SUSTAINABILITY

A CONCISE GUIDE

THE ROUTE TO A GREEN HYDROGEN ECONOMY

Strategy and tools to decarbonize hydrogen and achieve carbon neutrality.

DASSAULT SYSTEMES

MEET OUR EXPERTS

Clara WILTBERGER
Industrial Equipment Industry Sales Strategy Associate, Dassault Systèmes

Clara Wiltberger is responsible for the clean hydrogen segment within industrial equipment at Dassault Systèmes.

After studying management at Grenoble School of Management, specializing in the management of innovations and new technologies, she focused on analyzing new energies. Passionate about sustainability and solutions to global warming, Wiltberger naturally became interested in the clean hydrogen market two years ago.

After two years of research, Wiltberger now applies her knowledge of the market and technical skills on industry decarbonization to help industrialists better understand the stakes of the market in relation to economic and environmental interests.

Wiltberger now works closely with customers, sales and engineers managing clean hydrogen projects.

Charles LUZZATO
SIMULIA Industrial Equipment Industry Process Director, Dassault Systèmes

Charles Luzzato is responsible for the worldwide industrialization of industrial equipment and climate system solutions. After completing his Ph.D. in Thermo-Acoustic Instabilities at Imperial College in London, Luzzato joined Exa Corporation in Germany, working on aero-acoustics simulation topics for big German OEMs and suppliers.

Subsequent to joining Dassault Systèmes, he focused extensively on climate system applications across physics domains across industries. This knowledge was later applied in an extended scope, tackling heavy machinery and industrial equipment simulation-driven design to help harmonize product, nature and life in the world.

More recently, Luzzato has been concerned with sustainability topics and decarbonization. Focusing first on the energy efficiency of building equipment, he and his team are now also looking into alternative energy sources, notably green hydrogen production and storage.

Stefan CEULEMANS
Global Industry Business Consultant Director, Dassault Systèmes

Stefan Ceulemans joined Dassault Systèmes to lead the infrastructure, energy and materials industry solutions and technical team before moving to his current role as an industry business consultant focusing on clean energy transformation.

Ceulemans built up his industry experience over 15 years, in which he held multiple engineering and leadership positions in refining and chemical plants across Europe and the USA. His roles covered operations management, supply planning, plant optimization, engineering and project management.

Over the last decade, Ceulemans has been an industry consultant, manager and director on the forefront of business development and customer engagement activities. He focuses on helping owner-operators leverage technology to improve project execution and controls, asset information management and other tactical and strategic initiatives, such as transitioning to a clean and sustainable energy economy.

THE NET ZERO EQUATION FOR GLOBAL ECONOMIES

The climate crisis is the greatest challenge facing our generation. The Intergovernmental Panel on Climate Change (IPCC) warns that between 3.3 and 3.6 billion people live in settings highly vulnerable to climate change.

Net zero commitments are rising globally. The urgency to cut down carbon footprint to meet global sustainability goals, comes at a time of mounting pressure to produce and use energy responsibly.

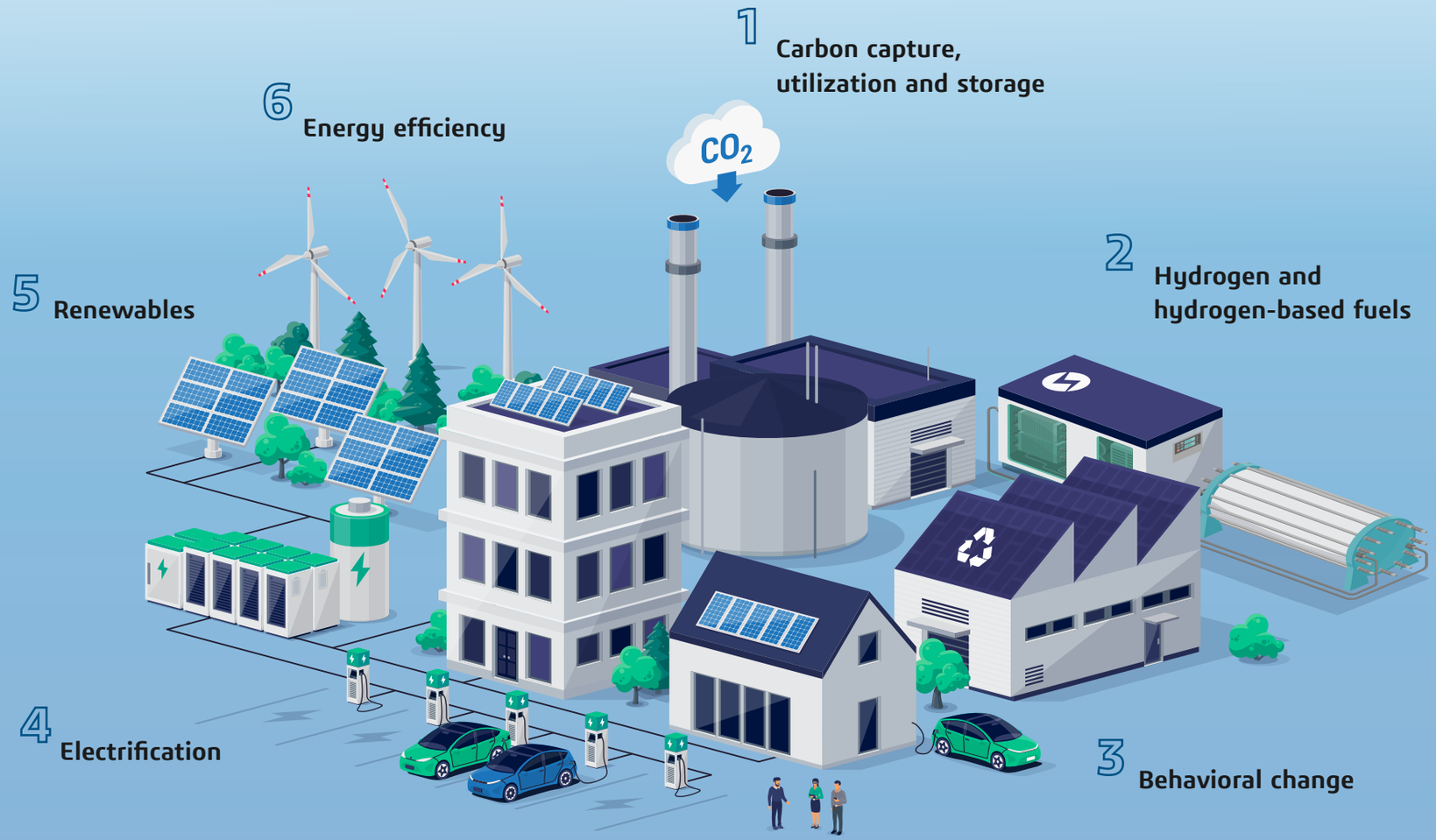
Enter hydrogen, an energy carrier that emits no carbon dioxide (CO_2) during use. This sets hydrogen apart from fossil fuels like coal, natural gas and petroleum with combustions responsible for the vast majority of energy-related emissions today.

Twenty-six governments have committed to adopting national hydrogen strategies with new developments emerging in Europe, the Asia Pacific region, the Americas and the Gulf Cooperation Council.

While hydrogen's success as a viable long-term climate solution will require a greater uptake of renewable power globally, policymakers have begun deploying hydrogen strategies for energy security by:

- Replacing fossil fuels in end-use applications
- Shifting fossil-based hydrogen production to renewables

Global hydrogen strategies are in line with the International Energy Agency (IEA)'s **key pillars** to decarbonize the global energy system, which include:



In this guide, learn how to deploy advanced digital solutions powered by the **3D**EXPERIENCE® platform to expedite your green hydrogen (GH2) transition.

Explore more below:

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THE HYDROGEN OUTLOOK

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DIGITAL TECHNOLOGY ENABLERS

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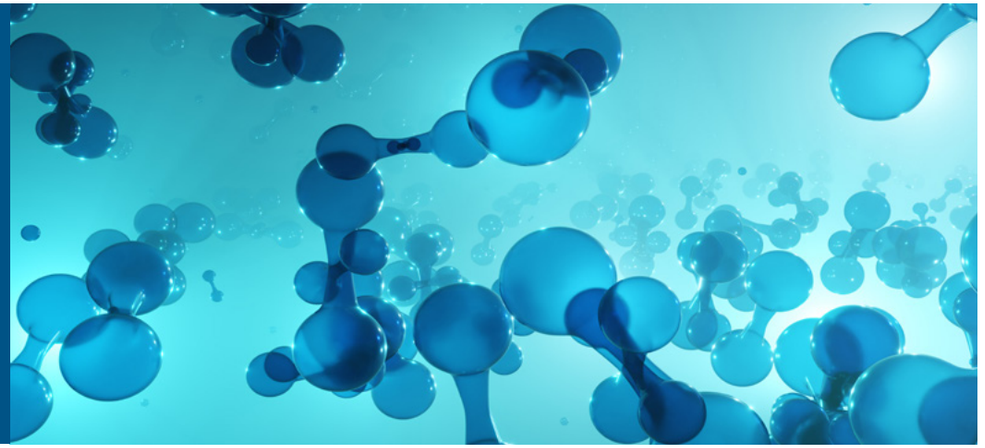
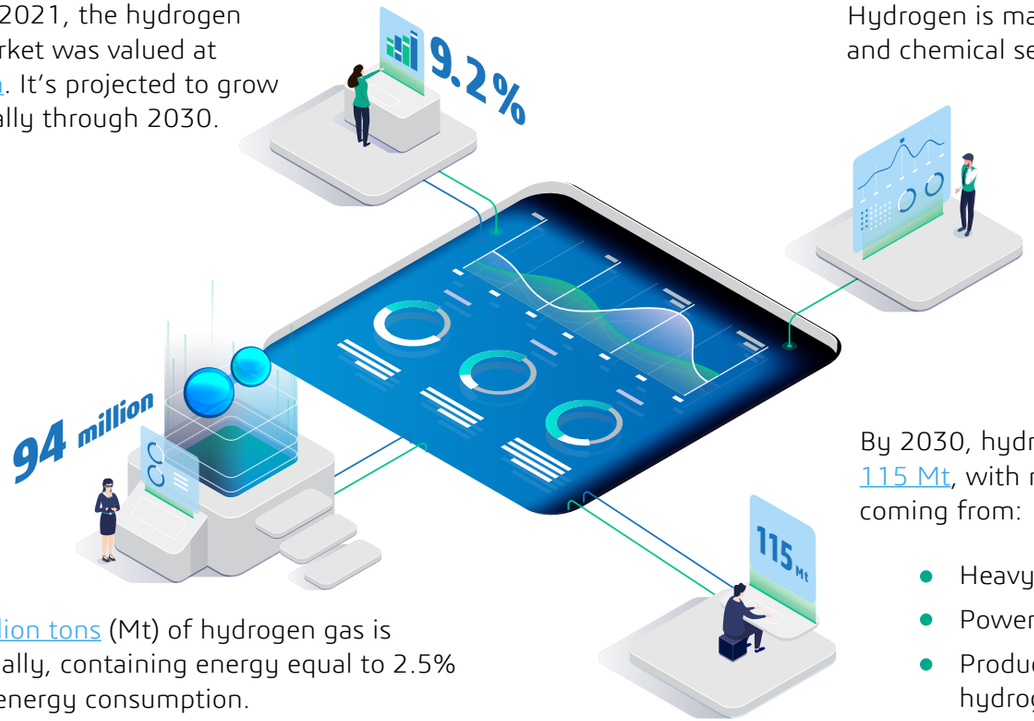
THE ONE PLATFORM ADVANTAGE

1 THE HYDROGEN OUTLOOK

Hydrogen key figures



From 2020 to 2021, the hydrogen production market was valued at USD130 billion. It's projected to grow by 9.2% annually through 2030.



Around 94 million tons (Mt) of hydrogen gas is produced annually, containing energy equal to 2.5% of global final energy consumption.

Hydrogen is mainly used in the refining and chemical sectors, accounting for:

- **6%** of global natural gas use
- **2%** of coal consumption
- **830** $MtCO_2$ of annual carbon emissions

By 2030, hydrogen demand could reach 115 Mt, with nearly half of that demand coming from:

- Heavy industry
- Power generation
- Production of hydrogen-based fuels

Not all hydrogens are produced equal

Not all types of hydrogen are compatible with sustainability initiatives to achieve net zero emissions. Hydrogen is assigned a color depending on the feedstock used, with every color representing a carbon impact spectrum:

Black hydrogen
Produced when black coal (bituminous coal) undergoes gasification.

Brown hydrogen
Produced when brown coal (lignite) undergoes gasification.

Grey hydrogen
Produced when natural gas undergoes steam methane reforming (SMR).

Blue hydrogen
Produced with natural gas or coal through SMR and incorporates carbon capture and sequestration (CCS).

Pink hydrogen
Produced through electrolysis, which is powered by nuclear energy. Nuclear-produced hydrogen can also be referred to as purple or red hydrogen.

Green hydrogen
Produced through electrolysis, using clean electricity generated from renewable sources such as wind, solar, tidal or hydropower.

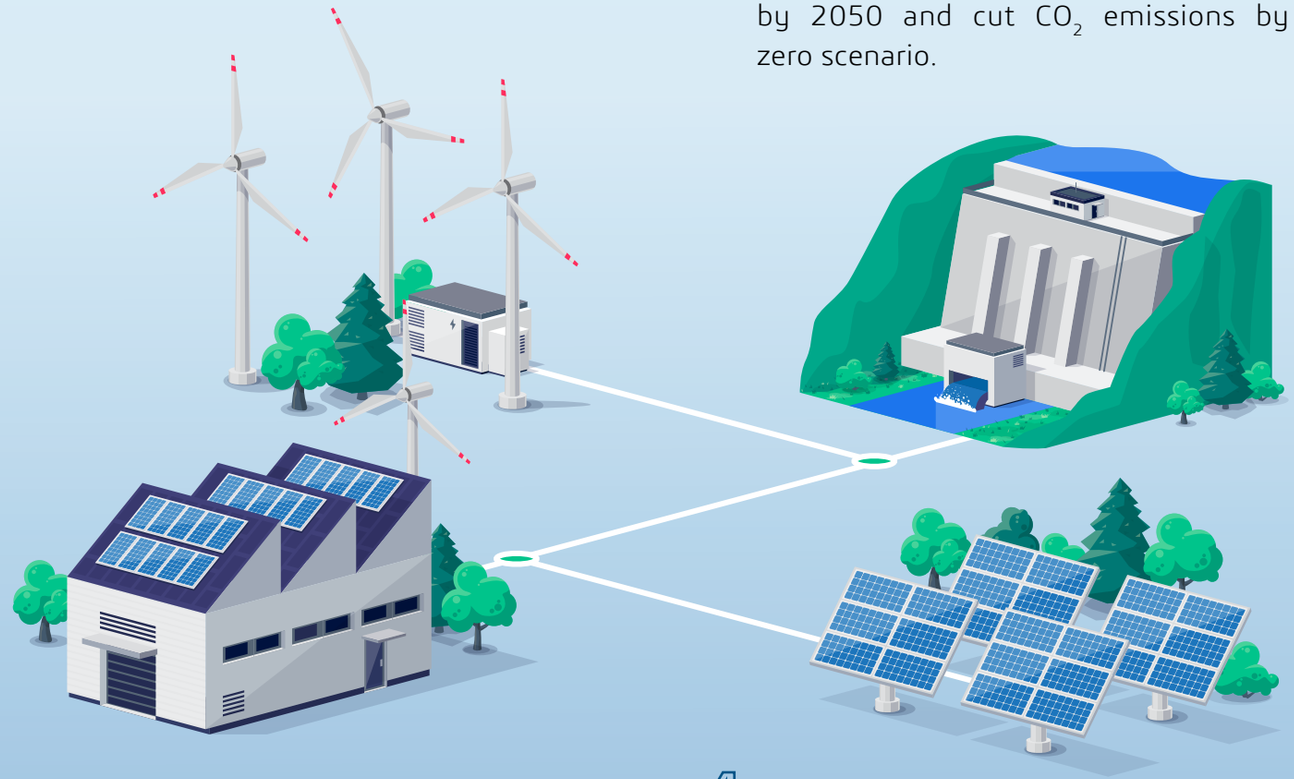
As it stands, 98% of the world's hydrogen is produced from fossil fuels, of which 75% is made from natural gas.

It stands to reason that replacing fossil fuels with renewable energies can substantially reduce the environmental impact of hydrogen production. So how big of a difference can GH2 make in the global transition to sustainable energy and net zero emissions economies?

The promise of GH2

1 According to Det Norske Veritas (DNV), electricity-based green hydrogen will be the dominant form of production by 2050 in a net zero scenario, accounting for **72%** of output.

2 The International Renewable Energy Agency's (IRENA) **World Energy Transitions Outlook** forecasts that hydrogen will cover 12% of global energy demand by 2050 and cut CO_2 emissions by 10% in a net zero scenario.



3 GH2's importance as a clean energy vector to meet global energy demand is underlined by its feature in all eight of the European Commission's net zero emissions scenarios for 2050.

4 The Hydrogen Council estimates that in 2030, GH2 can help reduce annual CO_2 emissions by 800 Mt. By 2050, it can abate **80 gigatons** of CO_2.

5 GH2 is forecasted to play these key roles:

- Distribute energy across sectors and regions
- Act as a buffer to increase energy system resilience
- Decarbonize transportation and heavy mobility (goods vehicles, freight transport and vehicle manufacturers)
- Reduce industrial and building heat and power emissions
- Provide clean feedstock for heavy industry (metallurgy, agriculture, steel and cement production)

6 In a net zero scenario, the Hydrogen Council envisions a global **hydrogen economy** by 2050, providing:

- 18% of the final energy demand
- 6 Gt annual CO_2 abatement
- USD2.5 trillion in annual sales of hydrogen and fuel cell equipment
- 30 million jobs

"Leveraging GH2 as an energy carrier has multiple benefits, including energy security, industrial competitiveness and carbon emissions reduction. GH2 forms a cornerstone of the shift away from fossil fuels. It's a versatile energy carrier that can be applied to decarbonize multiple sectors with high energy intensity."

— Clara Wiltberger
Industrial Equipment Industry
Sales Strategy Associate,
Dassault Systèmes

According to Wiltberger, "GH2's uptake will be essential for sectors like aviation, international shipping and heavy industry — where emissions are hardest to abate and other mitigation measures may not be available or would be difficult to implement."

"Around 80% of our world's energy consumption comes from fossil fuel, which pollutes. For example, the creation of steel using coal molecules to reduce the ore, represents between 7% to 9% of the world's CO_2 emissions," she says.

Wiltberger adds, "In steel production, it's possible to replace this molecule with green hydrogen molecules and reduce up to 95% of CO_2 emissions. This is just one example of decarbonizing molecules using green and other low-carbon hydrogen forms thanks to nuclear, solar, wind and hydro."

Getting there: A roadmap to the GH2 economy

Moving forward, producing GH2 on an industrial scale is critical for hydrogen to gain a strong foothold in decarbonizing economies and meet climate pledges by governments worldwide.

As hydrogen-based technologies mature, production costs will decrease over time due to continuously falling renewable energy production costs, economies of scale and lessons from projects underway.

The challenge is anticipating impactful trends and acting in time. Getting a head start requires having the right digital technology and solutions in place.

2 DIGITAL TECHNOLOGY ENABLERS

The value of virtual twin experiences

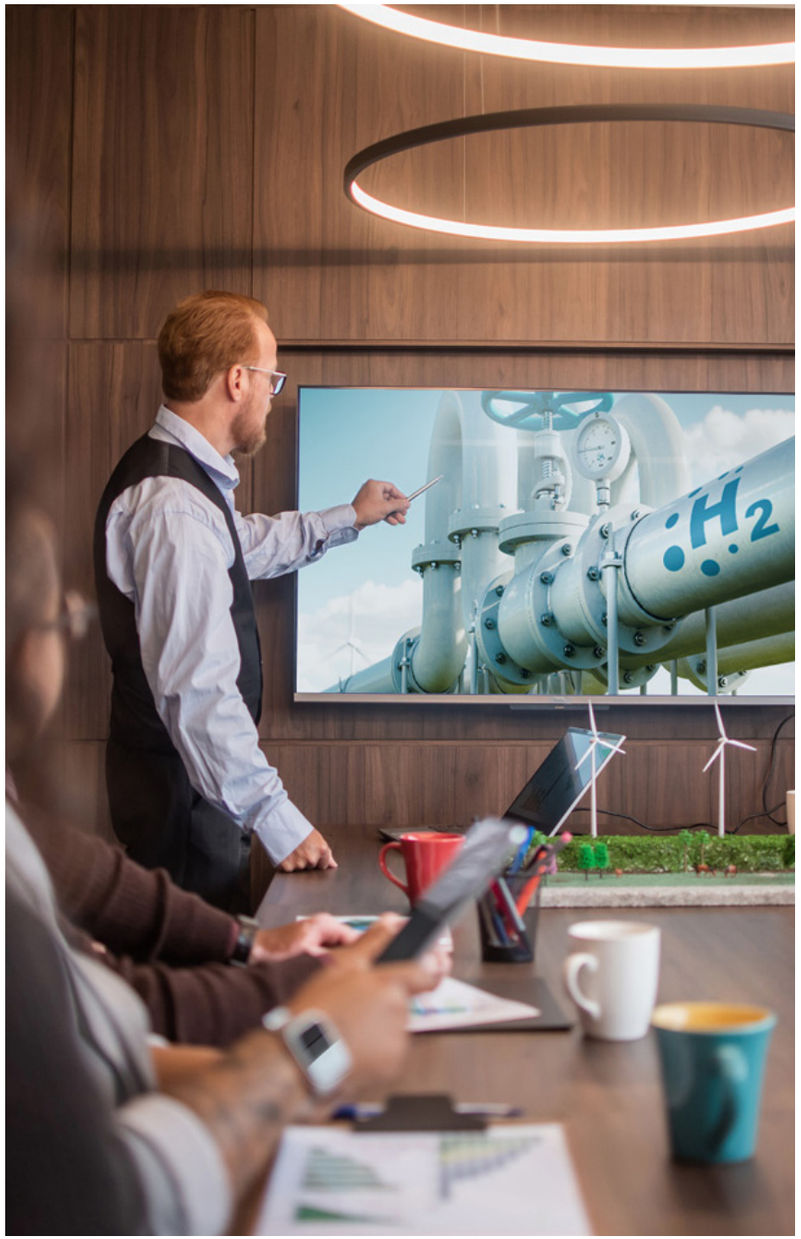
From electrolyzer capacity to hydrogen storage and fuel cells, multiple variables must be rapidly tested and analyzed to optimize hydrogen products, processes, operations and industrial usage.

This is where Dassault Systèmes' virtual twin technology shines.

Virtual twin technology is the most disruptive and efficient answer to help rethink processes through accurate 3D complex data representations: From a single GH2 process to an electrolyzer model or a giga manufacturing plant.

"The virtual twin experience provides a work environment to collaborate, analyze, visualize, simulate and ultimately extract knowledge and insights to drive quicker and more accurate decisions for each step in the hydrogen value chain. With virtual twins, companies gain real-time insights on behaviors and properties that could significantly impact decisions around production, transportation, storage and usage of H2."

– Stefan Ceulemans
Global Industry Business Consultant Director,
Dassault Systèmes



According to Ceulemans, "Reusing natural gas infrastructure for GH2 transportation is a perfect example of how a brownfield virtual twin can be used to determine and evaluate the physical and economic thresholds as the concentration of hydrogen in the existing gas infrastructure is increased."

"Creating a virtual twin of brownfield infrastructure that is being considered for hydrogen service will help companies stay competitive, agile and resource-efficient," he says.

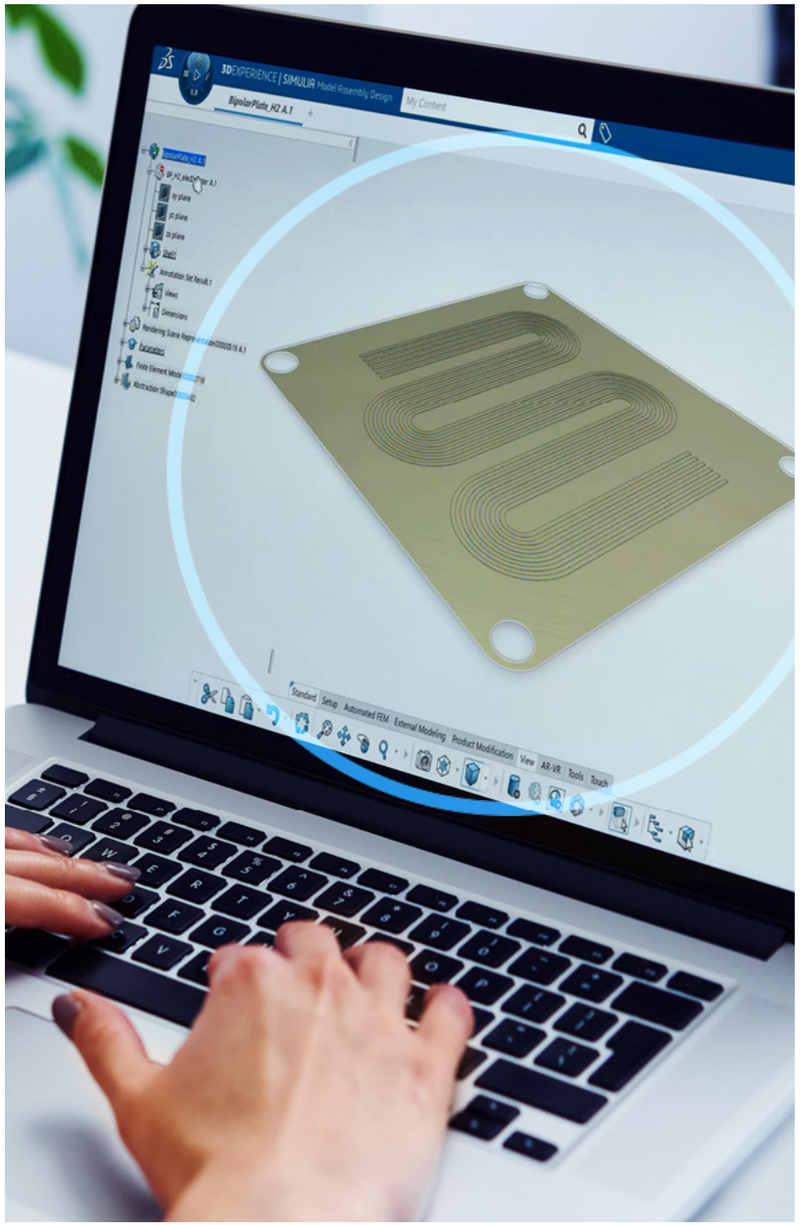
To test the hydrogen embrittlement of a metal structure such as a natural gas pipeline, manufacturers can simulate the interaction of hydrogen within the pipeline and the corresponding impact on the structure's integrity. The results will verify whether the pipeline is "fit for service" and can be used to transport hydrogen safely.

While 3D models cannot be submitted as evidence for regulatory compliance validation at present, bridging the gap between the virtual and physical worlds enables companies to rapidly test a 3D replica in different simulated scenarios to eliminate time-intensive physical testing and accelerate decision-making.

According to Dassault Systèmes' SIMULIA Industrial Equipment Industry Process Director, Charles Luzzato, virtual twins and simulation can help electrolyzer manufacturers:

- Optimize polymer electrolyte membrane (PEM) lifetime by improving electrolyzer plate designs
- Decrease material costs, particularly in PEM electrolysis
- Choose flow paths to maximize reaction surface area effectively
- Reduce the required energy for operations
- Predict thermal stresses and fatigue across electrolyzer plates
- Determine component durability and ownership costs

Wiltberger adds, "The model-based approach is paving the way for electrolyzer manufacturers to maximize output and achieve economies of scale. Virtual twin technology and simulation help support fast and efficient layout definition of new production lines and rapid testing of multiple production scenarios in realistic and immersive 3D environments."



Additionally, Dassault Systèmes' Hydrogen Fuel Cell Engineering solution will enable manufacturers to optimize workflows through virtual simulation and eventually move forward to the next phase for:

- Water management
- Cooling and durability
- 3D chemistry of proton exchange membrane at the molecular level
- Durability and stamping
- Parametric flow channel design

Platformized product lifecycle management (PLM)

Having access to the right information at the right time is the backbone of effective decision-making. This is especially critical for managing a GH2 manufacturing plant, which involves a highly complex ecosystem and spans a broad scope of interconnected operations and processes. Overlooking even the smallest details can exact a heavy price operationally and financially.

To this end, optimizing plant operations requires a unified platform that acts as the information and control center of PLM. Within this hub, stakeholders can capitalize on the vast resource of valuable real-time data collected in the system.

"To make right-first-time management decisions, stakeholders must be provided with a complete picture to understand a product's behavior through its entire lifecycle."

— **Charles Luzzato**
SIMULIA Industrial Equipment
Industry Process Director,
Dassault Systèmes

"Dassault Systèmes is the only company that can provide virtual twin models of people, products, plants and processes to support end-to-end PLM. These virtual replicas are simulated through their lifecycles in different scenarios to predict outcomes for continuous improvements," Luzzato shares.

Not all PLM solutions can provide a holistic view from end to end. For example, a legacy PLM solution only integrates manual processes and operates in silos. In contrast, a platformized PLM solution consolidates multiple databases and systems — providing easy access to the relevant partners while feeding this valuable data into the ecosystem for continuous process improvement from start to finish.

3 THE ONE PLATFORM ADVANTAGE

Connect and collabrate as one

An effective hydrogen strategy can't be carried out through standalone initiatives and innovation doesn’t take place in siloed environments.

A report by Accenture outlines how a cross-function collaboration strategy allows companies to innovate, stay relevant and drive profitable growth.

As a cloud-based digital platform, the **3D**EXPERIENCE platform connects the GH2 value chain from start to finish — providing complete visibility, a single source of truth and data insights for risks mitigation.

With extended value networks working from one place, decision-makers gain a holistic view of operations and can quickly respond to disruptions impacting time, cost and quality.

According to Wiltberger, “Integrating all project collaboration and planning solutions on the **3D**EXPERIENCE platform provides end-to-end visibility to support data-backed decision-making. Having digital continuity is particularly crucial for electrolyzer production, which involves complex systems.”

Wiltberger adds, “Through the platform, electrolyzer and bipolar plate manufacturers gain the agility to quickly communicate and exchange data if they need to revise design parameters before moving into production".

“For example, thermal and fluidic simulation and the parametrization of electrolyzer components on the 3D model, which can be integrated in a global system,” she shares.

De-risk processes with full visibility

According to the Hydrogen Council, hundreds of new hydrogen projects have been announced over the last two years. The council estimates the total investment into projects across the hydrogen value chain to reach USD500 billion by 2030.

Since establishing a GH2 economy requires substantial investment in new infrastructure, companies must mitigate risks during project execution to make GH2 processes financially viable. This is only possible with complete visibility across interfaces, changes, data and communication.

> “Having a unified architecture across all sites is a key step to industrial scaling up and facilitates seamless system integration. In addition, this advantage enables multiple team members to collaborate in real time wherever they are in the world.”
>
> **— Clara Wiltberger**
> Industrial Equipment Industry
> Sales Strategy Associate,
> Dassault Systèmes

With overall costs and time-to-market being critical parameters in a successful GH2 infrastructure build-up, project teams can leverage the **3DEXPERIENCE** platform to proactively:

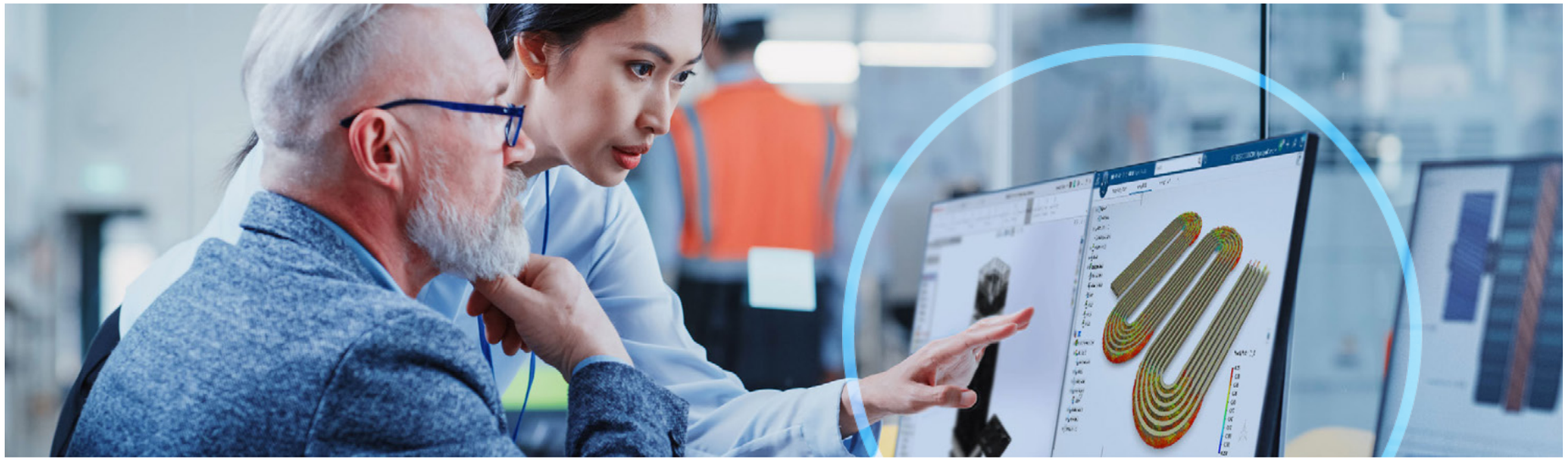
- Share information across interdependent stakeholders
- Reduce evaluation time and make changes at each stage of the hydrogen lifecycle
- Implement cost assessment of distribution networks to meet demand during project creation

Through the platform, companies gain critical insights into the hydrogen's end-to-end journey and the relative costs incurred at each stage of project implementation and final operations.

For example, having real-time visibility of tank filling workflows will provide stakeholders with information such as:

- Timelines from start to finish
- Overall tank construction costs
- Hydrogen storage capabilities

Furthermore, having complete visibility ensures that tank filling remains safe for production plants, trucks or car reservoirs.



Multiscale modeling and simulation

Dassault Systèmes' portfolio of end-to-end applications on the **3D**EXPERIENCE platform supports multidisciplinary, multiscale modeling and simulation in one central hub.

For example, companies can simulate the polymer electrolyte membrane fuel cell (PEMFC) according to its multiscale layer structure at the atomistic and molecular levels.

As a single source of truth, multiscale modeling and simulation on the platform can also be leveraged to synchronize end-to-end operations of brownfield infrastructures for GH2 services.

Additionally, the **3D**EXPERIENCE platform can also be leveraged to optimize processes for:

- Pore-scale microstructure transport
- Water-air flow in bipolar plates
- Thermal management
- Durability and stamping
- Parametric flow channel design
- Reactive flow for electrochemistry simulation

Digital continuity and traceability

Due to the many different ways hydrogen can be produced and the multiple carbon footprints hydrogen can carry, certification has often been regarded as a critical component to facilitating hydrogen trade.

With the climate change agenda taking center stage globally, certifying the renewable nature of all consumed electricity is one of the focus areas for regulators. For example, the Guarantee of Origin (GoO) is a prerequisite in the Netherlands as of October 2022.

Guarantee of Origin

- An energy certificate defined in article 15 of the European Directive 2009/28/EC
- Labels electricity from renewable sources to provide information to electricity customers on the source of their energy

The GoG certificate guarantees that hydrogen is produced from green electricity and enables consumers to verify whether it was produced sustainably. While the Netherlands was the first country to implement this system, a more international system of hydrogen certificates based on European regulations is in the pipeline.

The European Commission has also initiated hydrogen certification schemes across Europe to track hydrogen's origin and environmental attributes. This means a project developer can sell hydrogen with a certificate that reflects the carbon content and processes associated with production.

To comply, GH2 producers must quickly provide any document related to their products and development processes during an audit, including a breakdown of individual construction materials.

Luzzato says, "The **3D**EXPERIENCE platform serves as a single source of truth for the entire GH2 value chain and provides traceability from cradle to grave."

"Having a traceable digital process that is supported by test management tools in one closed-loop system will facilitate seamless compliance with safety and quality processes from start to finish," he adds.

GO GREEN TO DECARBONIZE HYDROGEN

Deploying the right strategy is key to success.

Decarbonizing hydrogen is only possible with a whole system approach to accelerate, de-risk and scale up GH2 innovation. This requires an integrated digital platform that holds it together and connects the dots between people, resources, processes and data. That's what Dassault Systèmes' **3D**EXPERIENCE platform can do.

Being equipped with the right tools for the job is equally as critical to ensuring the seamless execution of any strategy.

With advanced digital solutions like platformized PLM, virtual twin experiences and simulation, the **3DEXPERIENCE** platform supports faster, more efficient processes and unifies each function of the GH2's lifecycle – from research and development to engineering and system integration at scale.

Discover more sustainability insights and strategies here to address decarbonization challenges and achieve net zero targets.

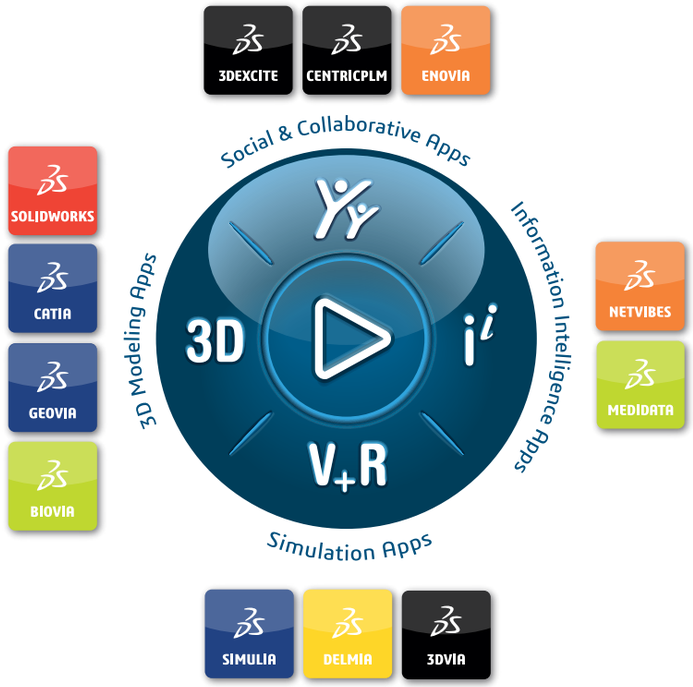
"As an enabler of leading industrial transformations with a proven track record of successful partnerships with global clients across major industries, Dassault Systèmes is uniquely positioned to provide companies with the agility and modularity to transition to a sustainable GH2 economy. And we have the capacity to address the infinite range of potential use for GH2 and adapt to different customer needs."

– Clara Wiltberger
Industrial Equipment Industry
Sales Strategy Associate,
Dassault Systèmes

Our **3D**EXPERIENCE® platform powers our brand applications, serving 11 industries, and provides a rich portfolio of industry solution experiences.

Dassault Systèmes, the **3D**EXPERIENCE Company, is a catalyst for human progress. We provide business and people with collaborative virtual environments to imagine sustainable innovations. By creating 'virtual experience twins' of the real world with our **3D**EXPERIENCE platform and applications, our customers push the boundaries of innovation, learning and production.

Dassault Systèmes' 20,000 employees are bringing value to more than 270,000 customers of all sizes, in all industries, in more than 140 countries. For more information, visit **www.3ds.com**.



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