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Status of Electrolyser Development at GENVIA

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Abstract

Genvia is a Clean Hydrogen Technology Venture created to enable individual organisations, industries and nations to meet their goals for decarbonization by accelerating affordable clean hydrogen production, energy storage and fuel applications at scale. By providing cost-effective access to high-performance electrolyser (SOEC) and fuel cell technologies (SOFC), Genvia will support heavy industry to decarbonise processes and achieve emissions targets. Genvia also enables energy providers to offer decarbonised electricity to consumers where and when they need it.
The result of 15 years' research and development from the French Atomic and Alternative Energies Commission (CEA), Genvia's high-performance electrolyser and fuel cell systems are based on a proprietary solid oxide stack technology that offers improved efficiency, process reversibility and fuel versatility over competing approaches.

In this publication, the strategic road map of GENVIA for SOEC technology development and manufacturing is described.

Introduction

Genvia was established on 1 March 2021 with the objective of **producing an electrolyser with the greatest electrical efficiency at the lowest possible price for industrial decarbonisation**.

Genvia is executing a multi-year research, development and industrialization roadmap to develop a solid oxide electrolyser to meet this objective. This paper seeks to unpack the challenges associated with building the world's most electrically efficient electrolyser and to explain how Genvia has spent its first year establishing a company capable of overcoming them.

The decarbonisation challenge

In 2020, 25% (8.5 Gt out of 33.9 Gt) of total CO_2 emissions were attributed to industrial activities (including energy use and production processes). The three heavy industries that contribute the most are chemicals, steel, and cement. Together these three industries account for around 70% of CO_2 [1] emissions of the industrial sector. The world needs these industries at even larger scale than today to be able to decarbonise and maintain a decarbonised way of life for the world's population. We need to build wind turbines, electric vehicles, hydrogen pipelines with massive quantities of steel. We need to rethink and redesign our urban environments, our energy and our mobility infrastructure for lower energy use and lower emissions, this needs building materials. And we need to develop and deploy at scale the cultivation solutions to feed the world's population in a net-zero world. Being able to scale up production volumes of these industries while reducing their emissions is a dual challenge that requires technical advancement as well as coordination efforts across various elements of the energy supply and process technology value chains.

The challenge faced by heavy industry

Let us consider the steel industry as an example. Steel making is the second most energy-intensive industrial sector (after cement). It is responsible for 9% of global CO_2 emissions. Primary steel making (where iron ore is reduced to iron in a blast furnace) produces 1.85 tonnes of CO_2 per tonne of steel and Secondary steel making (where predominantly recycled steel is reduced via an electric arc furnace) gives rise to 0.45 tonnes of CO_2 per tonne of steel. The sector is highly reliant on fossil fuels, particularly coal which accounts for 75% of its energy demand. Clean hydrogen lowers carbon footprint by replacing carbon reducing agents and replacing carbon-based heating fuels.

Producing this hydrogen molecule electrolytically is currently expensive and requires large amounts of energy. Economic viability is highly dependent on availability of low-cost clean electricity, high prices for carbon emissions and, critically, lower cost and higher performance electrolysers.

In heavy industries such as steel making energy in the form of heat is often more cheaply available than clean electricity. This lower-cost availability of heat energy strengthens the value proposition of the solid oxide electrolysis technology installation which can make use of the industrial heat available to reduce the amount of electrical energy required per Kg of hydrogen produced.

The challenge of building an electrolyser to meet industrial needs

The steel industry needs to be able to produce large quantities of low-carbon hydrogen at a cost that competes favourably with the coal they buy today. Deploying an electrolyser that has minimum operating cost per tonne of hydrogen produced at minimum capex is critical. The challenges in developing and building such an electrolyser can be summarised as follows.

- Reducing the kilowatt hours of electrical energy needed to produce each kilogram of hydrogen. **Driving kWh/Kg H_2 down.** This is about energy efficiency and cost leadership. Having a high efficiency electrolyser means less electricity is required for a same volume of hydrogen produced, this also translates to a lower levelized cost of hydrogen, as 80% of the cost is attributed to electricity fed to the electrolyser.
- Reducing the cost of purchasing an electrolyser to the lowest cost per Kilogram per hour. **Driving $/Kg H_2/ hour down.** This is a critical lever for massification and scale up of the clean hydrogen uptake. Every opportunity to lower the investment cost is an opportunity to accelerate the journey to net zero.
- **Maximising the lifetime of an electrolyser**. Longer lifetime has two impacts, a financial one, as this translates into a lower total cost of ownership, and a second impact is on overall carbon footprint with an equipment that has a longer useful lifetime.

This must be done while ensuring that safety considerations are uppermost and embedded CO_2 footprint is minimized.

Background

When Genvia was created on 1 March 2021 it did not start from zero in its quest to produce the world’s most efficient electrolyser. Genvia was established as a joint venture between Schlumberger, the CEA (the French Atomic and Alternative Energies Commission) and co-investors Vinci Construction, Vicat and the Occitanie Region of France. Contributions of technology, talent, industrial understanding and enthusiasm were made alongside their investment in Genvia. The result of 15 years’ research and development from the CEA, Genvia’s high-performance electrolyser and fuel cell systems are based on a proprietary solid oxide technology that offers improved efficiency, process reversibility and fuel versatility over competing approaches.

The high temperature (between 700 and 800°Celsius) at which the solid oxide electrolyser operates, coupled with the fact that it can make use of heat energy as well as electrical energy, means that at laboratory scale the CEA was able to exhibit very promising system electrical efficiency of up to 84% Lower Heating Value (LHV) which compares to that of currently available PEM or Alkaline electrolyser technologies at around 60% LHV [1]. Consequently, Genvia's Solid Oxide electrolyser system has the potential to use 30% less electricity per kg of H_2 produced than current technologies if heat (about 120-150°C) is locally available to produce the needed steam. Since the cost of production of a kilogram of electrolytic hydrogen is dominated by the cost of electricity (around 75% of the cost in today's systems) more hydrogen for less electricity means not only savings in running costs compared to competing technologies but also savings in the capital expenditure to install the necessary renewable production capacity.

Methodology

So, what does driving kWh/Kg H_2 and $/Kg H_2/hour down and maximising the lifetime of an electrolyser entail and how is the Genvia team going about it?

Let us first breakdown the three key challenges to understand the actions that need to be taken to meet the objective of building the world's most electrically efficient electrolyser for industrial applications.

- **Driving kWh/Kg H_2 down**
    - Optimising the conditions of the reaction itself such as steam conversion rate and temperature management in the stack.
    - Reducing losses and maximising value for every joule of energy that the system consumes.
    - Replacing electrical energy by heat energy as far as possible.
- **Driving $/Kg H_2/ hour down**
    - Scaling up highly efficient automated manufacturing to reduce the cost per stack.
    - Increasing the power density of the stack.
    - Scaling projects to optimise the balance of plant.
    - Integrating application heat sources in a cost-effective way.
- **Maximising lifetime**
    - Eliminating infant mortality by ensuring 'zero-defect' manufacturing approach.
    - Reducing degradation of the cell in particular but of all system components.

As we drill down into these three challenges it is clear that work needs to be done in three different areas at the level of cell and stack for some aspects, overall system design for other aspects and that a key part of the equation is high-quality, low-cost manufacturing of key components.

Genvia has built a multi-year roadmap which advances these three areas of Technology component development, System design and Manufacturability in a concurrent manner.

The Concurrent Engineering approach adopted encourages multidisciplinary collaboration between these three areas. The complementary technical skills and expertise of the Genvia teams is a key factor: expert teams in engineering, industrialisation processes, HSE and R&D work together on a daily basis. Genvia's teams are located in three different locations in France each a historical centre of excellence. Grenoble in South-eastern France (co-located with the CEA Liten) is the focus location for technology component development, Clamart (near Paris, co-located with the Schlumberger technology centre) for Systems Engineering and Manufacturing in taking place in Béziers in the South of France in one of Schlumberger's most highly automated factories.

Figure 1 - Genvia locations

The core of the idea of Concurrent Engineering is that by considering downstream activities (such as manufacturability, system deployment, operation and maintenance) while performing upstream activities (such as conceptual design, specification and testing) product development can be both focused and accelerated. This approach allows the manufacturing teams to be involved from the design stage onwards. Technical choices are thus made at the same time as the definition of the means of production, on a pilot line and Giga Factory scale and while real projects are being designed in an industrial setting.

Strong links in Genvia between research, engineering and manufacturing allow for 'fast-failure loops' to identify things that will not work early in the process while the technology is still in the design phase. Early recognition means that things are relatively inexpensive to fix, where later on even and small change can be costly. When technical people from different disciplines work together, they can work out the kinks as they go, reducing the number of changes that might occur late in the process.

The production workshop completed by Genvia in 2021 and the pilot production line currently being installed are key components of this fast loop – they enable the fast testing of stack designs in a real manufacturing environment allowing the continuous implementation of innovation.

This production capacity also enables a change in approach for the scientists involved in the research and technology development of the stack. Historically scientists have been looking to produce data while trying not to break prototype stacks that were expensive and complex to produce. Genvia's manufacturing capacity facilitates a verification and validation process that can gives engineers and scientists the possibility to test to destruction and stacks 'permission to fail' in the quest for a robust product. The Genvia manufacturing capability importantly enables the re-focusing of scientists' efforts on things that will really matter to the client.

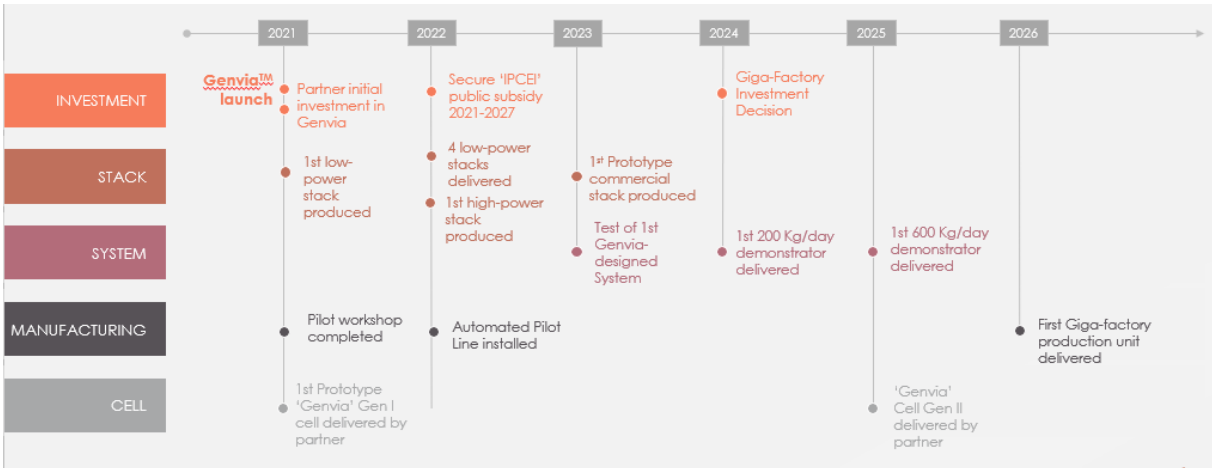

Figure 2 – Genvia's Roadmap

The multi-year research, development and industrialization roadmap serves as a guide to how the cell, stack, system and manufacturing milestones come together to enable Genvia to build the world's most electrically efficient electrolyser for industrial applications.

Results

Genvia has achieved a number of key results after just over one year of operation.

1) **The establishment of a stack pilot workshop on the Béziers site (figure 3).** The transformation of part of a historic manufacturing facility and its workforce from producing large oil and gas valves to producing state-of-the-art electrolytic stacks. The process of stack production established and validated by the CEA over many years has been reproduced in a manufacturing environment in Béziers by a team of 30 Genvia staff who have re-trained to apply their manufacturing expertise to a wholly different product.

Genvia's stack pilot workshop was validated at the end of 2021, 9 months after the creation of the company, by successfully producing its first reference stack.

Figure 3 - Genvia's pilot workshop in Béziers: view of the main tools and the conditioning benches (left)

2) Excellent test results on first Genvia-produced stacks. On completion of the installation of the pilot workshop in Béziers the Genvia team started the preliminary production of stacks to the historical CEA low-power design. This stack is made of commercial electrode-supported cells produced by Elcogen with a 10 x 10 cm active surface [2].

After initial characterization and Factory Acceptance Tests (FAT), the stack was tested in SOEC mode on SYDNEY test bench [3 - 4] at CEA Grenoble. The main objective was to fully validate the production process carried out by the new Genvia team in Béziers thereby giving the green light to start the manufacture of stacks for rapid testing.

These tests on the first stack, including OCVs and initial polarization curves at 700°C, produced results that showed performances in SOEC mode in the range of the highest performing stacks historically produced and tested by the CEA [5] to [12]. Subsequent stacks produced in the Beziers workshop have replicated this performance level.

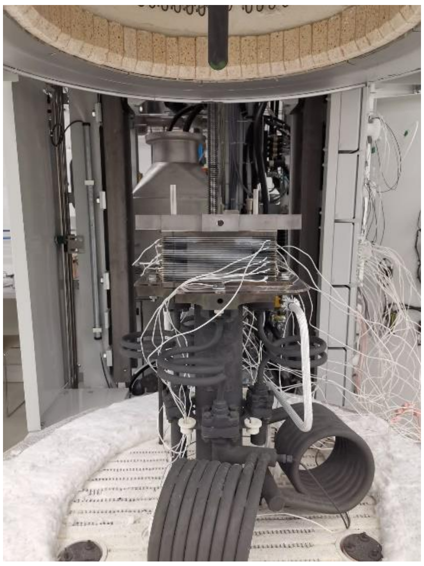

Figure 4 - First stack manufactured by Genvia

3) Concept design for Genvia's first industrial prototype demonstration projects has been created with industrial partners in the Steel and Cement industries. A 200kg H_2 /day prototype (SOEL200) has been designed that will undergo initial testing in 2023 before deployments in the context of prototype demonstration projects at different industrial sites. As well as Genvia teams learning the industrial processes of our demonstration partners, this work has also involved detailed engineering work and exchanges with a large eco-system of suppliers and technical partners.

4) Design of semi-automated stack pilot line. Thanks to the concurrent engineering work presented above, a pilot stack production line has been defined and ordered. It will be commissioned in autumn 2022 and will have an initial annual capacity of 300 stacks/year rising to 1000 stacks/year (figure 5). This production capacity is achievable through the integration of Industry 4.0 principles. The implementation of fully connected factories makes it possible to meet the challenge of maturing technology in a short cycle, and at the same time, deploying large-scale production very quickly.

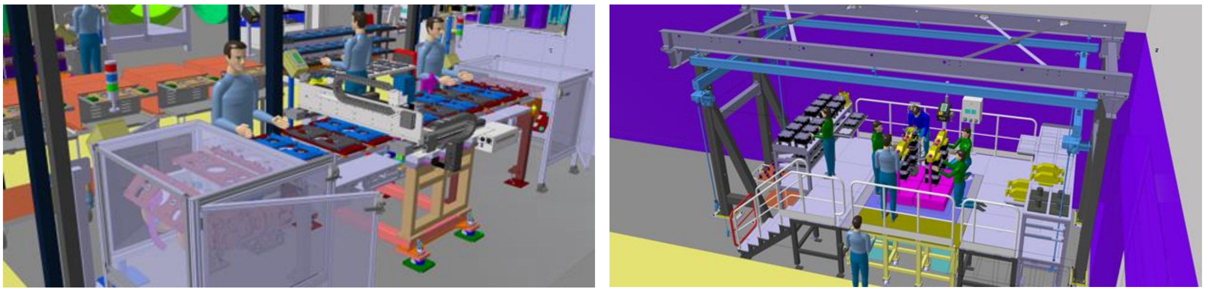

Figure 5 - Genvia's future pilot line in Béziers

This new way of architecting production systems allows data to be collected, distributed and used to improve products and reconfigure production systems quickly and continuously. The Genvia roadmap, based on Giga factory, is thus possible, realistic and highly efficient thanks to a huge investment in 4.0 tools.

Conclusion

In its foundation year Genvia has taken the first steps to proving that it is a unique company capable of overcoming the challenges associated with building the world's most electrically efficient electrolyser for heavy industry. This foundation year has been a year to understand the challenges and prepare the road ahead. And a year to structure the company and get the teams aligned on the key objectives to make our ambition a reality.

The establishment of a stack pilot workshop that has proved excellent quality of production of the current generation stacks is a key milestone, as is the concept design of Genvia's first industrial prototype, the SOEL200. Underpinning these advances is a concurrent engineering approach based on a culture that fosters collaboration and teamwork. These strong links in Genvia between research, engineering and manufacturing allow us to test the technology in 'fast-failure loops' as we progress.

A good moment to reflect on the first year and take stock of Genvia's achievements, and the contributions of everyone in the Genvia extended team, particularly our friends and colleagues at the CEA who had the foresight and tenacity to pursue ground-breaking research into the solid oxide technology over more than fifteen years which now offers such promise for decarbonisation. The task of taking even the most highly promising and innovative technology from lab to commercial deployment at scale should not be underestimated. It is an endeavour that requires talent, courage and a willingness to embrace the challenges and roadblocks along the way.

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