ADVANTAGES AND CHALLENGES OF ELECTROCHEMISTRY IN THE CONTEXT OF ENERGY TRANSITION

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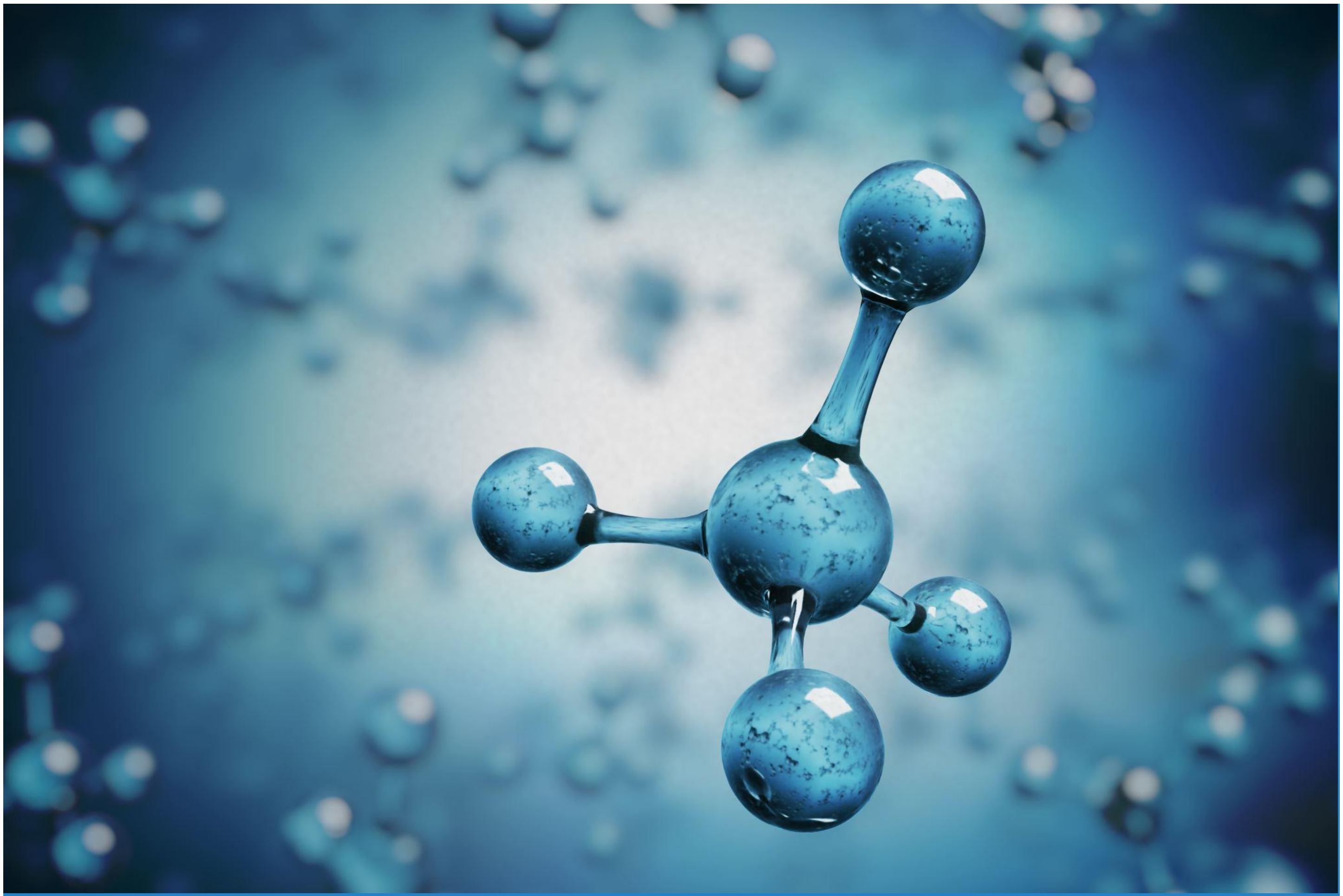

SUMMARY

Professor Marta Costa Figueiredo provided an overview of the role of electrochemistry in powering the transition towards a greener and more sustainable energy production. Marta explored solutions that might impact the future of energy, including hydrogen and electrochemistry, to generate essential outputs such as fuel or ammonia. Marta ultimately proposed rethinking the role of electrochemical processes in energy production, moving away from wasteful and unilateral current models (fuel-based) to circular electricity-based models made from renewable sources.

THE PROBLEM

Energy Models and Energy Transition

The current energy production model is linear and made of unilateral and wasteful flows of energy. To produce valuable outputs, the chemical reactions used in industry are mostly dependant on **burning fuel to produce temperature changes**. By burning those materials, the heat generated forces certain molecules to transform into new products. This model is however ineffective and produces large amounts of polluting outputs (CO2, CO).

Just like in a circular economy, Marta proposed a new way to look at energy production using chemistry and electrification. In this new model of energy production, **the linear and wasteful methods are replaced by a circular energy flow, reducing both waste and costs**. Instead of burning materials to generate temperature changes - hence forcing molecules to react - Marta proposes to use electricity to create the same chemical reactions and generate similar outputs (e.g., stimulating electrons to drive the process).

The premise: energy catch 22?

This new model of energy production is dependent on an **initial electric input.** This means that the process must necessarily be part of a larger movement towards the adoption of green electricity sources (wind, solar, hydro) that can initially power this process in a sustainable way. Otherwise, the entire energy generation remains largely pollutant, not at the output but at the input stages. The premise of Marta's work is therefore that the electrification of this new energy production process is done via the use of renewable energies.

This is possible through massive investment in renewable sources which is already visible in some E.U countries, such as the Netherlands.

Three Pillars of the Energy Transition

As Marta explained, according to the Dutch government, there are three main priorities to foster this new energy production system**: i) hydrogen production; ii) electrifying the chemical industry; and iii) green fuels.**

Marta addressed i) and ii) during the course of her presentation.

SOLUTION #1: HYDROGEN

Marta began by explaining the first potential solution for the new model of energy production: **hydrogen**.

In 1874 Jules Verne had already hinted at the technology:

'Water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable.'

Hydrogen can be used as a powerful energy source. When burnt, hydrogen produces zero polluting emissions and provides decent amounts of energy per gram. It is also vital in the development of several chemical applications.

Hydrogen Applications

Today, hydrogen is used in the chemical industry to produce different materials, including ammonia (55%), methanol (10%), fuels (25%), and other materials (10%). Although hydrogen has been used mainly as a source to produce these different outputs, Marta highlighted how we still need high levels of hydrogen production to have an actual energy transition landscape.

Hydrogen Advantages (if produced sustainably)

Hydrogen presents remarkable advantages in terms of sustainability and green energy production:

1. Production from water with **zero polluting emissions;**
2. **Stored in different forms** (liquid, gaseous, or even metal hybrid forms);
3. Can withstand **long delivery distances;**
4. Easy conversion to **many different energy forms.**

Hydrogen Disadvantages

Hydrogen is only attractive if we can produce it from sustainable sources. However, there are many drawbacks to using hydrogen to produce energy:

1. **Volume** - Hydrogen is voluminous in comparison with other materials such as liquified gas (logistic/transportation challenges);
2. **Safety concerns** – Hydrogen is highly inflammable if joined together with other materials (including oxygen), which raises potential application challenges;
3. **Breakdown molecules** – the process of breaking down molecules to produce hydrogen requires large amounts of energy which must be obtained from electricity, which again must be sustainable.

H2

Grey Hydrogen

Split natural gas into hydrogen and CO2 and release it into the atmosphere.

H2

Blue Hydrogen

Split natural gas into hydrogen and CO2 but store CO2 (e.g., barrels under the sea) or reuse it.

H2

Green Hydrogen

Split water into hydrogen by electrolysis powered by renewable energy and reuse all outputs (O2).

Hydrogen Electrolysers (producing green hydrogen)

Marta demonstrated how electrolysers can be a viable way to break down existing molecules into hydrogen (H2) and oxygen (O2), by using electricity. An electrolyser is a machine **that produces hydrogen through a chemical process (electrolysis) capable of separating the hydrogen and oxygen molecules of which water is composed using electricity**.

These systems use electricity to break down molecules into hydrogen (H2) and oxygen (O2). In order to work, this system uses a sophisticated membrane that is porous and allows substances to interact but not mix.

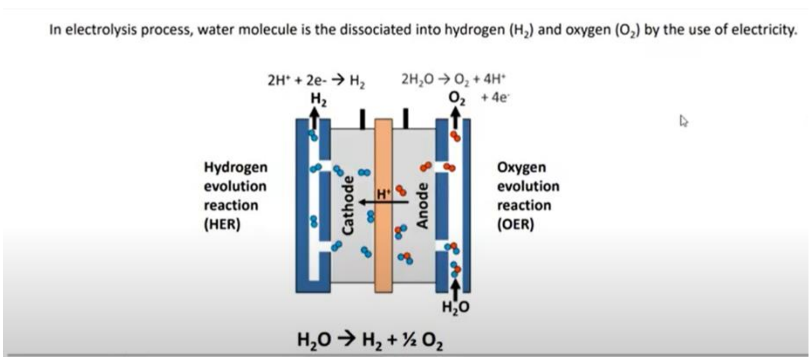

Fig 1. An example of a hydrogen electrolyser

There is still a long way to go in producing effective and cost-efficient electrolysers. Part of the problem is how membranes are still not size-effective and costly to maintain. Larger manufacturing must be fostered.

EUI Professor: what happens to the oxygen? Is it collected? Goes to the air?

Marta: *Oxygen can be collected as an output of the experience, fuelling a different industry (oxygen demand). However, this demand is low, and so is its market price. This is why researchers are now exploring ways to produce other products to pair with hydrogen instead of just producing oxygen.*

SOLUTION #2: ELECTROCHEMISTRY

Marta then progressed to her field of expertise, showing how similar processes can be used to produce other chemicals, more than just hydrogen.

Successful Cases

1. **Aluminium**

Aluminum is an excellent example of a successful application of electric-based chemical reactions. Before an electrical-based system was used to induce the necessary chemical reactions to produce aluminium, this material was as expensive as silver.

2. **Chlorine cleaning-based products**

All the cleaning products one uses at home are electrical-based generated chemicals, which have primarily reduced the costs and enhanced public access to these products.

> ***‘Electrochemical technologies have the potential to help in green production of chemicals, but upscaling challenges need to be met’***

The great question in any of these electric-based processes (electrolysis) is which raw material will be used to generate the chemical reaction. One of the most promising areas of research in the field is the transformation of the pollutant CO_2 (carbon dioxide) into different outputs. This process is still taking the first steps, with deficient production levels.

One of the significant challenges of using electrolysis is to pinpoint exactly which output will be generated by the process (for example, with CO_2, it could range from formic acid to methanol).

PhD researcher: can you use the same electrolyser for different outputs? And if so, can one use machine learning to determine how much electricity input is necessary to produce product X?

Marta: You can select the product by the energy input indeed. This is one of the advantages of electrolysis. However, this is not easily done for CO_2. The only material that does it properly is copper and once the chemical reaction starts is very unpredictable.

RESEARCH AND Q&A

Marta's own research is contributing to developing electrolysis of different chemicals as shown below:

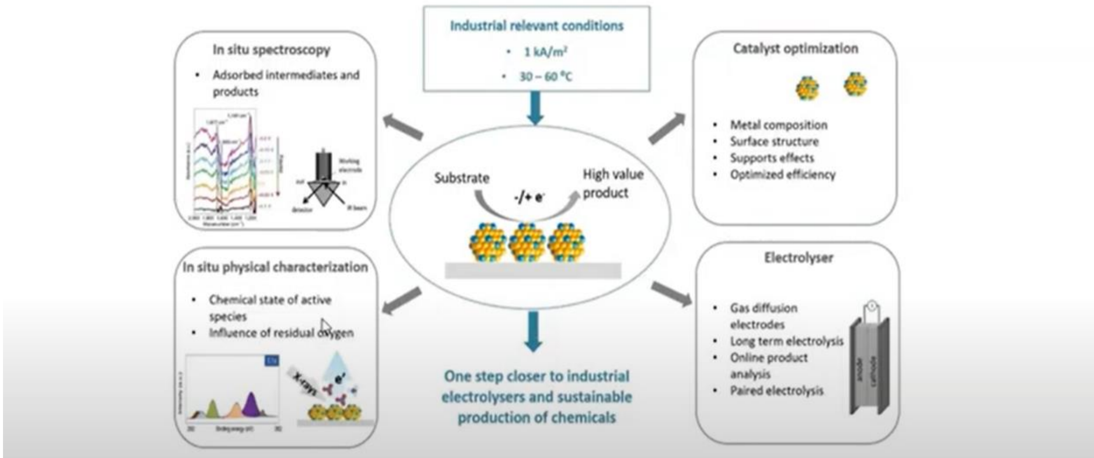

Figure 2. Marta Figueiredo's Research

Her team has also been actively developing their own experimental electrolyser, dealing with challenges such as size and materials' durability:

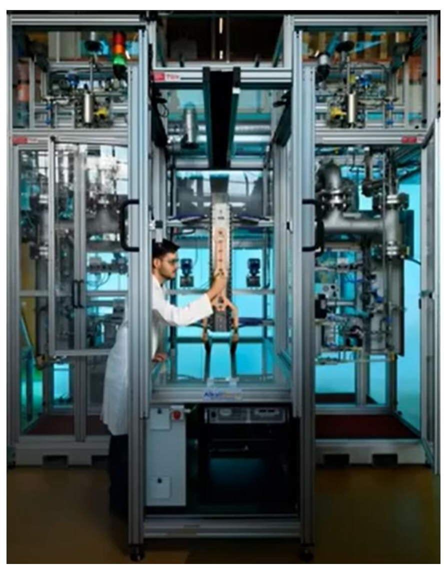

Figure 3. An Electrolyser Prototype at the Eindhoven Institute for Renewable Energy Systems (EIRES)

Marta also shared her experience as a researcher with the Cluster and answered different questions as to how science, research, and ethics are an essential part of her daily work:

PhD researcher: Photosynthesis seems such an easy process in Nature, by which plants break down air molecules and separate CO2. Why is it so difficult to reproduce?
Marta: Synthetic photosynthesis has been the El Dorado of the field since I started researching. We ask the same question every day. What enzymes do is very particular and requires very specific

environments that we cannot yet reproduce in a lab. CO2 is also a very stable molecule that is very difficult to break.

EUI Professor in Law: You are a scientist challenging the existing paradigm (generate heat = breaking down molecules) with a new way of doing things (using electricity). Have you felt a big push from the field?
Marta: Absolutely, there is a pushback in general. Electrochemistry and electrolysis are still expensive technology, and the industry is not keen on changing processes unless they see economic gains.

EUI Professor in Law: Does your field engage with ethical issues? And if so, what are they?
Marta: I have not personally encountered many ethical dilemmas in our work. We work at such a foundational level (not the application level), that most ethical questions are dealt with further along the chain**.**

EUI Professor in Economics: If you could have access to the policy-making directions on Europe right now, what would be your key suggestion there for them?
Marta: Very clear **– carbon taxes**. We need to start having powerful incentives for companies to change. No industry will change without these incentives and carbon taxes would touch their business-moels.

(follow-up)

EUI Professor in Economics: But wouldn't that somehow displace the funding for research like you are performing? Would it not be a risk for your own research?
Marta: I am still convinced that industry is where the money lies. Even companies such as Shell work with us, with a role in changing energy transition. A tax would not necessarily block that but incentivize them to join the discussion.
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EUI Professor in Law/PhD researcher: Both asked how intellectual property and data sharing shaped Marta's research field by restricting or amplifying the dissemination of knowledge.
Marta: Patenting plays a significant role in what we do, mainly because most of the research is sponsored by the industry. This means there is no academic/knowledge-sharing culture but considerable opacity and non-disclosure agreements. Companies ultimately want to have the technology for themselves for competitive advantages.

EUI Professor in Law: As a scientist, where do you set the redlines? Imagine you have a concern, but you do not know how serious or if and when it will happen. What should be the red line for further technological or scientific developments? Many people use the precautionary principle and simply refrain from investing in its development. Would you apply this across the board?
Marta: I think I set the red line on what Nature does. If Nature does not do it, we should think about it twice. E.g., CO2, yes, Nature does it; but in other actions (e.g., storing CO2 under the Earth's soil), there has never been any trace of it before. We just cannot predict its outcome. We might be generating a similar process and global warming and CO2 emissions and find out about it way too late.

Participant: One of the significant concerns with blockchain technology is energy consumption and environmental damage. Did you come across these concerns in your work?
Marta: We will have different technologies for different energy objectives/technologies. There is no one-size-fits-all solution. Small solutions can power small projects (e.g., on-site construction workers using a small electrolysis process to generate specific outputs), even if they cannot be scalable. The future might lie in multiple solutions tailor-made to different needs.