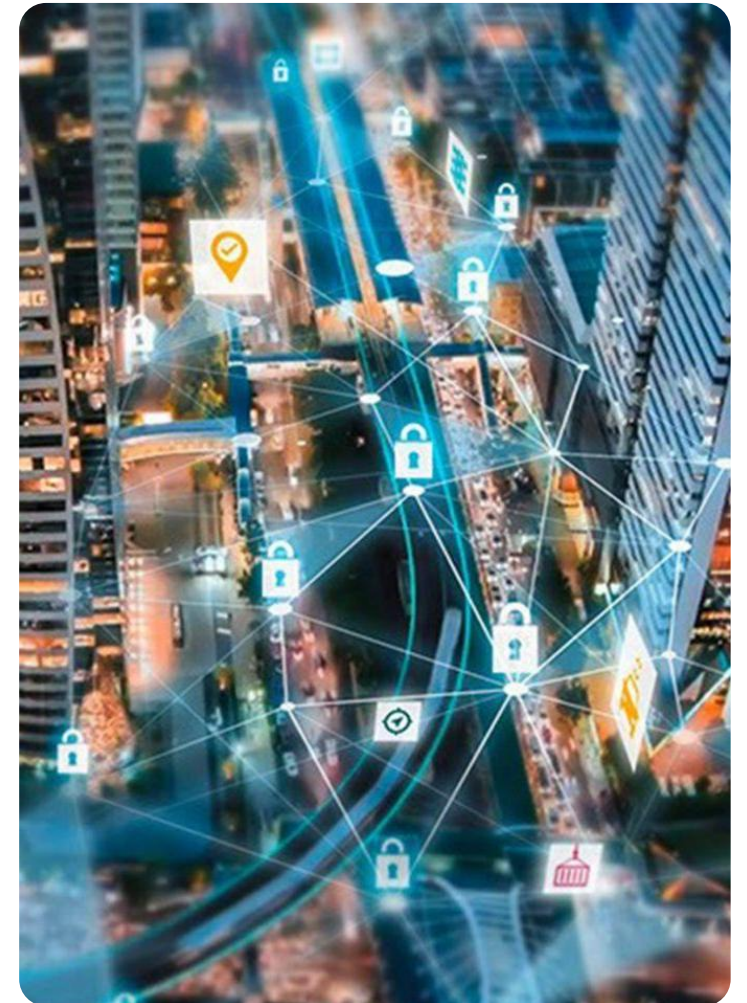
VPP

V2X

AI & Blockchain

Contactless charging

Fleet management





DETECTED THEMES

This segment consists of technologies and pathways to remove, store and/or utilisation carbon emissions from industrial processes or the environment.

The findings linked with carbon emissions have been divided into the following categories:

Carbon Capture

Carbon Utilisation

Carbon Compensation & Reporting

Net Positive & Regenerative Approaches

Carbon Capture

A look at recent developments



Observations

The buzz around the carbon capture at COP28 climate talks has brought renewed focus to carbon capture strategies. CCS faces challenges in terms of cost, scalability, and achieving complete carbon capture efficiency. Many are now promoting innovative carbon sequestration technologies, focusing on enhancing nature's carbon-absorbing capacity or nature-based capture approaches e.g. restorative agriculture, soil and plant enhancement.

Geographic focus

USA, Japan, China and the EU are leading with the development of capture technologies.

Technologies

Direct air capture

Modularisation

Biochar / bio-CCS

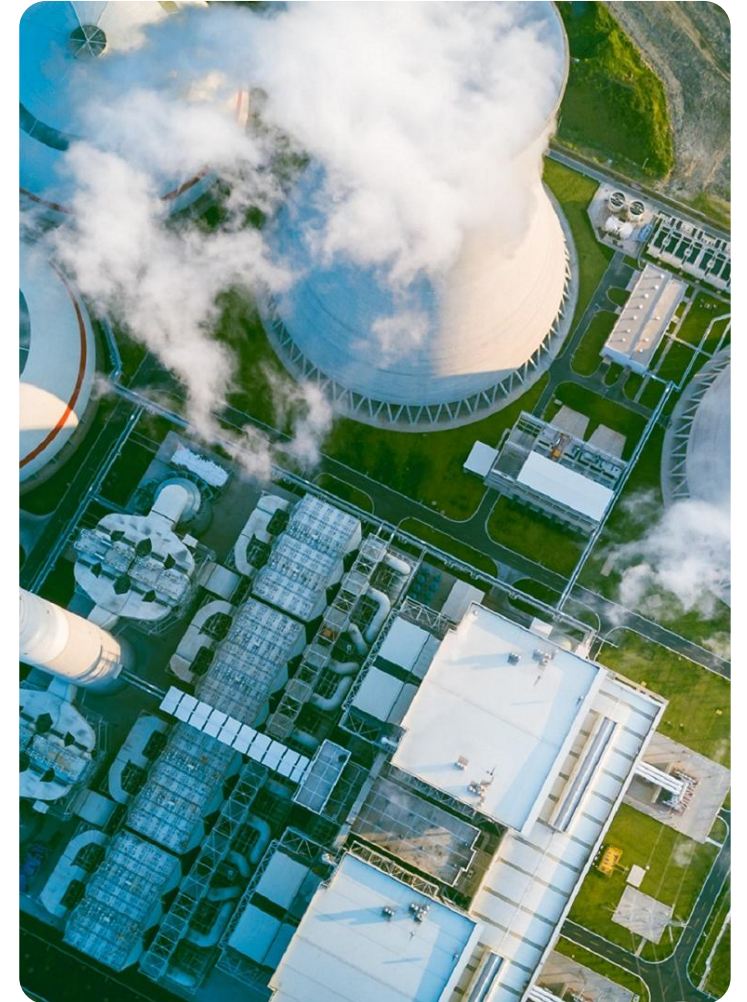
Membrane

Microbial carbon capture

Cryogenic

Solid sorbents /MOF

Photochemical



Carbon Utilisation

A look at recent developments



Observations

Overall progress in development is gradual but accelerating, hinging on joint advancements in cross-cutting technologies including transport or storage. While CO₂ use offers climate and economic benefits, its small market size makes dedicated storage a key focus in carbon strategies. There is increased policy and support for research and development for scalable, competitive CO₂-based products and services, with a primary focus on reducing energy required for converting CO₂ into fuels and chemicals.

Geographic focus

The US and UK are increasing funding for CCU projects, while the EU sets a CO₂ storage goal to encourage investment in the sector.

Technologies

Electrocatalytic

Mineralisation

Biotechnology

Photochemical

Catalytic
conversion

Electrolysis &
plasmolysis



Carbon Compensation and Reporting

A look at recent developments



Observations

Facing a credibility crisis, the carbon offset industry is turning to emerging technologies for a solution. Innovations like high-resolution imagery, AI, machine learning, and blockchain are being deployed to improve the accuracy and transparency of measurement, reporting, and verification. Software providers have developed more sophisticated LCA and carbon accounting platforms featuring automation and the complete digitalisation of the reporting process.

Geographic focus

A lot of the private sector technology development is coming out of North America and the EU.

Technologies

LCA /dMRV

Imagery-based indicators

Blockchain

Data ecosystems

AI/ML

Advanced sensors



Net Positive & Regenerative Approaches

A look at recent developments



Observations

As the general discussion has been shifting from carbon neutrality to more ambitious strategies, the terms net positivity, regenerative approaches and carbon handprint have started to take the limelight. So far the main focus has been on theories and frameworks for regenerative and net positive practices, and a lot of emphasis has been placed on the agricultural sector. However, new innovations are being developed for industries and the built environment.

Geographic focus

Europe is a thought leader for net positive and regenerative practices, offering emerging also in North America.

Technologies

Waste-based raw materials

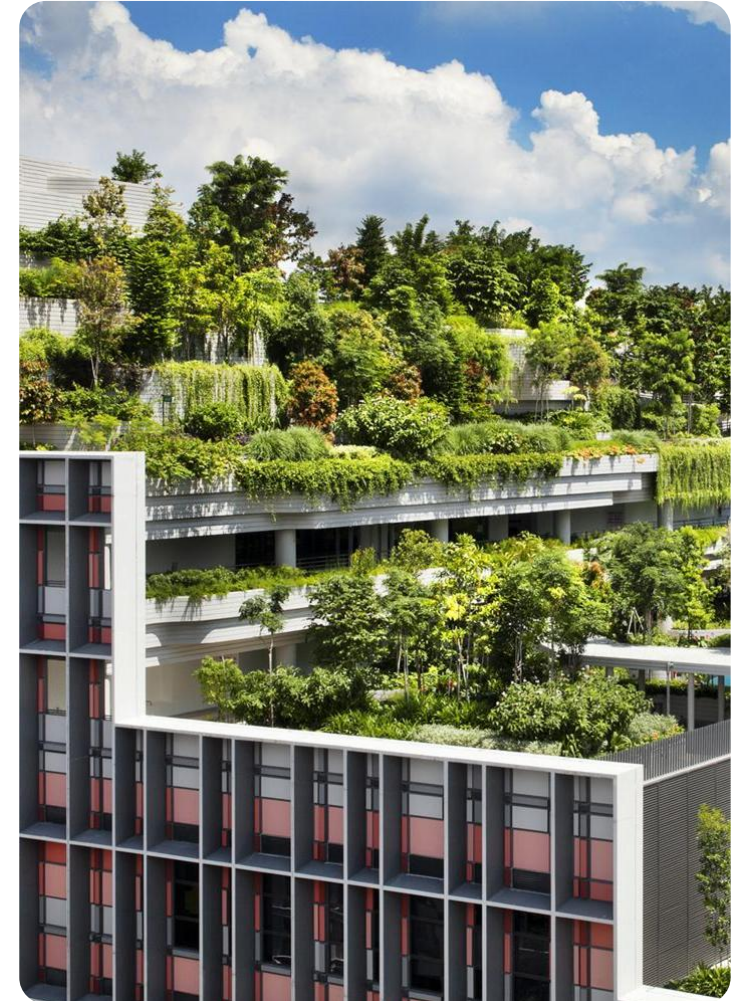
Regenerative fibres

Data sharing

Regenerative buildings

Quantification & monitoring

Supply chain management



Resilient Landscapes

Introduction



DETECTED THEMES

This segment consists of technologies that aim to create and conserve secure, responsive and adaptable environments in the era of climate change and extreme weather. Optimised built environments and mobility, availability of critical resources, circularity and self- sustaining buildings are core themes in this segment.

The early findings have been divided into the following categories:

Environmental Monitoring & Response

Climate-Adaptive Technology

Sustainable Cities

Circularity

Environmental Monitoring and Response

A look at recent developments



Observations

Advancements in IoT technology and remote sensing, including space satellite technologies and drones, have opened a range of opportunities from real-time emission data capture to grid surveillance and illegal logging detection. Paired with advanced AI algorithms and ML the data can be utilised in predictive analytics and climate modeling. In addition, disruptive solutions altering or reversing climate conditions are under development and gaining increasing attention.

Geographic focus

Early research indicates that majority of environmental monitoring technology developments is taking place in the U.S.

Technologies

Geo-engineering

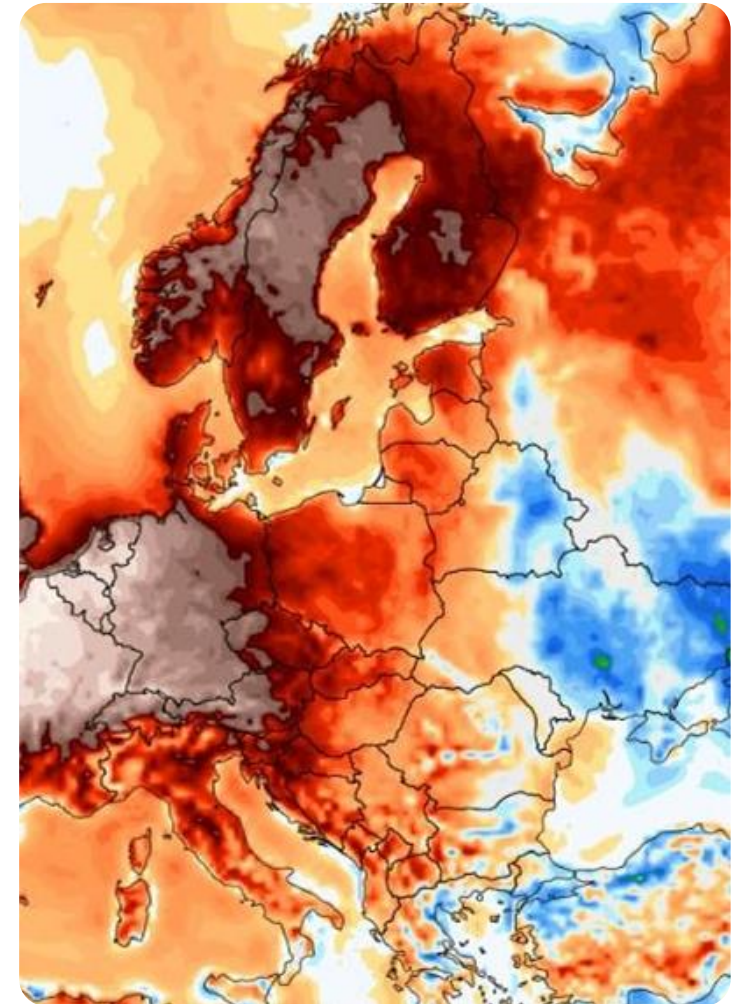
AI-based climate change modeling

Remote sensing

Data ecosystems

Satellite data and imaging

Climate risk modeling



Climate-Adaptive Technologies

A look at recent developments



Observations

With the advancing climate change, societies are faced with more adverse weather patterns that put existing infrastructures under pressure. Adaptive technologies try to mitigate the effects of draughts, floods and extreme storms and ensure resource security even under the new conditions, while even driving benefits from phenomena such as extreme heat.

Geographic focus

Data shows offering mainly from United States, China, Japan, South Korea and the EU with activity also in India and Singapore.

Technologies

Desalination tech

Biomimicry

Flood & drought resistant materials

Vertical farming

Water capture & treatment

Heat capture



Sustainable Cities

A look at recent developments



Observations

Developments in advanced connectivity technologies including 5G, IoT and AI are emerging as key components in climate resilient urban planning. Additionally, nature-based solutions and intelligent infrastructure including smart buildings and mobility, are expected to play an increasing role in climate change response. Currently smart cities are at the forefront of adapting and responding to climate change induced hazards.

Geographic focus

Majority of developments appear to be made in China, Japan and South Korea, followed by Germany and the U.S.

Technologies

IoT & AI

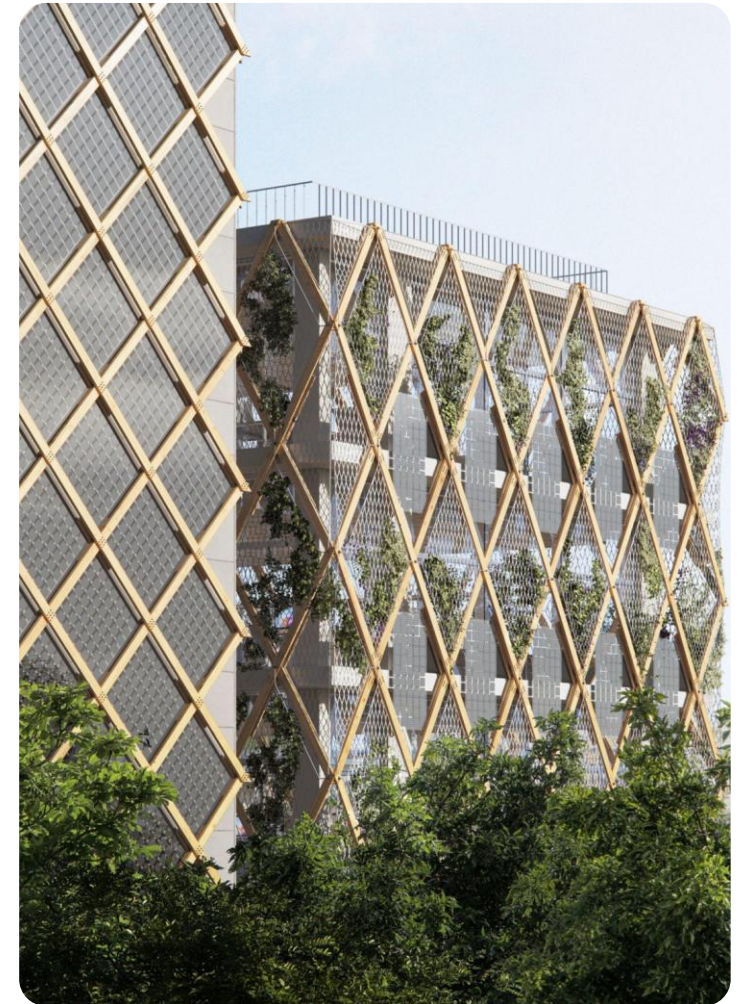
Green roofs

Electrochromic windows

V2B

CO2 absorbing infrastructure

Self-sustaining energy



Circularity

A look at recent developments



Observations

The data shows that circularity is most visible in industrial settings where production side streams are being utilised in new applications. In addition to converting waste to energy and fuels, circular materials are being used increasingly in 3D printing. More attention is put on end-of-life services that feed raw materials to the value chain, and especially battery recycling is trending to decrease dependency in China to source critical raw materials.

Geographic focus

EU countries and Japan are leading the way in circular economy.

Technologies

Process optimisation

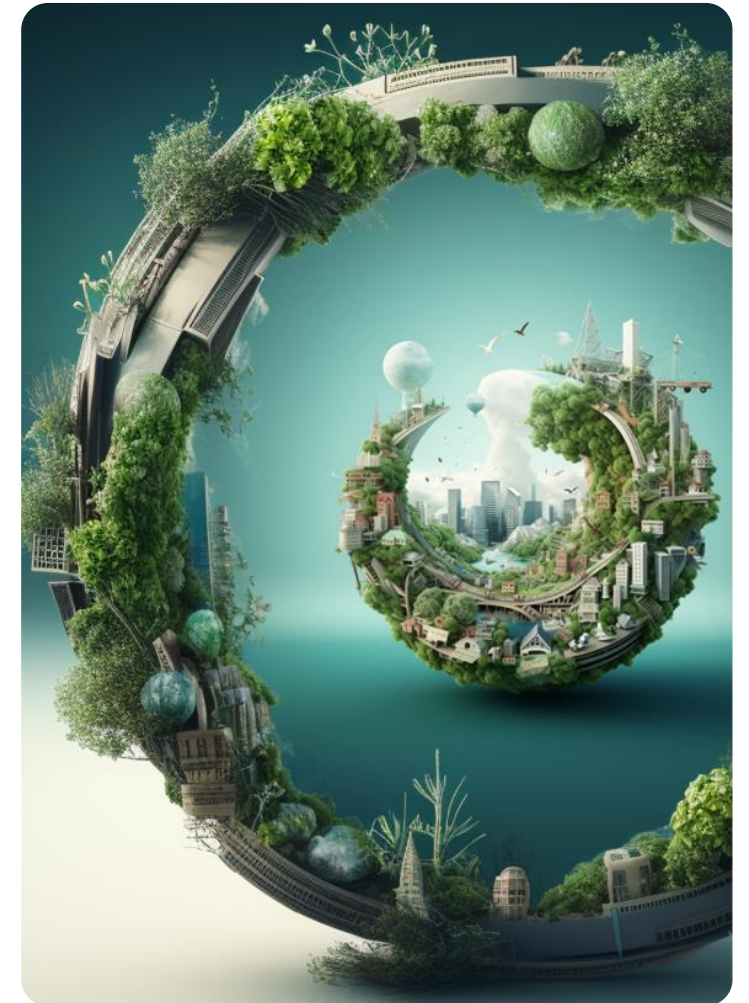
Battery recycling

Alternative materials

Closed-loop water systems

Membrane technology

End-of-life service concepts





Part 3

Emerging Climate Technology

Emerging Climate Technology

The themes, topics and prioritised areas



Energy

Power-to-X and conversion pathways

Active role of buildings in the energy systems

Decentralised energy production and flexible energy systems

Carbon

Carbon utilisation

Data-driven emissions compensation and reporting

Resilient Landscapes

Climate-adaptive technology

Circularity & regenerative technologies

Alternative materials specifically related to e-waste/EV batteries

Regenerative Climate Technologies



The transition from sustainable to regenerative approaches

Regenerative agriculture

The primary focus is on regenerative agriculture, which aims to improve soil health, biodiversity, and restore degraded land.

Environmentally, regenerative agriculture helps limit deforestation and grassland conversion by making existing farmland more productive and restoring unproductive lands. Companies like [Seqana](#) are supporting the transition to regenerative agriculture.

Some supporting technologies include:

Automation

SynBio

Soil monitoring & measuring

Robotics

Regenerative carbon capture

Emerging

Regenerative approaches to carbon capture are emerging that go beyond reversing the negative, and directly provide value to ecosystems.

Restoring pre-industrial systems, like the carbon cycle, is crucial. Nature-based solutions can efficiently and affordably remove carbon, enhancing permanence.

Regenerative materials

Emerging

Regenerative materials seem to be gaining increasing attention in multiple industries from [textiles](#) and [leather](#) to [industrial pigments](#) and alternative [building materials](#). One such example is [Green Charcoal](#), a brick that allows plants and insects to thrive on its surface.

In addition to the end products, also production processes are cultivated to adhere to regenerative principles. As an example [Interface's Factory as a Forest](#) concept utilises biomimicry in designing the production facilities as forest ecosystems.



Soil Carbon Sequestration



Harnessing carbon dioxide and boosting agricultural production

Microbial Carbon Storage

Emerging microbial biotechnologies for cropping systems can enhance drought resilience, boost productivity, and sequester carbon by enhancing plants' natural carbon storage in soil.

One example of a recent development is [CarbonBuilder](#), a microbial seed inoculum designed to enhance carbon sequestration in agricultural soils. The technology enhances carbon accumulation in soil structures known as micro-aggregates, leading to increased long-term CO2 storage.

Tech dependencies

Technology is commercially available but needs to be adjusted per seed making growth slow. Challenges may also arise from regulation.

Active players

Loam Bio

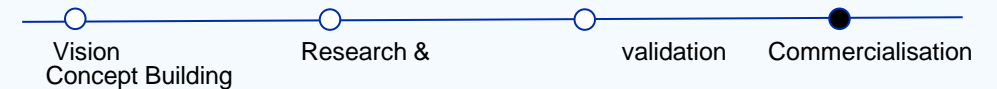
Rhizocore

Groundwork BioAg

Impact

Building soil carbon brings productivity and climate resilience benefits to farmers and can reduce the amount of nitrogenous fertiliser used in agricultural production, further reducing emissions.

Stage





Power-to-X and Conversion Pathways



P2X

The increased introduction of renewable energy and their nature of intermittency has pushed for new developments in the conversion of energy.

Such technologies are improving the uptake of RES and are expected to play a key role in the decarbonization of several industries.

Here we have looked beyond the production and storage of hydrogen and electrolysis, and have identified the following as key developments in the power-to-x scene:

Power-to-ammonia

Power-to-methanol

Power-to-gas

Power-to-Ammonia



Green Ammonia

Water, air & electricity

Green ammonia is becoming an attractive solution compared to hydrogen because of its higher volumetric energy density, making it easier to store and transport. Since ammonia can also be split back to hydrogen and nitrogen after being transported, green ammonia serves as a very good hydrogen and energy carrier. Ammonia is already well traded around the world creating a very good case for green ammonia.

Tech dependencies

Water electrolysis, re-configured and electrified Haber-Bosch process.

Active players

University of Oxford

Oxford Green Ammonia Technology

Ammonia Energy Association

Thyssenkrupp

Siemens Energy

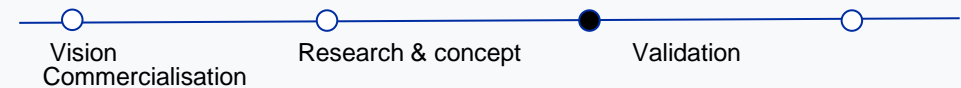
Nel Hydrogen

Høst

Impact

Green ammonia presents a great potential in decarbonizing the agricultural sector and the shipping industry as it has a mere 10 % carbon footprint of conventional ammonia.

Stage



Green Ammonia



A closer look at the methods for green ammonia synthesis

Haber-Bosch with green hydrogen

This common method modifies the Haber-Bosch process by replacing grey hydrogen (from fossil fuels) with green hydrogen (from water electrolysis using renewable energy).

Its full viability hinges on green hydrogen's availability and cost, affected by water electrolysis efficiency and renewable energy prices.

Emerging players have refined the Haber-Bosch process to work under milder conditions, significantly reducing engineering risks and simplifying the scale-up for industrial applications.

Active players

Liquium

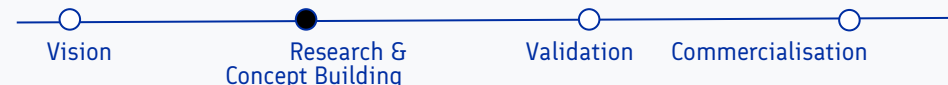
PlasmaLeap

Direct electrolysis & photocatalytic

Direct electrolysis approach seeks to create green ammonia from water and nitrogen, eliminating hydrogen production. However, direct electrolysis struggles with slow ammonia production and high energy needs due to nitrogen's strong triple bond.

Photocatalysis uses solar energy and semiconductors to catalyse ammonia and oxygen production, but faces low conversion efficiencies and challenges in light use and catalyst effectiveness.

Stage



Power-to-Methanol

e-Methanol



Catalyst technologies

Decarbonising the production of methanol, which is widely used in chemical, construction and plastics industries, by synthesising hydrogen and carbon dioxide.

Research is focusing on advancing catalyst technologies, so that the price of producing methanol decreases. Examples of that are Synspire, a new catalyst developed by BASF, or the latest generation of MegaMax by Clariant.

Tech dependencies

Carbon capture technologies

Water electrolysis

Materials innovation

Active players

Methanol Institute

BASF

Clariant

Europe Energy

Impact

What makes e-methanol an attractive alternative is the fact that it is compatible with existing liquid fuel infrastructure. An alternative fuel cutting down carbon emissions by 95%. Besides being an alternative fuel (specifically shipping industry), e-methanol finds applications also in paints, carpeting, and plastics.

Stage



Power-to-Gas

Microbiological Methanation



Microbia

Microbiological methanation is the process of capturing CO₂ from various sources, mixing it with water in a bioelectric chemical reactor, where micro-organism obtain the hydrogen, dissolve CO₂ and produce methane.

There are several pilot projects taking place, especially at steel plants where the emission of CO₂ is very intense, so that the process will be as efficient as possible.

Tech dependencies

Carbon capture technologies and water electrolysis.

Active players

E-fuels Tech

Q-Power

European Biogas Association

Wageningen University and Research

Impact

92% reduction of CO₂ emission compared to fossil fuel, easier transportation even in cases of long distance. It has the potential to become a source for heating homes, powering different industries, trucks or even personal vehicles.

Stage



Conversion Pathways

Sustainable conversion technologies



Conversion

Multiple technologies are emerging that utilise various inputs and convert those into alternative fuels or products. The research on alternative fuels is focused on moving away from food related products as they have a negative impact on the environment and the food supply chain. Hence, woody feedstocks, emissions or waste are being considered as a sustainable solution to obtain alternative fuels and products.

More specifically we have chosen to highlight the following emerging technologies:

Woody biomass to Ethanol

Emissions-to-syngas

Waste-to-products

Biomass-Based Fuels



Woody biomass to ethanol

Woody biomass to Ethanol

Innovation in biofuels is geared towards finding solutions that are non-food based and a promising feedstock is woody biomass. Recently, Berkeley Lab successfully used non-toxic chemicals, commercially available enzymes, and a specially engineered strain of yeast to convert wood into ethanol in a single reactor.

Tech dependencies

Work is underway to launch a pilot project that would convert one ton of biomass per day to ethanol. Berkeley Lab is cooperating with Aemetis, a renewable fuels company, to commercialise the technology.

Active players

Berkeley Lab

Aemetis

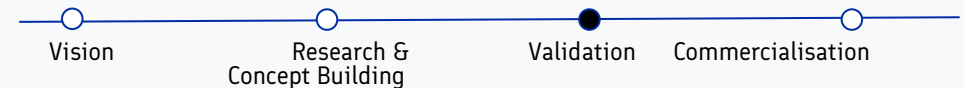
VTT

SINTEF

Impact

The new method claims to reduce costs in production of biofuels and its wider adoption will have a direct impact in avoiding wildfires from the overgrown biomass.

Stage



Synthetic Biology



Biotechnological pathways to turn various waste streams into products

Waste into High-Value Products

Synthetic biology (SynBio), focusing on creating new biological entities and redesigning existing ones, is emerging as a key technology in the creation of chemicals and materials.

Innovative methods are underway, such as using waste methane and oceanic microbes to produce biopolymers, replacing plastics and curbing greenhouse gases. Another approach is gas fermentation, converting industrial waste into sustainable chemicals like aviation fuel and ethanol.

Tech dependencies

Safety and environmental concerns, AI/ML, gene-editing technology like CRISPR to make these organisms more efficient, as well as cost optimisation and policy challenges.

Active players

Newlight

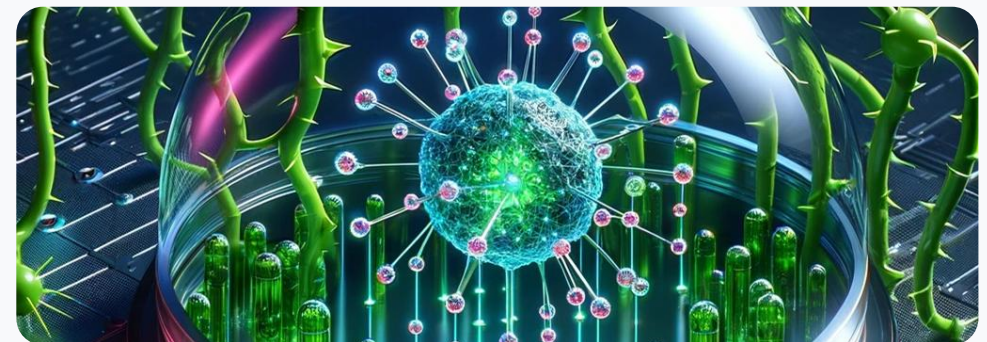
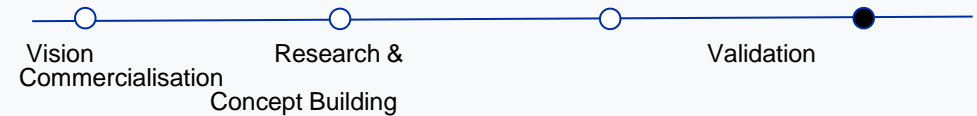
LanzaTech

SynBioBlox

Impact

Enhancing natural carbon capture and utilisation processes offers more sustainable alternatives to traditional practices: contributes to circular carbon economy, higher yields, renewable characteristics, and may even have reduced environmental impact.

Stage



Plasma Carbon Conversion



Turning CO₂ and CH₄ into syngas and hydrogen

Emissions to syngas

The plasma carbon conversion transforms CO₂ and methane (CH₄) into hydrogen and syngas, which are further used in products such as chemicals, fuels, and energy.

A novel technology which has gained attention for being an energy efficient method to capture and utilise carbon emissions. It leverages floating microwave plasma technology to break the bonds of greenhouse gases to make clean fuels and products.

Tech dependencies

The efficiency and sustainability of plasma-based conversion heavily depends on the source of electrical energy used to generate plasma.

Active players

Recarbon Inc.

Impact

Plasma carbon conversion can contribute to the development of a circular carbon economy, where two of the world's most harmful greenhouse gases are captured and converted into hydrogen and synthetic gas, creating value from waste. The technology is expected to help decarbonize industries such as steel, chemicals, and cement.

Stage





Built Environment and Energy



Creating flexible energy infrastructures



Active role of infrastructure

The nexus between the built environment and the energy market is undergoing transformative changes characterised by decentralized energy systems coupled with advancements in energy storage and smart grid.

Technologies are emerging that promise a future where buildings not only consume less energy but can also produce and manage it.

These developments drive innovation in this field:

Distributed Energy Resources / VPPs

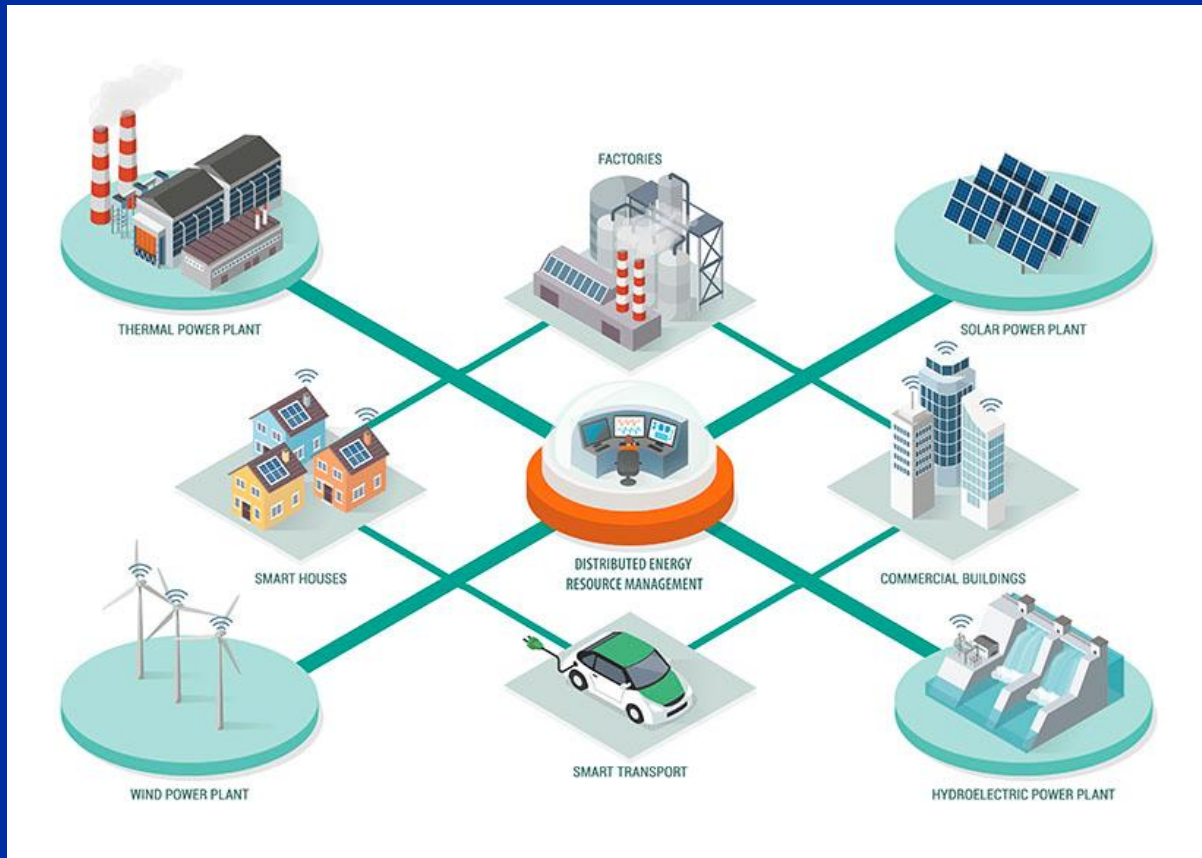
Radiative cooling

Alternative energy harvesting

Built materials as an energy source or storage

Distributed Energy Resources

Decentralising Power Generation



Revolutionising the Energy Landscape

Major developments are taking place in boosting local energy production at residential and commercial level towards increasing consumers' independence and at the same time supporting grid management. Introduction of DERs is transforming how energy is produced, traded, distributed and consumed.

Some of the key developments in this field include:

Smart meters

Peer-to-peer trading

Integration & control

Residential energy storage

Grid modernization

Microgrids

Local flexibility markets

Demand response

Virtual power plants

Energy analytics

Distributed Energy Resources



Virtual Power Plants

Cloud-software Solution

Virtual Power Plants are software solutions that orchestrate energy technologies and optimise operations by using AI & ML. They enable integration and management of distributed energy generation, storage, EVs, and heat pumps - regardless of the location of the resources.

For example, Sonnen is deploying thousands of residential batteries and utilising those as a source of flexibility through their VPP software.

Tech dependencies:

- Smart metres
- IoT - smart devices
- AI and ML models

Active players

OhmConnect

Statkraft

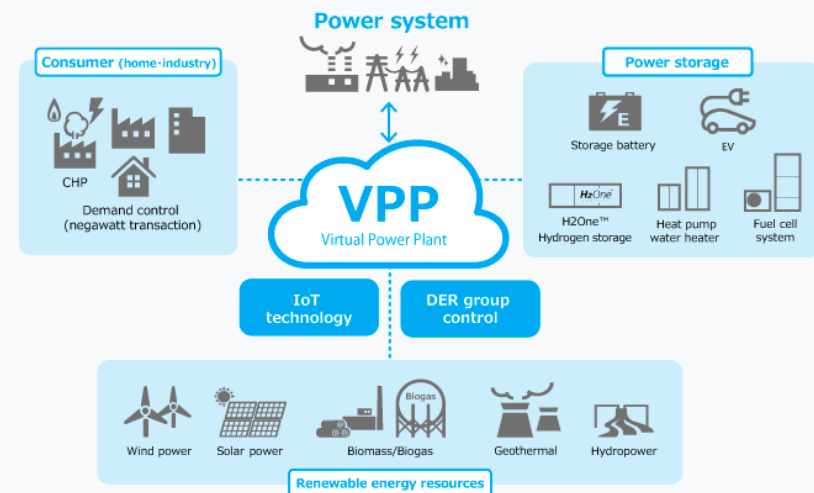
Next Kraftwerke

Sonnen

Impact

VPPs have a wide impact in the energy sectors such as capitalising on any size of generation or storage, opening up the market to individual consumers, providing demand flexibility, and optimising operations.

Stage



Molecular Solar Thermal Energy Storage



Storing energy in the chemical bonds of molecules

MOST

MOST is an innovative technology storing solar based energy in the chemical bonds of molecules. An ongoing EU project has identified molecular photoswitches that can absorb and store solar energy at room temperature. Utilising quantum computing, the researchers were able to analyse a large database (400,000 molecules) to find molecules best suited for MOST. The technology presents a promising way to harness and store solar energy due to its high density and long duration storage (18 years).

Tech dependencies

Molecular systems, catalysts, heat release devices and specialised hybrid solar collectors, which will all be developed as part of the project.

Active players

Technical Uni. of Catalonia

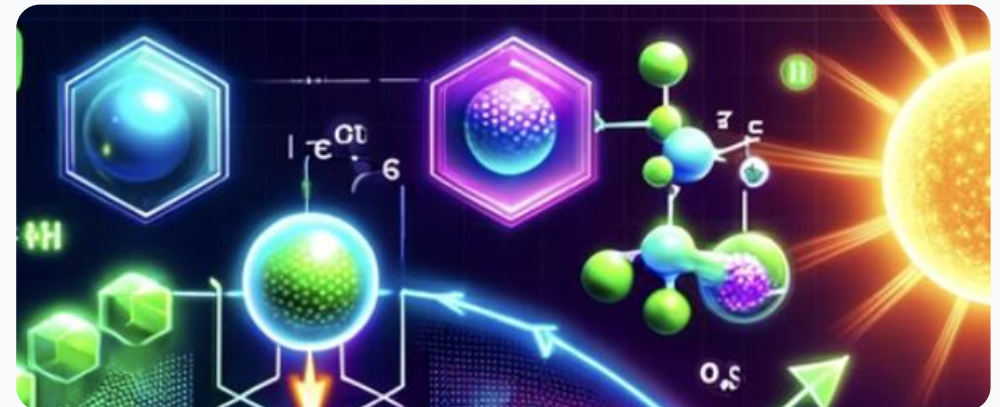
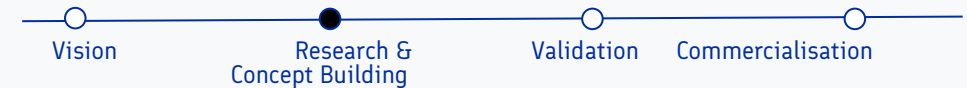
Uni. of Copenhagen

MOST EU Project

Impact

A zero-emission solar energy system based on benign, all renewable materials. The prototype devices have been developed.

Stage



Carbon-Cement Supercapacitors



Electrified cement

Electrifying Buildings & Infrastructure

MIT engineers have created a promising supercapacitor technology for renewable energy storage. This innovative method uses cement and black carbon, readily available materials that, when combined with water, form a supercapacitor, providing a new energy solution.

The technology could eventually be integrated into structures like building foundations or roads, allowing for energy storage and usage as needed. Tradeoffs between storage capacity and strength have been researched and the material can be altered based on use case needs.

Tech dependencies

The principle has been proven, next steps include increasing the size of the block to validate theoretical assumptions.

Active players

MIT

Impact

Claimed to be easily scalable and if successful could provide an alternative to battery storages. Initial use cases could include isolated houses or buildings far from grid power. Other applications could include roads that can wirelessly charge electric vehicles.

Stage



Thermal Energy Storage



Waste-heat recycling and net-zero heat and power

Integration of TES into Buildings

A significant area of exploration is the use of common building materials as energy storage solutions, specifically through Thermal Energy Storage (TES) systems. These utilise inexpensive, mineral-based construction materials like bricks, stone, and sand, to store heat and release it over time. One emerging approach is using volcanic rock to store heat, employing water to transfer the stored heat as steam for utility and industrial applications.

This concept is reimagining building systems, transforming them into dual-purpose solutions to support energy capture, with the bonus of heating and cooling capabilities.

Tech dependencies

Industrial process and grid utility integration, dependent on advances in thermal engineering.

Active players

Rondo Energy

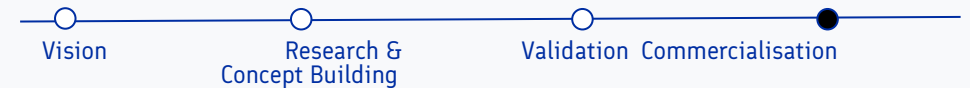
Brenmiller

Antora

Impact

Cost-effective alternative to electricity storage, avoiding the issues related to Li-ion batteries and playing a crucial role in achieving a clean energy economy. These TES systems leverage materials readily available in construction, thereby presenting a viable and scalable solution to energy storage and use.

Stage



Eco-Active Building Envelopes



Passive cooling mechanisms for buildings

Radiating heat into space

Developers of passive cooling and heating systems are tapping into the concept of radiative cooling. Innovations are evolving around coatings that can be directly applied to building walls, panels or vehicles. The reflective technologies integrated into surfaces emit longwave infrared radiation back into space preventing the building from absorbing the heat.

One promising technology is cooling glass, a microporous glass coating reflecting 99% of solar radiation back to space. Possible to apply to multiple surfaces including bricks, tiles and metal.

Because multiple new innovations arise within this theme, challenges appear to arise in understanding and comparing the actual cooling effects.

Active players

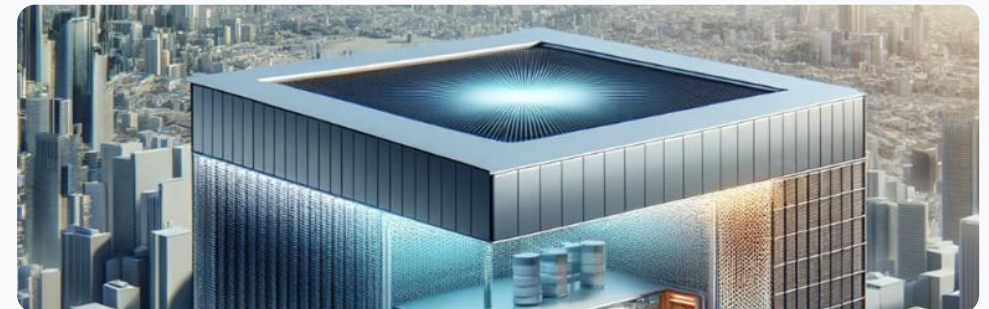
University of Maryland

SkyCool Systems

Impact

These coating technologies have the potential to reduce carbon emissions by offering a way to provide electricity-free cooling. They can positively contribute to mitigating urban heat island effects by providing passive cooling.

Stage



Alternative Energy Harvesting



Mechanical energy harvesting from rain

Triboelectric Nanogenerator (TENG)

Rain panels capture electrical power from falling rain, utilizing a new "bridge array generators" design to enhance efficiency by overcoming previous technical constraints. This innovation significantly boosts power output, positioning rain panels as a feasible renewable energy source alongside or as an alternative to solar panels.

The technology shows promise for widespread raindrop energy harvesting, potentially transforming renewable energy landscapes.

Tech dependencies

Not tested at scale. Future integrations into energy systems.

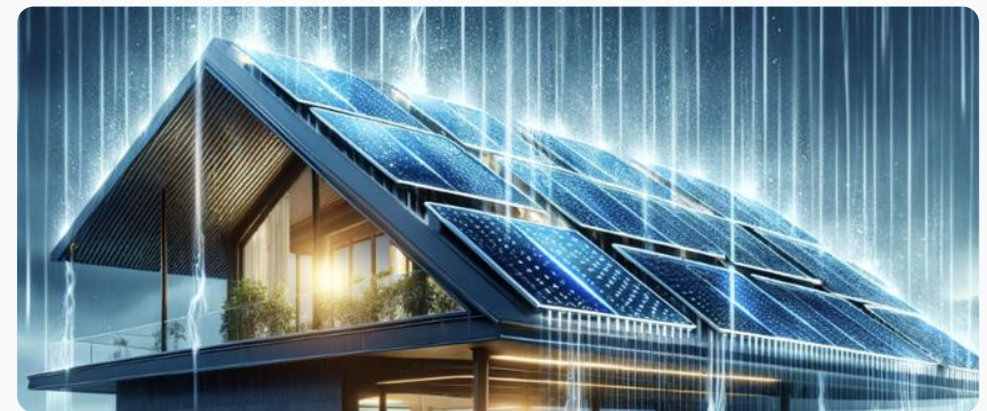
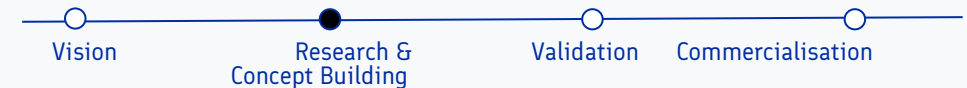
Active players

Tsinghua University

Impact

Substitute and complement solar panels. Potential to be integrated into buildings, enabling energy production also in cloudy or rainy conditions.

Stage





Alternative Materials and Processes

Reducing Dependencies

Emerging technologies and approaches for battery materials and processes



Expanding alternatives

As the demand for critical raw minerals escalates concern arises over their finite supply and reliance on a handful of nations for procurement.

Consequently, recent innovations have focused on confronting this issue by pioneering alternative material development and spearheading the advancement of low-carbon recycling methodologies. Research suggests that particularly alternatives to REE are developed in the U.S., South Korea, and Japan.

Some technologies and developments include:

Iron-nitride magnets

Aqueous rechargeable batteries

Microbial battery recycling

Alternative Battery Materials



What is the current status of alternative battery materials and chemistries?

Overall status

A lot of early research is underway for high-performance substitutes to rare earth elements (REE) used in batteries. [Northeastern University engineers](#) have patented a method to produce an alternative to rare earth magnets using tetrataenite, a mineral from meteorites, aiming to mitigate the global rare earth crisis and lessen reliance on China.

Japanese companies are leading the charge, enhancing their development of alternative technologies to reduce dependence on rare earths. Some alternatives being developed:

Iron-nickel

Iron nitride

Samarium-iron isotropic

Iron-nickel superlattice magnet in the spotlight

Emerging

[Denso](#), a top global automotive parts manufacturer, has developed an alternative magnet called the "iron-nickel superlattice magnet." Made solely from iron and nickel, it matches or exceeds the performance of neodymium magnets. Denso aims to commercialize this innovative magnet in the near future.

Sustainable mining methods

Emerging

Biomining is also emerging as a promising green technology that could revolutionise the way we recover rare earth elements. The traditional process of extracting these elements is energy-intensive and environmentally damaging, involving high temperatures and harsh chemicals.

[Researchers](#) in the US have engineered bacterial strains that can biosorb up to 210% more rare earth elements, suggesting a potential to replace solvent extraction methods with a more environmentally friendly process.



Iron Nitride Magnets

Replacing rare earth elements



Industrial Permanent Magnets

The need to find alternatives to REE magnets is growing at a rapid pace. Companies are piloting on REE-free possibilities to replace the need for REE's such as neodymium, praseodymium and dysprosium.

One promising option is seen in iron nitride magnets, currently in scale-up piloting phase. The technology utilizes nanomaterial engineering and mature metallurgical methods to produce high-strength, rare earth-free permanent magnets.

Tech dependencies

Large car manufacturers have pledged to move to REE-free magnets, making the industry attractive. Challenges may rise in funding industrial scale production facilities.

Active players

Niron Magnetics

Proterial

Impact

Reducing supply chain dependencies on rare earth elements by replacing previous critical minerals with more available elements.

Stage



Aqueous Rechargeable Batteries



An alternative to lithium-ion batteries

Zinc-ion batteries

Aqueous batteries have long shown promise as a viable alternative to lithium-ion batteries, but safety concerns have hindered their commercial success. Recently breakthroughs have been made in both the safety and durability of AZBs positioning them as a strong competitor in energy storage to conventional lithium-ion batteries.

Tech dependencies

While commercialisation and scaling of zinc-ion batteries is taking place, research into their characteristic and further enhancements of their energy capacity continue.

Active players

KIST Energy Storage Research Center

Salient Energy Inc.

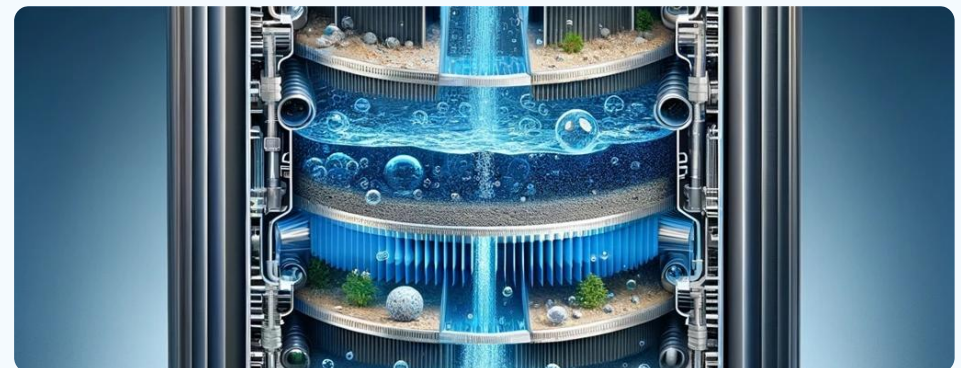
University of South Wales

Enerpoly

Impact

Due to the materials used in AZB's, they are less expensive, safer, and regarded as more environmentally friendly than lithium-ion batteries. Impact on the advancement of electrification seem promising.

Stage



Microbial Battery Recycling



Biotechnology's role in recycling e-waste

Engineered bacteria

Biotechnology has emerged as a viable, low-emission alternative for recycling precious metals from electronic waste and other waste streams, most recently from EV lithium-ion batteries. Newly tested engineered bacteria has been created to simulate natural reaction of fermentation that enables the break down of EV batteries into nano-sized metallic compounds of precious metals.

Tech dependencies

While microbial e-waste recycling is piloted by some companies, innovation is yet to find scalable business models. For each project, specific microbiomes need to be identified. If commercially viable could present a step towards more sustainable, low-emission battery recycling.

Active players

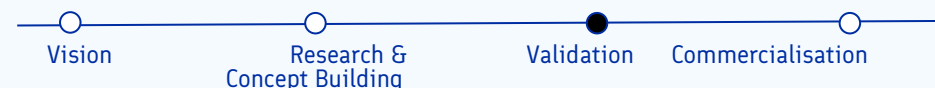
University of Edinburgh

BRAIN Biotech

Impact

Utilizing microbes to extract metals significantly reduces the CO2 footprint compared to traditional mining and recycling methods. This petrochemical free method of recycling and repurposing valuable materials such as cobalt, manganese, nickel, and lithium also has the potential to improve supply chain security and stability.

Stage





Carbon Management

Emission Management

Some emerging approaches for carbon validation and reporting



Tackling transparency and traceability

Sensors are increasingly crucial for gathering and transmitting real-time data, enabling organizations, for example, to optimize energy consumption instantly (scope 1-2). Digital twins are emerging technologies enabling organisations to model, analyze, and improve operations and resource consumption.

However, a major challenge is acquiring high-quality vendor data, especially on scope 3 carbon emissions, which form the bulk of an organization's carbon footprint but often lack adequate reporting.

Some emerging approaches and technologies in this field include:

Centralised Data Platforms

Distributed Ledger Technology

Centralised Data Platforms



Platforms for data sharing and value chain impact verification

Carbon Management Platforms

Some of challenges hindering Scope 3 reporting are limited data transparency and traceability.

New platforms are emerging to centralise data, enabling businesses and their suppliers to measure and share emissions data more easily. These platforms allow companies to directly obtain emissions data from suppliers, moving beyond conventional carbon surveys and providing more accurate tools for carbon accounting than traditional revenue-based estimates.

This also covers social data like working hours, labor practices, and worker demographics at supplier sites to refine emission estimates.

Active players

Persefoni

Plana

SustainCERT

Emitwise

CO2 AI

Impact

As the demand for accurate and comprehensive climate reporting intensifies, these data platforms mark a significant step forward in driving sustainable practices and creating a more transparent value chain. As AI solutions evolve, they will enhance the precision, efficiency, and decision-making in managing emissions.

Stage



Distributed Ledger Technology



Decentralised technology for emission reporting

Blockchain and dMRV

The emerging trend of utilising blockchain for collecting and reporting Scope 3 emissions is gaining momentum. By establishing a permanent and transparent data ledger, this approach ensures that all relevant users have access to the necessary information in a consistent format, enhancing both efficiency and supervision.

This approach ensures uniformity across technical frameworks while utilizing the strengths of distributed ledgers, such as auditability, discoverability, and liquidity, to improve emission offsetting and sustainability reporting.

Tech dependencies

Blockchain development and acceptance and, decentralised platforms, dMRV solutions

Active players

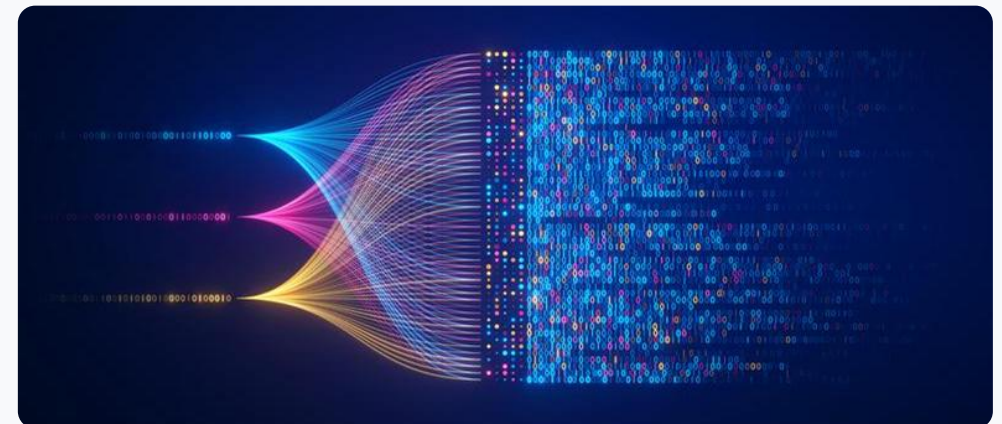
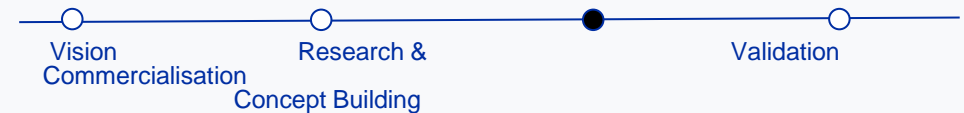
The Hedera Guardian x Hyphen

TraceX Technologies

Impact

These development set potential new standards for sustainability reporting to ensure credibility and accuracy from disparate data sources.

Stage





Part 4

Concluding Notes



Energy and Power-to-X

Green ammonia, from green hydrogen, is becoming viable route to carbon neutrality in hard-to-electrify industries, benefiting from its existing market and transport ease. Overall, hydrogen ecosystems hold significant promise beyond energy considerations in transforming manufacturing and bringing in new raw materials for various industries.

Buildings are poised to evolve into energy storage hubs with the development of new thermal energy storage solutions.



Carbon

There is increased interest and development in microbial and biological technologies for carbon capture and utilisation.

The task of reporting and verifying Scope 3 emissions poses a considerable challenge. Significant efforts are being made to create cooperative data platforms that enable the transparent sharing of data and the verification of emissions reporting. Europe seems to be leading this initiative, with pioneering solutions originating from European startups.

Alternative Materials & Processes

The US, South Korea, and Japan, in particular, lead in creating commercial alternatives to rare earth battery materials. There's also a rising focus on more sustainable and effective recycling and mining.

Another emerging area is regenerative approaches to materials and the concept of biomimicry, which is gaining more attention in industries ranging from textiles to construction.

Further opportunities

Collaboration ideas

- A comprehensive solutions level research into energy storage solutions or power-to-x players
- Deeper research into regenerative climate technologies
- Alternative materials linked to specific industries
- A closer look at synthetic biology and its applications across different sectors



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“Catapult provides the means for corporations to implement their digitalization strategy on a practical level.”

Johannes Milén | Director, Pepsico

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