ANEMEL

Annual Report

Clean hydrogen
from dirty waters

2025

European Innovation Council

Funded by the European Union

About

ANEMEL

ANEMEL is a project, funded by the European Innovation Council and the Horizon Europe programme, focused on making green hydrogen from plentiful and sustainable resources, such as seawater and waste water.

To do this, the project will develop an electrolyser (a system that uses electricity to break water into hydrogen and oxygen) powered by green energy sources. This device will make use of non-critical raw materials within all its basic parts, including electrocatalysts and membranes.

European Innovation Council

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Innovation Council and SMEs Executive Agency (EISMEA). Neither the European Union nor the granting authority can be held responsible for them.

Table
# of contents

WP1
Catalysts

Work package 1 (WP1) prepares catalysts for both the cathode and the anode of our electrolysers. This also means optimising the substrates that will support these catalysts and the coating techniques to apply them.

Catalysts are essential in speeding up chemical reactions. In water splitting, we need them to increase both hydrogen and oxygen production. These reactions happen at two separate electrodes of our electrolysers: the cathode and the anode, respectively. **Finding the best catalysts** for both processes is the central task of this Work Package (WP).

The challenge is far from simple. Platinum-group metal catalysts are well known for their high reaction rates and stable performance, but considered critical raw materials, and **we are committed to finding more abundant, cheaper alternatives**. On top of that, operating in saline conditions means corrosion is our constant companion.

Despite these obstacles, we have already identified some promising catalysts. For example, the ANEMEL WP1 team explored **nickel ion-based catalysts as substitutes for platinum-group metals**. Our problem now lies in the substrate to support them: if it fails, the catalyst is lost, and the electrolyser stops working. In other words, the substrate is the foundation of the entire system, and WP1 is working to make this foundation as robust as possible. We initially considered nickel foam as a substrate, but it couldn't withstand the saline environment of seawater. Titanium offered greater resistance, but it wasn't conductive enough. Our team is now **focused on increasing titanium's conductivity**. Achieving this could match, even exceed, the performance of platinum-group metals catalysts.

A second important task WP1 has done over the past year is **optimising the coating techniques** used to apply the catalysts on the substrate, as this also plays a key role in keeping the catalysts firmly in place. Since our objective in ANEMEL is to run our electrolysers continuously for 2,000 hours, this still remains the major challenge for WP1.

But before moving to full-cell testing, WP1 must **achieve stability for at least 100 hours in half-cell studies** as a critical step. Half-cell studies use a three-electrode setup —anode, cathode, and reference electrode— to test the reactions separately. This allows the team to examine oxygen and hydrogen evolution in detail and separately. Our ANEMEL researchers have measured current density at different potentials, evaluated stability over time, and even studied structural changes in the catalyst. The refined electrodes have been shipped to other WPs to scale them up.

Mimicking seawater

At ANEMEL, we work with seawater. Well, not exactly real seawater **—our researchers are mimicking it in the laboratory by dissolving salt in water—**. The salt contains chloride ions, which corrodes nickel and other catalysts we might use. For this reason, we require resistant, resilient catalysts, ready to withstand such a corrosive environment. This is why we are focusing on titanium-based substrates, as they are far more resistant to chloride and chloride oxidation products.

“If we are able to increase the conductivity of the titanium substrate, we will be able to get a performance like platinum-group catalysts.”
Praveen Kumar

WP2
Membranes

Membranes are essential for an electrolyser to work. They keep the hydrogen and oxygen gases separated while allowing ions to pass through and travel to the electrodes. Our researchers have managed to overcome the obstacles of previous years and achieve promising results. The focus is now on scaling up the membranes so other WPs can build our stacks.

Membranes make the heart of our electrolysers. They serve as the bridge that connects the electrodes and enables the transportation of ions in the device, while also keeping the hydrogen and oxygen gases safely separated! At ANEMEL, we are pursuing a membrane that allows ions to move very quickly without losing any extra energy. Additionally, we want membranes to remain mechanically strong, to effectively separate the two sides of the electrolyser, while keeping chemical stability. All this is not easy, given that **membranes are exposed to extremely reactive and corrosive conditions** during electrolysis, particularly when using seawater, which is already a highly saline and oxidising environment.

To build our membranes, **we work with polymers with different fluorine-free "functional groups"**, fragments that allow ions to move through the membrane quick enough, enhancing the efficiency of the electrolyser. Over the past year, we have continued in the same direction as before, working on these promising polymers, as well as on the scaffolding that provides them with extra mechanical stability. However, we have encountered some plot twists along the way...

At the beginning of the project, we worked with commercial polymers, improving them with key chemical modifications. Since the project has a limited timeframe, it made sense to build on something that already worked. Later on, however, we explored **designing polymers from scratch**. ANEMEL considers sustainability and scalability from the start, and, in an industrial perspective, materials built "brick by brick" may be better. We therefore started to focus on this second approach.

The work here has involved studying new polymers by modifying the properties of their building blocks, the monomers. We achieved very promising results, with both a boost in conductivity and stability. However, when it came to scaling up, this approach was less successful. The polymers were not mechanically strong enough, which eventually made ANEMEL researchers **return to commercially available alternatives.**

We have not only achieved excellent results with this material, it also works well at a larger scale. This required identifying a suitable commercial scaffold that we could use. WP2 is now focusing on scaling up the membranes, not yet to an industrial level, but large enough to allow WP3 and WP4 develop our stacks.

Thinking bigger in different scales

Our focus at ANEMEL is on the industrialisation of our prototypes. Some members of WP2 are **exploring how to scale up the synthesis of our membranes**, identifying what is needed to make this possible. Some key considerations include staying within certain cost limits, a feasible polymer design, and selecting appropriate coating technologies. What we aim to achieve within the lifespan of the project is a sufficiently large membrane, enough to build and assemble a functional stack, but still at a laboratory level.

> "We went back to the very first polymer, which is flexible, works at a larger scale, and delivers good performance."
> **Mohamed Mamlouk**

WP3
Cells

By combining the catalysts and membranes developed in other WPs, this team assembles complete electrolytic cells –the fundamental building blocks for splitting water and producing green hydrogen–. This year at ANEMEL, we carried out some final tests that have brought us even closer to a fully functional electrolyser.

WP3 is responsible for the electrolytic cells. This means **assembling the electrodes, the electrolyte, the membrane, and eventually an encasing system to hold everything together**. Cells are the basic units that, repeatedly, will serve to build our stacks, which are essentially our objective devices.

Over the past year, this ANEMEL team has focused on cell design itself, using components —catalysts and membranes— developed in WP1 and WP2, while also advancing critical elements, particularly the electrodes. A key task here was the fabrication of both anodic and cathodic electrodes incorporating the catalysts from WP1. This required some optimisation, since the catalysts provided by our partners are based on novel materials. To achieve this, our researchers have worked on **formulating inks containing the catalysts and perfecting deposition techniques onto substrates** to obtain robust and efficient electrodes.

Regarding cell configurations, our goal is to identify the option that delivers the highest performance, even at alkaline conditions. WP3 has carried out extensive screening across different combinations and operating conditions, including reducing the pH before moving towards sodium chloride solutions. This reduction in the concentration of OH^- ions, however, also reduces their availability, which means the cell must be highly conductive to maintain efficiency. Luckily, our work was more than successful! We were able to identify promising candidates for further testing in sodium chloride and even future scale-up.

Part of the work here involved **screening different catalyst layer architectures**, including studying the incorporation of the ionomer into the electrolyser, while also considering the impact of lowering pH. The results? Including the ionomer significantly improved performance, especially when adding the ionomer as a separate layer on top. This research, focused on the architecture of the ionomer within the electrolyser design resulted in a **paper published in *ACS Energy & Fuels***. Hooray!

But WP3 had its struggles too. Our project is structured around defined deliverables and timelines for each WP. If one WP cannot meet a deadline, this can affect the others. WP3 is particularly sensitive in this regard, as it has the strongest connections with the other WPs. Some deliverables were postponed over the past year, but we expect to complete them by the end of 2025.

Fitting the pieces of the puzzle

The importance of WP3 is that it **identifies the best materials and configurations before scaling them up** into the final stack. After all, there's little point in building a full electrolyser only to find that the membrane doesn't work properly or the catalyst is detaching from its substrate. WP3 saves both time and resources, making sure that every piece of the puzzle is right and works properly, so the complete system can be put into work successfully.

"We first investigate a single cell to better understand certain phenomena before moving on to stacking."
Fabio Dionigi

WP4
Stacks

If a single cell is powerful, imagine a pile of them! We built stacks of five cells, offering a more practical and scalable approach to hydrogen production. By building on this one-kilowatt proof-of-concept stack, WP4 has improved durability, enhanced corrosion resistance, and prepared everything for the final tests with salty water.

Last year, we proudly reported that our team had reached one of ANEMEL's key milestones: a five-cell stack reaching more than one kilowatt of power input. The prototype exceeded expectations, as it was completed well ahead of schedule. However, it was essentially a short-duration proof of concept. This year, the focus has shifted from demonstrating feasibility to proving stability. To that end, WP4 carried out its **first long-term operation test, running electrolysis in the stack for nearly 1,500 hours**.

Our team has also worked on **building a new test bench**. Unlike the earlier setup, which was housed in a small hood and suitable only for short runs, the new design will allow us to host larger stacks and reach higher power levels. The researchers plan to redo the one-kilowatt stack using the same state-of-the-art materials, which will provide a consistent baseline for validating the new test bench while avoiding too many simultaneous variables. Future plans include testing our own ANEMEL materials, of course, as soon as other WPs produce sufficient samples.

The new test bench presents another new feature, as it is also though to use up to eight stacked cells. This gives ANEMEL researchers the opportunity to operate at lower current density while still having enough voltage to reach more kilowatts —potentially five, maybe ten! Another objective is to improve efficiency even further, ready to reach ANEMEL's long-term goal: **an efficient electrolyser running continuously for 2,000 hours**.

As we want to run the stack on saline solutions, we will require additional protection from their highly corrosive nature. The **bipolar plates in our stacks therefore need strong protective coatings**, which was the main focus of ANEMEL's WP4 during the last few months. In addition, we upgraded our corrosion-testing setup, which helped us identify the best coatings, optimised for the seawater tests.

So, although WP4 achieved its main goal early in the project, important work still lies ahead. With robust coatings identified and the new test bench in place, WP4 is now ready to move forward with long-term durability studies. We cannot wait to next to see how the stacks perform with ANEMEL's own materials!

A high-impact paper

Among WP4's achievements over the past year is a **paper published in *ACS Energy & Fuels*, which became the most downloaded paper in its category** soon after its release. In this work, the team operated a full cell for over 1,000 hours to perform detailed structural and electrochemical characterisation. Our researchers combined reference electrode measurements with an analysis of the distribution of relaxation times (DRT) to gain unprecedented insight into performance losses within AEM water electrolysers.

"We achieved a one-kilowatt proof-of-concept stack in the first year, everything now builds on top of this."
Jan Van Herle

WP5
Sustainability

WP5 focuses on developing an eco-friendly prototype design with minimal environmental impact. By the end of the project, our researchers will conduct a full life cycle analysis (LCA), and also economic and social assessments, to compare our results with existing AEM water electrolysis technologies. These tasks have already started by collecting data from all partners, with some preliminary assessments already on the table.

We take sustainability very seriously. That's why we ANEMEL researchers work to ensure **the design of our electrolysers has the smallest possible environmental impact**. Among other tasks, we are conducting a full life cycle analysis (LCA), as well as life cycle costing (LCC) and social life cycle assessment (S-LCA), comparing the results to industry standards and state-of-the-art electrolysers —to provide a prototype as eco-friendly as possible—.

Throughout this year, our sustainability partners have continued collecting data from all WPs, a task started almost at the beginning of the project. With that, ANEMEL researchers will **implement models to improve the preliminary environmental impact assessments** and start studying the social impact assessments. This work will shape the eco-design process and support the developments in the technical WPs until the end of the project.

As a result, our sustainability team has already developed models for state-of-the-art AEM water electrolysis technologies, as well as for our own ANEMEL solutions from an LCA perspective. These studies highlight the potential of **our electrolysers to lower the overall environmental impacts along the life cycle**. Although the assessment is preliminary and still at small scale, it provides a key starting point for future analyses.

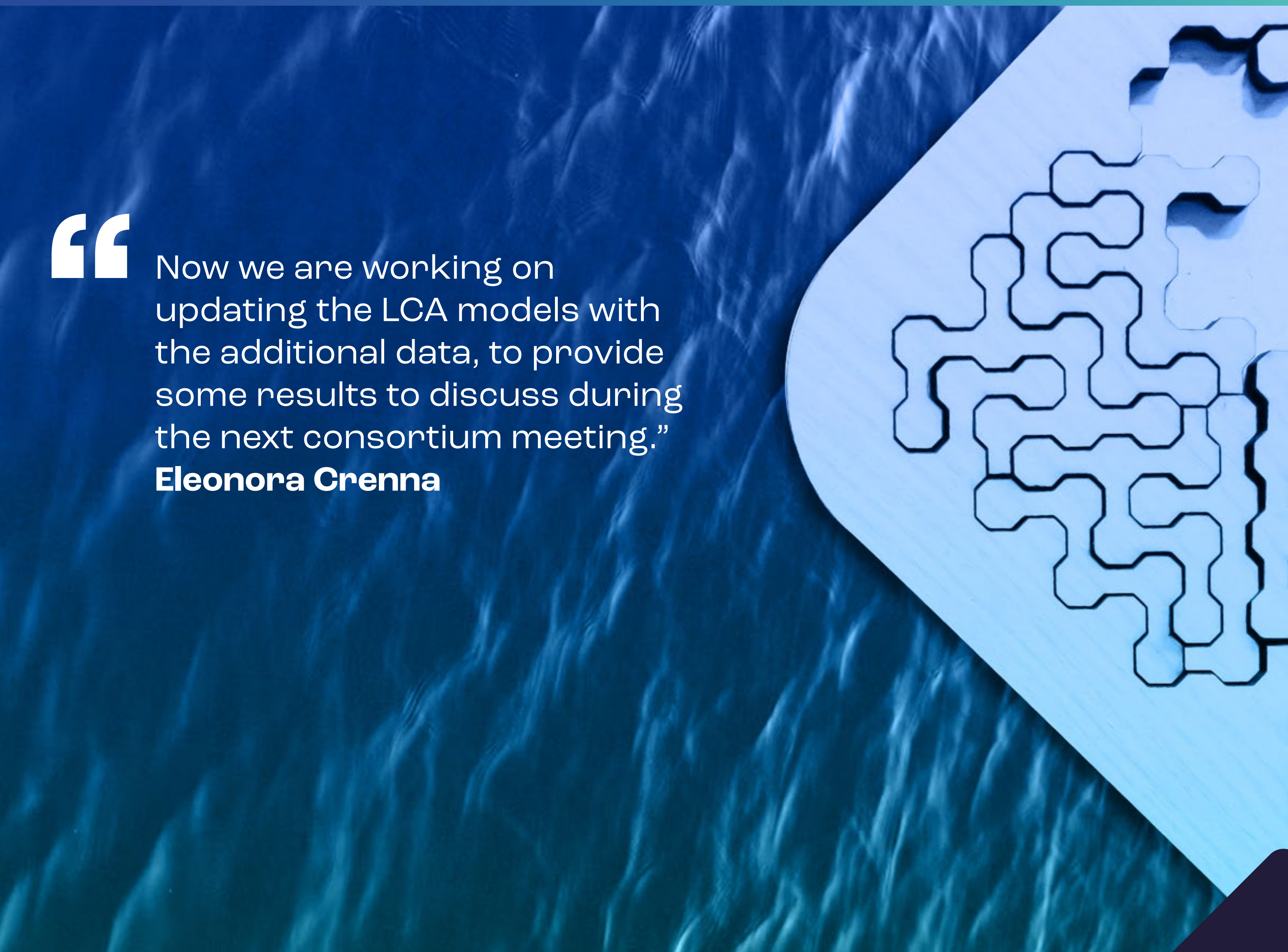
WP5 has integrated both models in an eco-design tool, moving from a previous Excel-based file to an online version that includes the life cycle of selected materials developed within the consortium. The new tool was tested with the project partners during a **dedicated workshop** that took place in our plenary meeting in Newcastle, UK. Without a doubt, the workshop was a success, with fruitful exchanges of ideas between all WPs. It allowed WP5 to draw preliminary recommendations, such as favouring longer durability or using materials with higher recycled content, particularly for metals.

But not all results are quantifiable. Thanks to collaboration with the partners, WP5 has gained a better understanding of the technology as non-experts on the technical aspects, and other partners are now more involved in the LCA data collection process.

Currently, the sustainability team is **more active on social and economic aspects** and started data collection. They plan to achieve some preliminary analyses of social hotspots for a deliverable due by the end of 2025. Future plans also include conducting a preliminary assessment to evaluate the content of critical and strategic raw materials (CRMs) in the ANEMEL stack and any associated environmental implications. Additionally, WP5 will explore the potential for CRM recycling to reduce environmental impacts across the life cycle of the AEM electrolyser stack.

Doubly critical raw materials

Critical raw materials (CRMs) are minerals, metals, and other raw materials considered key components of our modern technology and industry. They are indispensable for a wide set of strategic sectors including clean energy, digital devices and aerospace. But, at the same time, CRMs face significant **supply risks due to geopolitical, economic, scarcity factors**, and the fact that they are still irreplaceable. They are therefore *doubly* critical. There are some possible actions regarding the problems related to CRMs, which include recycling these materials or fully replacing them with greener alternatives, the approach we prefer at ANEMEL.



“Now we are working on updating the LCA models with the additional data, to provide some results to discuss during the next consortium meeting.”
Eleonora Crenna

WP6
Communication

Our dedicated communication and dissemination team has been very busy sharing all of ANEMEL's achievements. This included managing our social media channels and our website, as well as organising stimulating webinars. WP6 also participated in several events to ensure that potential partners from both academia and industry are aware of our latest results.

We not only do science, we also explain it. Our main goal is to make the complex **chemistry of ANEMEL understandable to everyone**, eventually ensuring that industry incorporates our innovative results into their product pipelines.

Communicating and disseminating our project involves many different actions. Through our social media channels (X and LinkedIn) and our website, we have shared our latest developments, from publications to events, as well as celebrated our successes. We were very proud to **showcase our plenary meetings** and the hard work done during them! We have also taken the opportunity to talk about the world of green hydrogen, writing more in-depth articles on topics such as the current applications of hydrogen and the issue of fluorinated "forever" chemicals, or PFAS.

Last year, the WP6 team launched the **ANEMEL webinar series**, an initiative that has continued this year with great success. It too provided an excellent opportunity for our younger researchers to present their results. We also had the pleasure of welcoming Stephanie Metzger, Policy Advisor at the Royal Society of Chemistry, in one or our sessions, who explored the regulatory framework PFAS, with a particular focus on European legislation.

The communication and dissemination team has also showcased the project at various events. The goal of these communication and dissemination efforts is to engage with potential partners from both academia and industry while fostering strong connections with policymakers. A highlight here is the road mapping event on renewable hydrogen, fuels, and chemicals, co-organised by the **EIC and the EU-funded initiative SUNERGY**. It took place in March in Brussels, Belgium, coinciding with the meeting with our sister projects from the Green Hydrogen Challenge Portfolio, which we also attended and shared in our communication channels.

Our Zenodo community

WP6 also keeps track of published papers within ANEMEL and maintains a **repository of open-access articles within Zenodo**. It also coordinates the communications and collaborations with the portfolio of projects in the “Green Hydrogen” challenge– check out WP9 for more information on the joint activities carried out this year. On top of following our website and social media, it’s easy to stay tuned with our latest results by subscribing to our newsletter. This bimonthly booklet, published digitally, also includes interesting information and news stories in the world of hydrogen production. Check it out here!

“Thanks to the communication and dissemination of our results, we have increased the project’s visibility.”
Leyre Flamarique

WP9
Portfolio activities

The European Innovation Council (EIC), the funding agency supporting ANEMEL, envisioned Pathfinder Challenge projects as an opportunity for cross-collaboration. The EIC proposed portfolios on different topics, to promote the pollination of innovative ideas. Nine projects on green hydrogen, including ANEMEL, became the pioneers of the format, with a total of €29 million in funding and a coordinated strategy for communication, dissemination, and innovation. WP9 leads the interactions with other projects, the EIC, and other initiatives, to catalyse cooperation.

Our consortium belongs to an even bigger initiative: the **'Novel routes to green hydrogen production' portfolio of projects, all funded by the European Innovation Council.** While ANEMEL works on making green hydrogen from dirty waters, other projects in the portfolio explore different areas, including valorising biomass, using sunlight as a source of energy, and novel technologies such as flow chemistry and microfluidics —all in an effort to transform the technological landscape and decarbonise the economy—. Additionally, the Green Hydrogen portfolio promotes platforms to build bridges with other EU and international initiatives in the field, such as the Clean Hydrogen Joint Undertaking, Hydrogen Valleys, and Hydrogen Europe, among others.

In 2025, WP9 kicked off its activities with a **plenary meeting in Brussels, attended by all nine portfolio projects**, as well as EIC Programme Manager Carina Faber and all of our project officers. It was a day full of discussions, in which projects presented their latest discoveries, and started delving deeper into important aspects towards scalability and commercialisation, such as life-cycle assessments and techno-economic assessments. Moreover, the meeting created the perfect opportunity for an in-person discussion between our communication, dissemination, and exploitation teams, which started discussing the opportunities for in-person events in the final stage of the portfolio projects, including the EU Hydrogen Week.

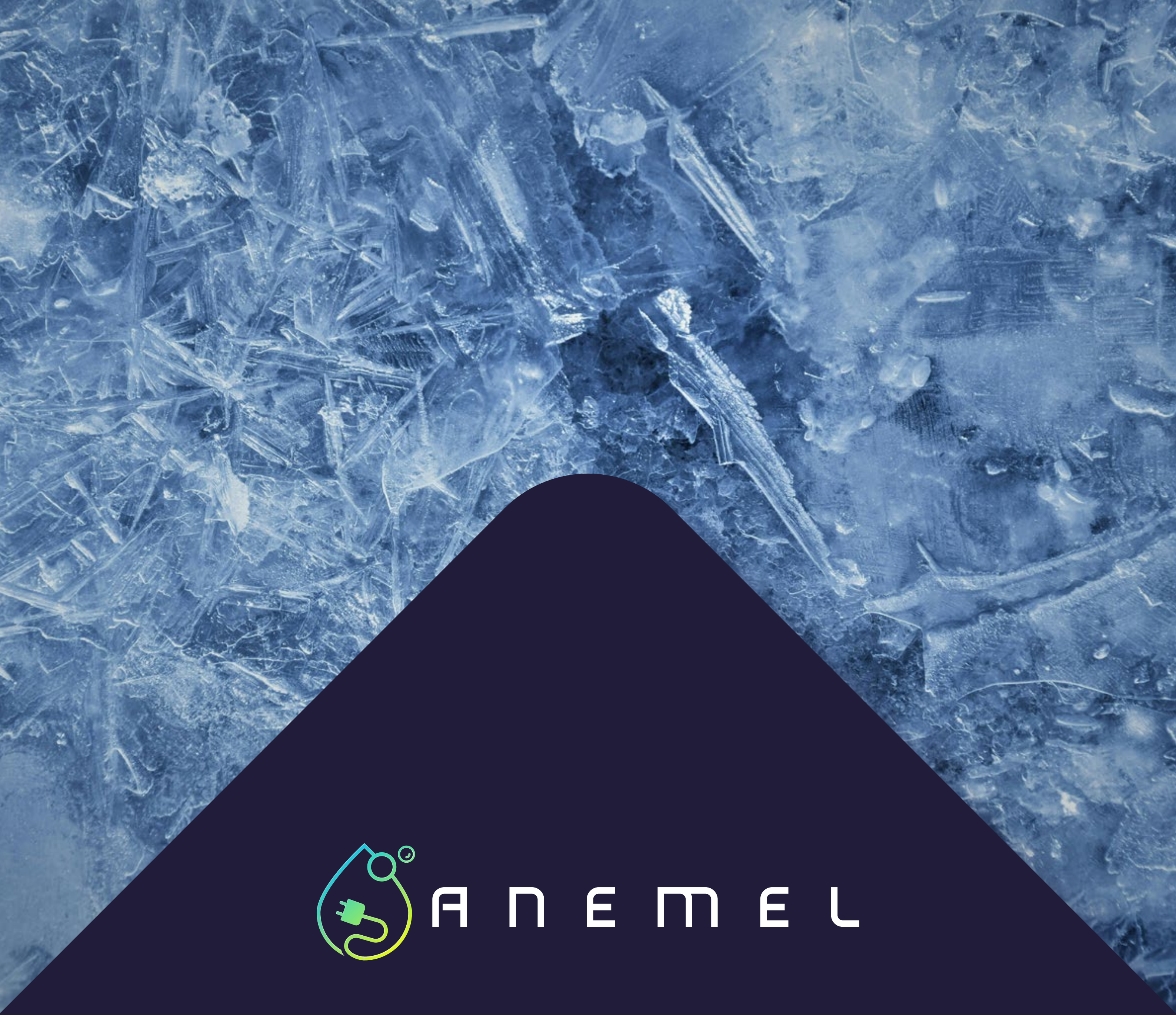
Just after the meeting in Brussels, the portfolio partners pitched the projects during a **workshop co-organised by the EIC and SUNERGY**, a European initiative focused on sustainability and renewable fuels. The event was well attended by experts across fields, including academics, SME representatives, industry leaders and policymakers. It was a full house! Our coordinator Pau Farràs presented the latest discoveries in ANEMEL, stressing the importance of sustainability across the value chain. In our case, the project plans beyond just green hydrogen, considering aspects such as the scarcity of fresh water, the access to key catalysts and materials, and the reduction of pollutants like PFAS, better known as "forever chemicals".

Additionally, ANEMEL was instrumental in the organisation of cross-collaborations to present the portfolio projects in events in Spain, Ireland, and Belgium. In February, **we coordinated a research meeting with ELOBIO and MacGhyver in Ciudad Real, Spain**, which was key to identify interests in common, particularly in catalysis and materials. Just a few weeks later, ANEMEL contributed to the organisation of an **outreach event in San Sebastián, Spain, with local catalysis collaboration Cat&Scale**, which counts on a strong support from OHPERA researchers, as well as partners in other EIC projects, such as CONFETI and SuperVal, both part of the CO2 and nitrogen portfolio, and closely connected to our vision of circularity and sustainability. During the second half of 2025, we focused on facing industry leaders and policymakers. In September, we attended the **European Hydrogen Week Conference in Brussels**, then in October **we presented the portfolio at WHTC 2025 in Dublin, Ireland** —an event that gathered green hydrogen and energy experts from all around the world, including the EU, US, Japan, China, and Latin America—. The latter created the perfect opportunity to showcase a shared booth with our portfolio partner projects ELOBIO, MacGhyver, EPOCH and GH2 —all of which also presented a pitch to the delegates—. The session started with a special speech by EIC Programme Manager Carina Faber, focused on the strategy of Pathfinder portfolios, as well as higher TRL projects like EIC Transition and EIC Accelerator, to identify innovative ideas and catalyse the commercialisation of technologies born and bred in the European Union.

The importance of innovation

Beyond communication and dissemination, a key focus of WP9 is innovation. In this sense, **Praveen Kumar, from the University of Galway, participated in portfolio activities with other projects and interesting training opportunities offered by the EIC**. Among other things, these sessions spanned topics including intellectual property, industrialisation, finances, funding, and leadership strategies. In 2025, the EIC's pioneer programme led to the identification of several value propositions for ANEMEL and its potential products, such as the AEM electrolyser stack. Other discussions delved into potential partnerships across projects, particularly with platforms of offshore windmills, which could facilitate the fitting of ANEMEL electrolysis solutions in-situ to store excess energy as green hydrogen.

> "The many events in 2025, visiting Spain, Belgium, and Ireland, created the perfect opportunity to present the portfolio to potential clients and collaborators."
> **Fernando Gomollón Bel**



ANEMEL

Visit us!

anemel.eu

European Innovation Council

Funded by the European Union