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SUSTAINABILITY MONOGRAPHS

THE 'CLEANTECH' REVOLUTION

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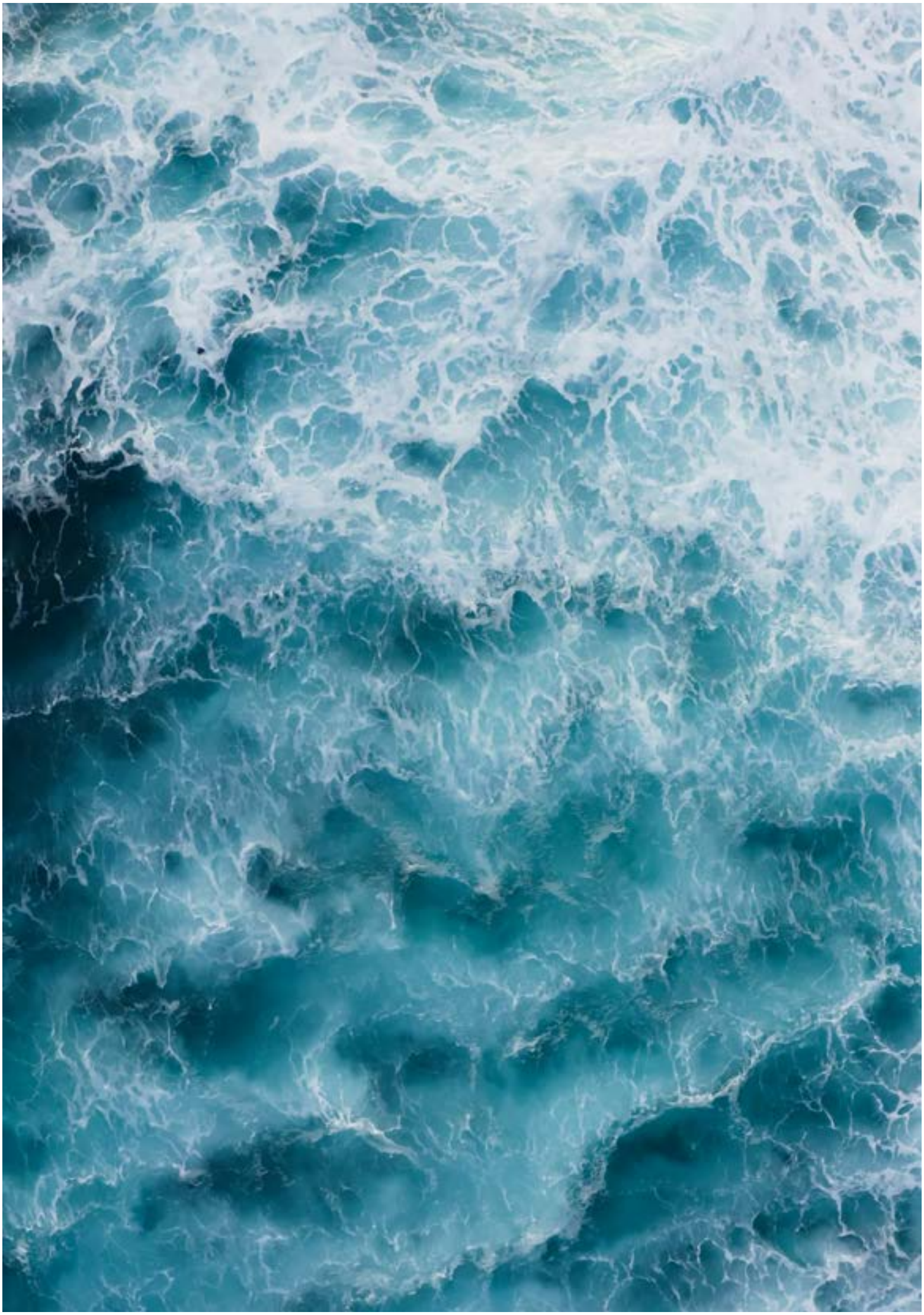


ÍNDICE

INTRODUCTION. THE GIANTS WEREN'T IMAGINARY

P.4

WHAT IS CLEANTECH?

P.9

ROAD TO MATURITY: FROM WINDMILLS TO SALT BATTERIES

P.18

FOUR 'CLEANTECH' VERTICALS TO SAVE THE WORLD: SUCCESS STORIES

P.27

CONCLUSIONS

P.38

INTRODUCTION

> For look there, friend Sancho Panza, where thirty or more monstrous giants present themselves, all of whom I mean to engage in battle and slay.
>
> (...) "Look, your worship," said Sancho; "what we see there are not giants but windmills, and what seem to be their arms are the sails that turned by the wind make the **millstone** go”.

Who could have imagined that, 420 years after its writing, **one of the best-known tales of 'Don Quixote' would speak of a revolution?** Not a struggle of knights and giants, but one powered by clean technologies, poised to confront one of humanity's greatest challenges: climate change.

POUL LA COUR, WORKING AT A LOCAL SCHOOL, BUILT WHAT IS NOW REGARDED AS THE FIRST MODERN WIND TURBINE.

But back to windmills, whose origins are shrouded in history. The earliest known wind machine was built over 3,500 years ago in Mesopotamia, now Iraq. Its use for grinding grain followed soon after, though its exact birthplace remains unclear, with near-simultaneous references from China, ancient Greece, and Rome. What is certain is that windmills arrived in the Iberian Peninsula under the **Caliphate of Cordoba** and have remained ever since.

The true giants, however, wouldn't emerge for centuries. **Their story begins in late 19th-century Denmark**, where physicist **Poul la Cour**, working at a local school, built what is now regarded as the first modern wind turbine. Today, not far from that school, stand turbines towering over **250 metres**. These structures are so vast that they might have made even Cervantes question his imagination.

Wind is not the only clean energy we have harnessed for millennia. There may be no famous novels recounting their origins, but the **power of water and the energy of the sun have long served humanity**. Water wheels were common in **Sumer and Babylon**, while the Romans devised intricate systems to heat **their public baths using solar energy**.

Historical anecdotes, however, pale in comparison to the current advancements in clean energy. Today, **renewable sources generate more than 30 percent of the world's electricity**. There are approximately 30,000 wind farms globally, housing around **half a million wind turbines**. Additionally, there are photovoltaic plants stretching to the horizon, capable of producing energy for over **a million homes**.

Moreover, the numbers continue to rise. Driven by innovation, **the cleantech revolution will shape our future**. Our ability to avoid the worst effects of climate change and achieve numerous additional benefits depends largely on our success in this effort. To ensure that success, we must rely on more than just wind turbines.

CHAPTER 1

WHAT IS CLEANTECH?

A factory in a Swedish village capable of producing steel without burning fossil fuels. A system for reusing polyester from clothing over and over again. Jet fuel produced from carbon dioxide extracted from the atmosphere. Limestone rocks that trap greenhouse gases and store them forever.

Clean technology encompasses far more than just wind turbines and solar panels. It represents a comprehensive ecosystem of **products, services, processes, and business models that address global environmental challenges** while striving to remain competitive and profitable for investors. This ecosystem spans sectors such as energy, transportation and logistics, materials, agriculture and food, resource management, and recycling.

The three shared attributes of all cleantech solutions are: "They provide superior performance or lower costs compared to earlier solutions, significantly reduce or eliminate negative environmental impacts, enhance resilience to the effects of climate change, and optimize the use of renewable resources or avoid the use of polluting ones”, eexplains Sofia Karagianni, Senior Policy Officer at Cleantech for Europe.

Clean technology is therefore a crucial tool for accelerating decarbonization, **fostering economic growth and job creation**, and enhancing the competitiveness of economies. At the European level, it has become a priority. The European Commission's strategy **for the next five years** includes key initiatives such as an agreement to decarbonize industry and lower energy costs, a plan to support European industries through the transition, and a competitiveness fund to invest in strategic clean technologies.

Widespread implementation of 'cleantech' solutions is no longer a luxury, but a necessity based on scientific evidence," adds Karagianni. **"Europe is the fastest warming continent in the world and is largely unprepared to deal with major climate risks."**

The promotion of clean technologies also **translates into wealth and employment**. In the case of Europe, cleantech companies in the European Union have a combined value of more than **€100 billion and, according to the latest available data, the EU's green economy supports 5.2 million direct jobs**.

In the Iberian Peninsula alone, cleantech will mobilize more than €150 billion of investment by 2030 and create 2.65 million new jobs,"

explains Bianca Dragomir, Director of Cleantech for Iberia, an initiative established to coordinate efforts among innovative companies, investors, and policymakers to strengthen the cleantech ecosystem in the region.

The large-scale deployment of clean technologies is critical, as it offers an unprecedented opportunity to reindustrialize and sustainably develop our continent. This is essential not only for Europe's sovereignty and competitiveness but also for meeting climate goals," she says.

The outlook for the coming years indicates clear global growth. The ***S&P Global Commodity Insights*** report highlights that global investment in clean energy alone—the most mature cleantech sector—will reach $800 billion in 2024, representing an increase of 10-20% compared to 2023. By the end of the decade, this figure is expected to surpass $1 trillion.

Cleantech challenges and the investment gap

As powerful as it may seem, the future of cleantech also has its own giants to contend with. **The first is financing**. According to estimates by **Cleantech for Europe**, Europe faces an investment gap of €50 billion by 2030 just to scale up photovoltaics and wind energy, battery production, electrolysers and heat pumps, and carbon capture and sequestration.

The challenges in terms of financing are considerable. We need to find a way to fund an unprecedented technological disruption, and we must do so quickly, in an uncertain market and amidst evolving regulations,"

explains Natalia Ruiz, partner at Suma Capital, a responsible investment manager specializing in waste management for biogas and biomethane production.

In general, cleantech requires long development periods and capital to mitigate technological risks. Once validated on a small scale, scaling up to commercial levels also demands high capital intensity, making it challenging to find suitable financial instruments."

But these challenges are solvable, says Ruiz.

> **Public-private financing is crucial. Tax incentives and subsidies can make investments more attractive by lowering upfront costs and the expenses associated with scaling up,"** she emphasizes. **"There is also a need to support specialized venture capital funds, which understand the unique challenges of the sector and can offer creative solutions to facilitate financing."**

For Sophia Karagianni, there are two other major challenges: one concerns **demand**, and the other pertains to access to clean and affordable electricity. On the one hand, demand for cleantech solutions is not as strong as it should be, and there are no comprehensive measures in Europe to introduce green solutions on a large scale in sectors such as construction, the automotive industry, or aviation. Additionally, inconsistent access to and the **high cost of clean energy** continue to pose significant economic barriers for businesses and consumers, diminishing incentives to invest in cleantech.

To these three major challenges, Bianca Dragomir adds a fourth: **scalability**. Unlike other startup segments, the initial costs of cleantech startups are high and their solutions are in direct competition with well-established industries with well-developed economies of scale.

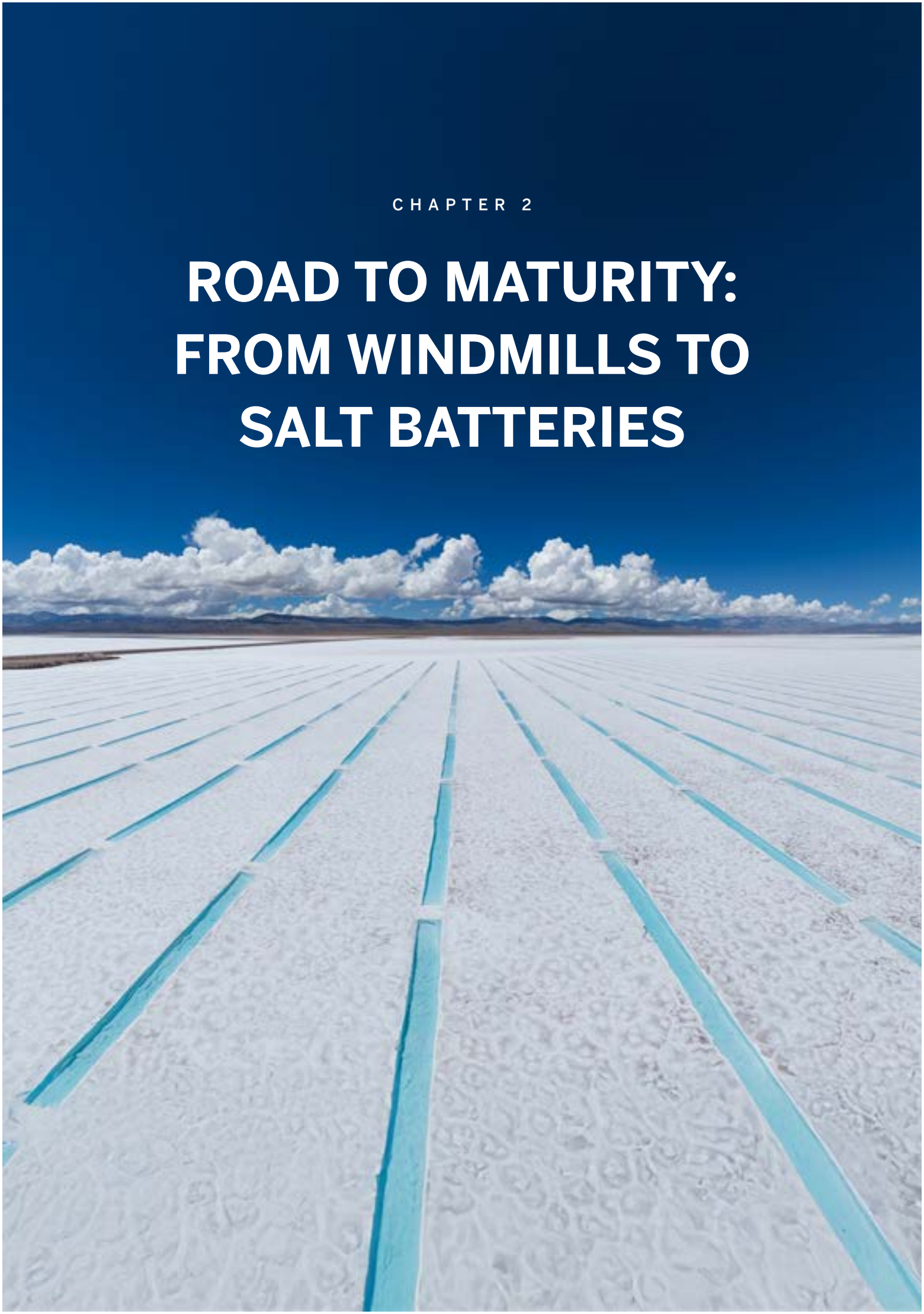
Campos de litio en el desierto de Atacama, Chile.

Finally, there is a fifth major challenge related to resource use and the **environmental impact** of clean technologies. According to the **International Energy Agency**, the production of batteries and renewable energy technologies will increase the demand for lithium by 43 times, nickel by 41 times, and cobalt by 21 times by 2040. This could lead to significant environmental impacts and create major bottlenecks for certain critical resources.

> **The solution to this dilemma is emerging from clean technologies themselves. Recycling and reusing critical materials presents a great opportunity for innovation in cleantech. Furthermore, we have the chance to develop new clean technologies that serve as alternatives to certain critical materials. For instance, we can produce batteries for electric vehicles without cobalt or create magnets for wind power generation that don't require rare earth elements,"** adds Dragomir.

CHAPTER 2

ROAD TO MATURITY: FROM WINDMILLS TO SALT BATTERIES



The cleantech ecosystem comprises a **broad range of products, services, and processes** across various industry sectors. According to **Cleantech for Europe**, when classified by industry, cleantech can be found in agriculture and food (from regenerative agriculture to bio-based fertilizers), energy (renewables, batteries, or grid management technologies), materials and chemicals (such as alternative fuels), transportation and logistics (electric vehicles as well as sustainable planes and ships), resources and environment (carbon capture or circular economy initiatives), and enabling technologies (including artificial intelligence and quantum computing).

MANY OF THE PROPOSED SOLUTIONS REMAIN LITTLE MORE THAN PROJECTS OR PROTOTYPES.

However, this classification does not always provide a realistic picture of the sector's level of development, as many of the proposed solutions remain little more than projects or prototypes. To this end, several analyses suggest that clean technologies should be categorized according to their level of maturity and their medium- and long-term potential. The following classification is based on data from the **International Energy Agency** (IEA), the **European Commission**, Cleantech for Europe , and the **U.S. Department of Energy**.

Advanced maturity

Today, solar and wind technologies are among the most mature 'cleantech' solutions and play a key role in the green transition, as they significantly reduce carbon dioxide emissions from the energy sector," says Sophia Karagianni**. "Energy storage solutions, such as lithium-ion batteries, are also crucial for managing the intermittency of renewable energy sources."**

According to data from the I**nternational Energy Agency**, **solar energy production is the fastest growing**. By the end of 2023, there were 1.6 terawatts (TW) of photovoltaic capacity installed worldwide, an increase of 446 gigawatts (GW) compared to the previous year. The agency estimates that more than 30 percent of the electricity generated globally now comes from renewable sources.

With regard to energy storage, pumped-storage hydroelectric power plants (which move water to higher reservoirs during times of excess energy production and then release it when needed) remain the most common solution. However, in recent years, the deployment of **large grid-connected battery systems** has increased. According to **the latest IEA data**, more than 28 GW of battery storage is already installed, with projections to reach 1,000 GW by the end of the decade.

Other clean technologies that have already reached a high level of development and are expected to gain market share in the coming years include offshore wind power, electric vehicles (**with around 40 million already on the road globally**), and geothermal energy, which harnesses the high temperatures present in the Earth's inner layers.

Medium maturity

This category covers innovative technologies and developments at a mid-growth stage. Their boundaries are less defined—while some have only been proven in small-scale projects, others are beginning to operate at an industrial level. Included here are, among other solutions:

Tidal power and wave energy. The first uses tidal energy, while the second taps into wave power. Though neither has been widely adopted on a large scale, both are clean technologies that have existed for years. For instance, the Rance tidal power plant in France, opened in 1966, generates 600 million kilowatt-hours annually.

Advanced nuclear reactors. Small Modular Reactors (SMRs) have reignited interest in nuclear power in recent years. These compact, modular reactors are simpler to deploy than large power plants. The **International Atomic Energy Agency** reports that 80 SMR projects are currently in development worldwide.

Green hydrogen. Hydrogen is extensively used in industry, but over 99% is still produced from natural gas. Recently, however, interest in cleaner hydrogen production methods has grown significantly. The three main alternatives are blue hydrogen (produced from natural gas with carbon emissions captured), pink hydrogen (from water electrolysis powered by nuclear energy), and green hydrogen (produced using renewable energies). Several low-emission hydrogen production plants are currently under development in China, the European Union, India, and the United States. According to the **IEA**, global hydrogen production is expected to reach 38 million tons by 2030, sufficient to meet nearly half of the projected demand.

Low maturity

Lastly, this category encompasses all cleantech solutions that are still in the **early stages of development** or whose implementation relies on scaling up some of the previously mentioned technologies. Examples include green steel and **alternative aviation fuels**, both of which largely depend on green hydrogen for their production.

One of the most promising yet still immature "cleantech" innovations is **carbon capture and storage** (CCS). Currently, the most common approach involves technologies that capture carbon dioxide directly at its source and then use it "in situ" within an industrial process. However, **according to the IEA**, there are only around 45 such facilities globally, and their capacity remains limited.

WE NEED TO REDUCE EMISSIONS AT A RATE 12 TIMES FASTER THAN WE ARE DOING NOW.

Plants solely dedicated to extracting carbon dioxide directly from the atmosphere are in a **much earlier stage of development**. The United States, the European Union, the United Kingdom, Canada, and Japan are home to the few projects currently underway, most of which are still in the testing phase.

Another highly promising technology is **solid-state batteries**, which offer the potential for greater capacity, improved efficiency, lower costs, and reduced reliance on metals like lithium. These batteries are primarily designed to address the electricity storage needs of the transportation sector. Meanwhile, another innovative type of battery is being developed specifically for large-scale energy storage: **molten salt batteries**. There are different technologies under development and their big challenge is that they have to operate at high temperatures.

In general, I believe that the key technologies will be those with the greatest potential to transform the economy and tackle global challenges like climate change, resource scarcity, and the energy transition," says Natalia Ruiz. **"These include technologies for more sustainable mobility and logistics, increasing the efficiency of renewable energies, energy storage, decarbonizing the industrial sector, and leveraging and valorizing waste, driving us toward a circular economy."**

To achieve the climate goals outlined in the Paris Agreement, the world must be firmly on a path toward decarbonization by 2030. Clean technologies play a critical role in this journey.

We need to reduce emissions at a rate 12 times faster than we are doing now. "Clean technologies are the backbone of our climate action, but they are also the key to our competitiveness and prosperity," adds Bianca Dragomir.

CHAPTER 4

FOUR 'CLEANTECH' VERTICALS TO SAVE THE WORLD: SUCCESS STORIES

Covering the vast array of cleantech solutions and companies in detail is an almost impossible task. Below, we explore four promising areas—**alternative fuels, green steel, circular economy, and carbon capture**—through four real-world success stories.

Alternative fuels case-study: Twelve

Aviation is one of the **most challenging sectors to decarbonize**. The primary obstacle is the lack of a more efficient and economically viable alternative to jet fuel, which is derived from various petroleum products. While several long-term solutions are under development—such as electrification and hydrogen—and advancements in aircraft efficiency are already making progress, the most mature and promising option currently available is sustainable aviation fuels (SAF).

THESE FUELS FUNCTION THE SAME AS TRADITIONAL PETROLEUM-BASED FUELS, REQUIRING NO MODIFICATIONS TO AIRCRAFT, AND THEY CAN BE PRODUCED FROM WASTE MATERIALS.

These fuels function the same as traditional petroleum-based fuels, **requiring no modifications to aircraft**, and they can be produced from waste materials, such as used oils, or from carbon captured from the air. That's where Twelve comes in. This U.S.-based startup describes itself as a carbon transformation company with the mission of eliminating global carbon dioxide emissions and creating a future free from fossil fuels.

Twelve has developed a **groundbreaking carbon transformation system**: an industrial-scale electrolyzer that mimics photosynthesis by converting carbon dioxide, water, and clean energy into hydrocarbons. These hydrocarbons can then be used to produce chemicals or fuels. Its flagship product is carbon-based SAF, which generates 90 percent fewer emissions than conventional fuel and uses significantly less water and resources compared to SAF made from vegetable oils and by-products.

Our technology has been proven to work. The main challenge now is scaling up production of SAF (Sustainable Aviation Fuel) to a level that can meaningfully reduce the carbon emissions generated by the aviation industry. Aviation accounts for 3 percent of global emissions, with commercial airlines consuming 380 billion liters of fuel annually," company representatives explain. "Our next step toward this goal is the completion of AirPlant One, Twelve's first SAF production facility, located in Moses Lake, Washington, USA. This plant will be the first of many across the country dedicated to producing sustainable aviation fuel."

Within the **alternative fuels sector**, **SAFs are not the only option**. Biofuels for cars and trucks (produced from vegetable oils, animal fats, or recycled restaurant grease), synthetic fuels (created from synthesis gases derived from coal, natural gas, or biomass), as well as synthetic methane, biomethane, and methanol for freighters and other large cargo ships are among the most promising cleantech solutions.

Green hydrogen for industry: H2 Green Steel

Steel production still heavily relies on coal. The majority of the world's steel mills use the traditional production method, which combines iron ore, limestone, and coke—a coal derivative. Additionally, many facilities continue to use coal as a fuel to heat their furnaces. In fact, several decarbonization reports, such as those from the IEA, predict that the steel industry will remain one of the final strongholds of coal for years to come. This sector alone accounts for 7 percent of global carbon dioxide emissions—and 5% in Europe. While green steel production **remains minimal** for now, that could be on the verge of significant change.

We are set to begin production in 2026. We have obtained the necessary environmental permits and secured €6.5 billion in financing. Construction of the plant began in mid-2022, and this summer, we successfully installed the first equipment for sustainable steel production,"

explains Karin Hallstan, Head of Public and Media Relations at H2 Green Steel, a Swedish company currently building Europe's first large-scale green steel plant in Boden, located in the north of the country.

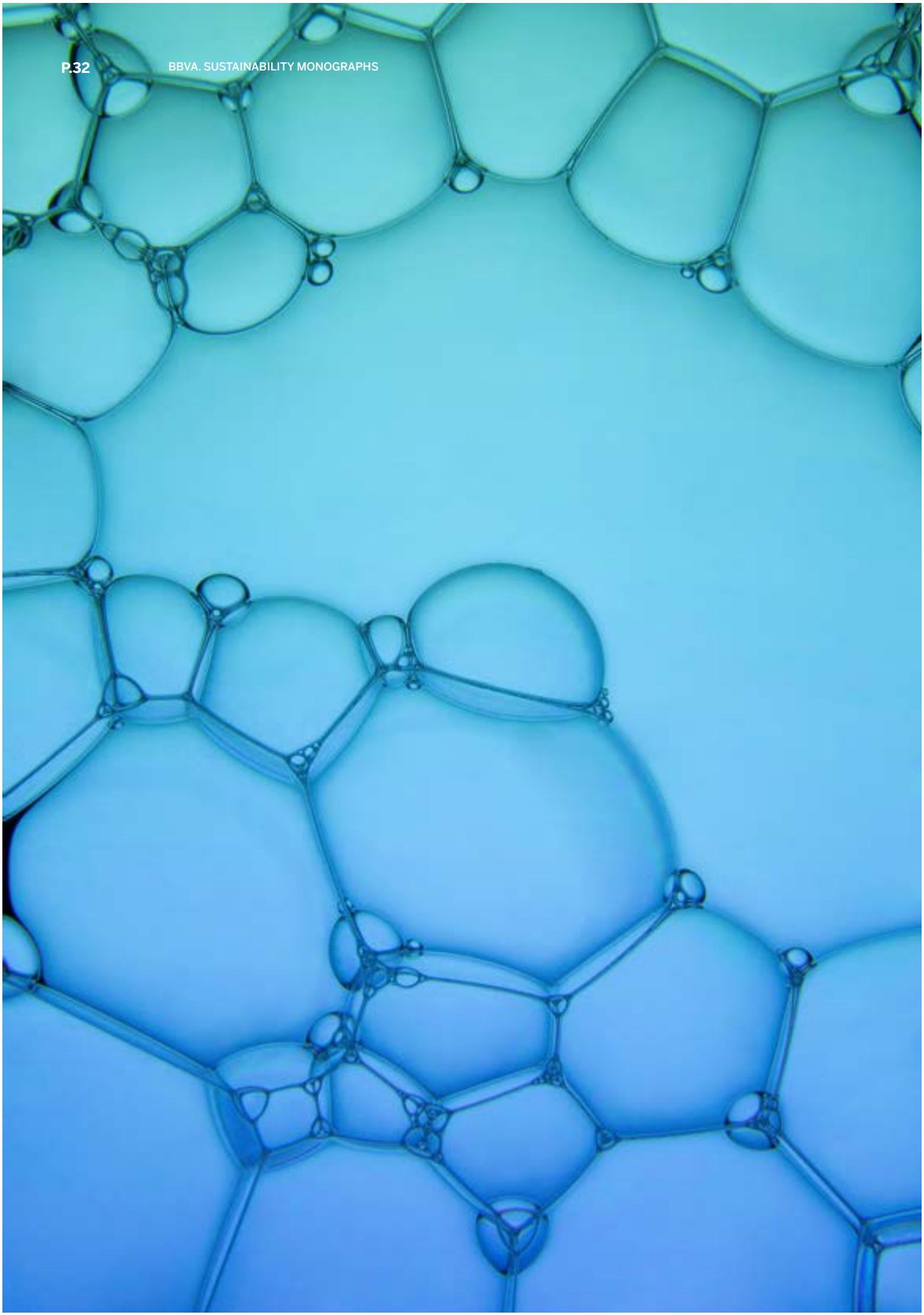
WE RELY ON THE POWER OF SCIENCE. WE NEED TO TRANSFORM OUR ECONOMY TO MEET THE GOALS OF THE PARIS AGREEMENT AND REDUCE THE EMISSION OF GREENHOUSE GASES.

The goal is to achieve a production capacity of 5 million tons of this material annually by 2030, while reducing emissions by 95 percent compared to traditional methods. To accomplish this, the first step is to produce hydrogen sustainably through the electrolysis of water, powered by electricity from renewable sources.

This hydrogen will then be used to reduce iron ore into steel, eliminating the need for coal in the process. This approach, known as direct iron reduction steelmaking, traditionally relies on natural gas. Finally, the necessary smelting to homogenize the material will be carried out in electric furnaces.

"We rely on the power of science. We need to transform our economy to meet the goals of the Paris Agreement and reduce the emission of greenhouse gases that are causing climate change. If we don't transform some of the world's most polluting industries, we won't make it. In several of these industries, such as steel and cement, cleantech is the solution," adds Hallstan.

Green hydrogen is also a key hope for the cement industry, which accounts for approximately **7 percent of global carbon emissions**. The European HYIELD project is currently **constructing Europe's first industrial-scale waste-to-hydrogen plant in Spain**. Once operational, this green hydrogen will be used in cement production, aiming to reduce final emissions by 47 percent.



Circular economy: SYRE

The fashion industry is not typically the first industry that comes to mind when considering major polluters. However, across its entire value chain, the production of clothing and footwear is responsible for 10 percent of global carbon emissions and 20 percent of water pollution, particularly during fabric manufacturing and dyeing processes. Moreover, it **contributes significantly to the waste problem**: the average European discards 11 kilograms of clothing annually, and globally, **less than 1 percent of this waste is recycled**.

The fashion industry is grappling with concerns about its sustainability. In response, various projects and initiatives have emerged in recent years aimed at **enhancing fabric durability**, adopting more sustainable materials, utilizing cleaner energy in production, and promoting circularity by improving the collection and recycling of used garments. This is where SYRE, a company within the H&M Group, plays a key role.

SYRE's mission is to decarbonize the fashion industry and eliminate textile waste, with a focus on polyester. Polyester is the most widely used textile fiber in clothing production, with **60 million tons manufactured annually**. As a petroleum-based material, it is also a significant contributor to the industry's emissions, accounting for roughly 40 percent of its total emissions. Currently, the majority of recycled polyester used in fashion does not come from discarded garments but rather from recycled plastic bottles.

THE CIRCULAR ECONOMY IS A KEY GLOBAL STRATEGY FOR REDUCING RESOURCE CONSUMPTION AND MINIMIZING WASTE GENERATION.

SYRE's business model focuses on establishing an efficient large-scale textile recycling system, facilitating the shift from a linear to a circular value chain, and reusing resources repeatedly. The company's primary aim is to operate **12 production plants** at full capacity by 2032. These plants are expected to produce over 3 million tons of recycled polyester annually, cutting manufacturing emissions by more than 15 million tons of carbon dioxide.

The **circular economy** is a key global strategy for reducing resource consumption and minimizing waste generation. Beyond the textiles and fashion sectors, industries such as plastics, food, and electronics are increasingly viewing the circular economy not only as a means to enhance sustainability but also as a significant economic opportunity. In fact, the **Ellen MacArthur Foundation** estimates that achieving full circularity in the complex manufacturing sector within the European Union alone could result in annual savings of $630 billion.

Carbon capture: Heirloom

THESE TECHNOLOGIES CAN BE HIGHLY EFFECTIVE IN DECARBONIZING INDUSTRIAL PROCESSES THAT CURRENTLY DEPEND ON FOSSIL FUELS.

Carbon capture and storage (CCS) has been discussed as a climate solution for decades. In recent years, however, it has evolved from a concept on paper to a **promising, actionable project**. The latest report from the Intergovernmental Panel on Climate Change (IPCC) emphasizes that CCS solutions need to play a crucial role in combating climate change over the medium and long term.

The report acknowledges that significant challenges remain in the implementation of carbon capture facilities and large-scale storage solutions. However, it highlights that these technologies can be highly effective in **decarbonizing industrial processes** that currently depend on fossil fuels.

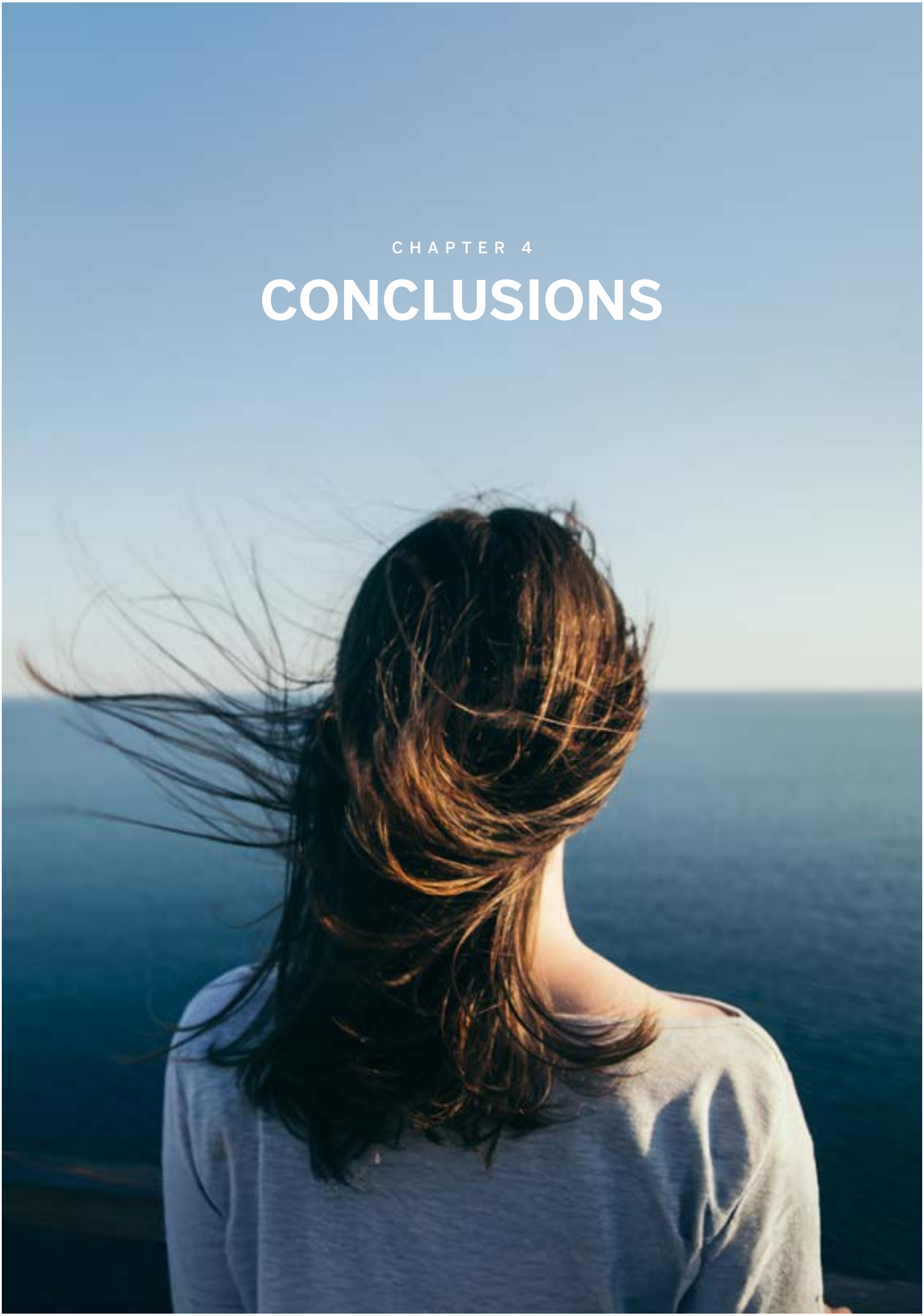
In northwest Louisiana (USA), Heirloom is building two large-scale carbon capture plants that extract carbon dioxide directly from the air. Once fully operational, these facilities will have the capacity to remove 320,000 tons of greenhouse gases from the atmosphere annually. The system they have developed replicates **a natural process that occurs in limestone rocks** but accelerates it significantly—reducing the time it takes for lime to transform back into rock **from several years to just three days**.

The **Heirloom system** also enables the carbon to be extracted from limestone rocks and converted back into lime to restart the process. Meanwhile, the **extracted carbon is securely and stably stored underground**, preventing it from returning to the atmosphere as carbon dioxide.

Beyond direct capture from the atmosphere, numerous solutions are being developed to trap carbon dioxide **during industrial processes** in factories. This capture can occur after combustion by extracting carbon dioxide from the waste gases generated by burning fossil fuels, or before combustion by converting fossil fuels into synthetic fuels and capturing the carbon dioxide before it is burned.

CHAPTER 4

CONCLUSIONS



Since humans overcame their fear of the giants hidden in the wind, renewable energies have been propelling the world forward. After a brief interlude—historically speaking—where fossil fuels dominated, it is once again time for air, sun, and water to take the lead. However, the clean technology revolution extends far beyond renewable energies. Our progress depends on their success. Below is a summary of the key points covered in this monograph:

1/ All **cleantech** solutions share three attributes: they improve on previous solutions in terms of performance or cost, reduce their ecological impact and contribute to the use of regenerative resources or, at least, avoid the use of polluting resources.

2/ Cleantech is not just about fighting climate change, it is also about **business and employment**. Cleantech companies in the European Union alone have a combined value of more than €100 billion and support 5.2 million direct jobs.

3/ The key challenge for this emerging sector is **financing**: Europe alone faces an investment gap of €50 billion by 2030 to scale up photovoltaics and wind energy, battery production, electrolysers and heat pumps, and carbon capture and sequestration. Demand momentum, energy costs, scalability and the environmental impact of materials are other key challenges.

4/ **Solar and wind technologies**, along with batteries, are the most developed and mature clean technology solutions. In the medium term, the most promising advancements include advanced modular nuclear reactors, green hydrogen, green steel and cement, as well as carbon capture and storage.

A publication of: