

# SIEMENS











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# Simulating a viable future with hydrogen

Enabling engineers to design, virtually test and optimize complex systems across industries and applications



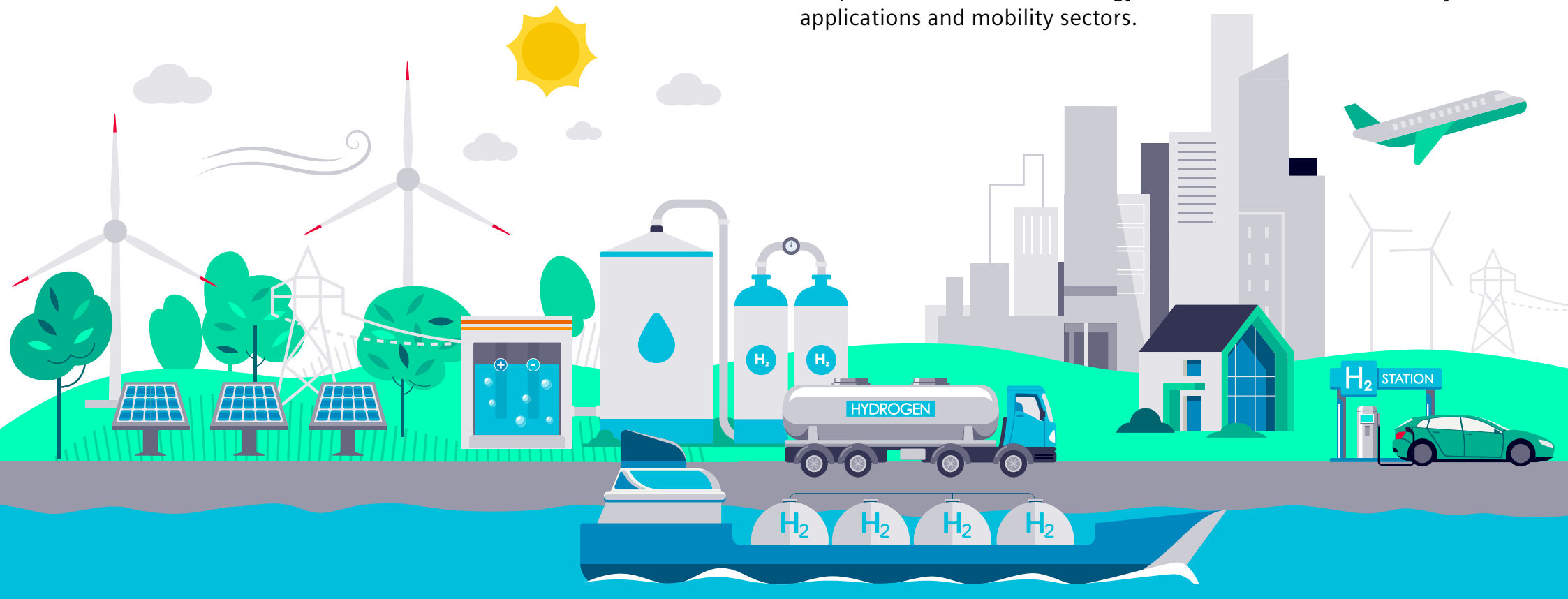
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# Understanding Hydrogen

Hydrogen has emerged as a crucial element in the global energy transition, offering a clean and secure energy future. As a versatile and abundant element, (green) hydrogen production generates no greenhouse gases, making it well suited for decarbonizing energy systems.

In recent years, simulation has emerged as a powerful tool for engineers to design, virtually test and optimize complex hydrogen systems across diverse industries and applications. This includes everything from green hydrogen production using renewable energy to fuel cell systems and hydrogen combustion engines. In this e-book, we break down this complex ecosystem and discuss how optimizing hydrogen storage, transport and distribution has the potential to transform energy-intensive industries, stationary applications and mobility sectors.



# Properties and challenges of hydrogen

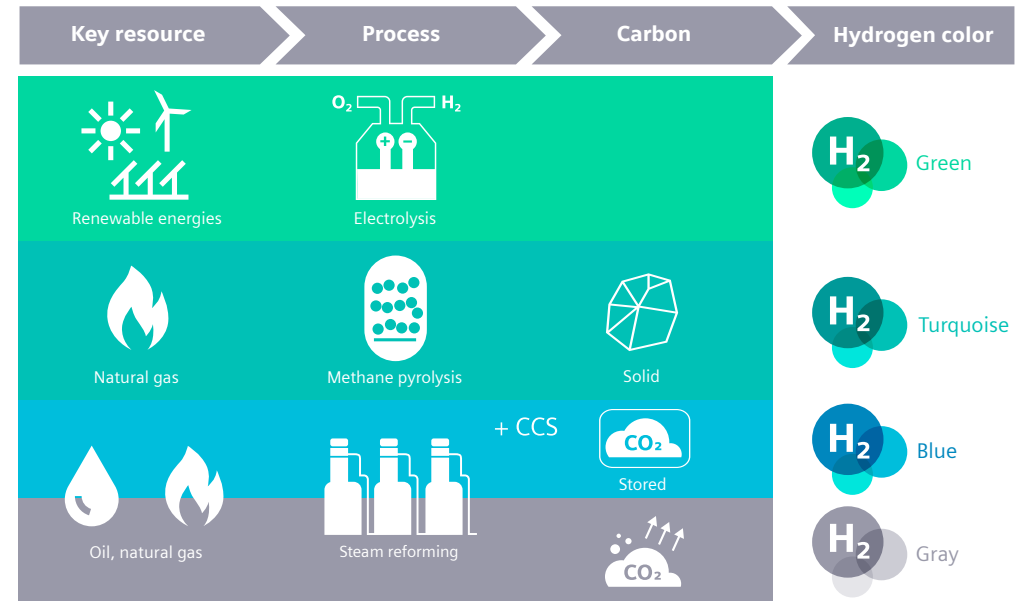
Hydrogen's low density makes storage and transport complex, requiring high-pressure tanks or cryogenic liquefaction, which adds cost and technical challenges. Its flammability and potential for leaks necessitate rigorous safety standards and infrastructure upgrades. Moreover, hydrogen production via electrolysis remains energy-intensive, highlighting the need for advances in efficiency and system scalability.

## Role of hydrogen in key industries

**Hard-to-abate Industries:** Hydrogen enables emissions reductions in energy-intensive sectors like steel, cement and chemicals, fostering a circular economy with cleaner processes

**Stationary applications:** Hydrogen supports energy storage and power generation, balancing the intermittent nature of renewables like solar and wind, while enhancing grid resilience

**Mobility:** Hydrogen overcomes battery limitations in long-haul transport, offering practical solutions for trucks, ships and planes while bolstering energy security with local production



## The hydrogen color spectrum

Hydrogen is categorized by its production methods:


- **Gray hydrogen:** Produced from natural gas, but emits carbon dioxide (CO<sub>2</sub>)
- **Blue hydrogen:** Similar to gray hydrogen, but with CO<sub>2</sub> captured and stored using carbon capture and storage (CSS)
- **Green hydrogen:** Produced with renewable-powered electrolysis, offering a clean, zero-emission solution


Other variants include **turquoise hydrogen** (via pyrolysis with captured carbon) and **yellow hydrogen** (solar-powered electrolysis)

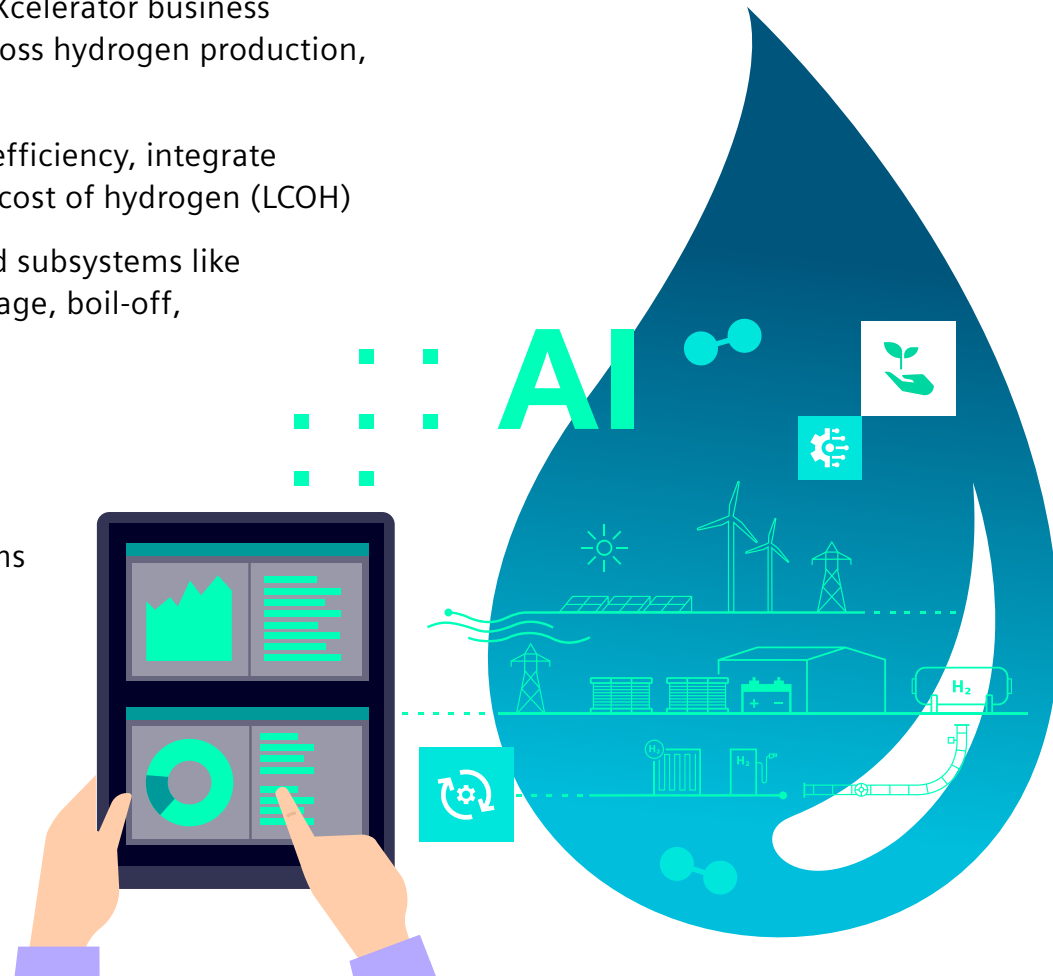
# Driving hydrogen adoption with simulation and modeling

Simulation tools like Simcenter™ software, which is part of the Siemens Xcelerator business platform of software, hardware and services, help address challenges across hydrogen production, transport and usage:

- **Production feasibility:** Leverage advanced simulations to enhance efficiency, integrate renewables and reduce levelized cost of energy (LCOE) and levelized cost of hydrogen (LCOH)
- **Critical equipment and storage:** Optimize pumps, compressors and subsystems like compression and water management, while managing cryogenic storage, boil-off, dispersion and explosion risks
- **Distribution:** Model flow dynamics, pressures and thermal effects to enhance safety and efficiency
- **Offtake management:** Simulate refueling, predict consumption and manage complex thermal-electric interactions in hydrogen systems

 **Mobility:** Design and optimize hydrogen refueling stations with integrated Siemens Digital Industries Software and hardware solutions<sup>1</sup>

 **Power generation:** Explore hydrogen blending for power generation and high-temperature processes and integrate with energy storage systems like (battery energy storage systems (BESS) to enhance grid stability<sup>2</sup>



To build a viable hydrogen ecosystem, a holistic simulation approach proves to be an important lever to minimize risk and maintain project timelines and budget.

A digital twin and artificial intelligence (AI) enhance real-time decision-making, providing predictive insights for operational reliability and scalability.

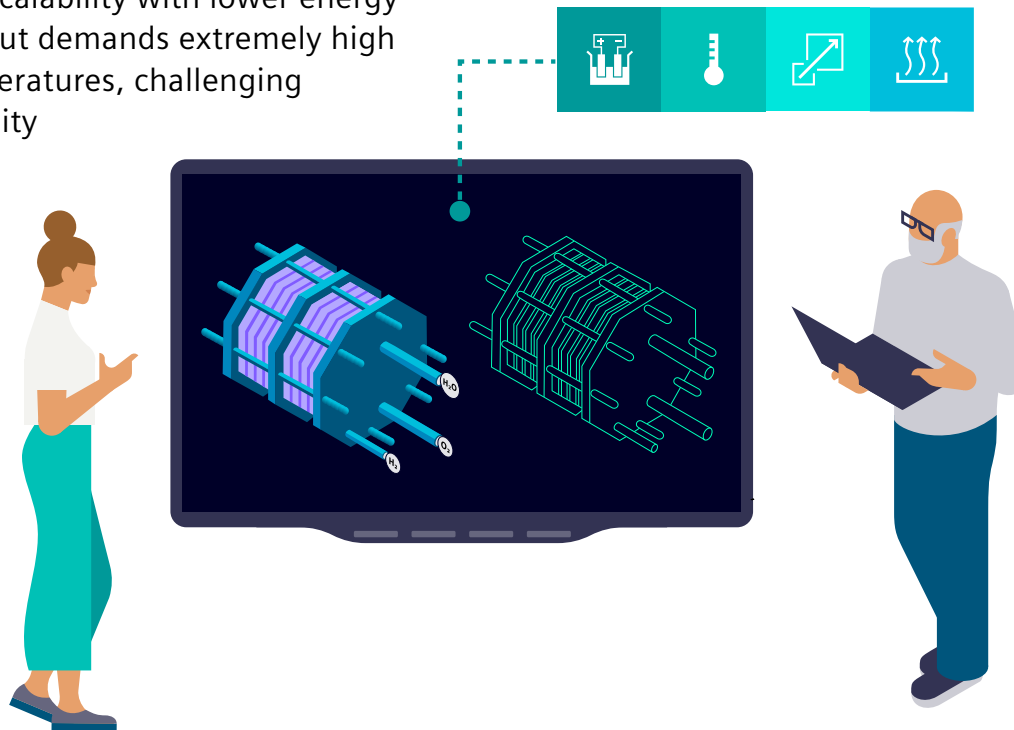


# Simulation for hydrogen production

## Simulation for green hydrogen production

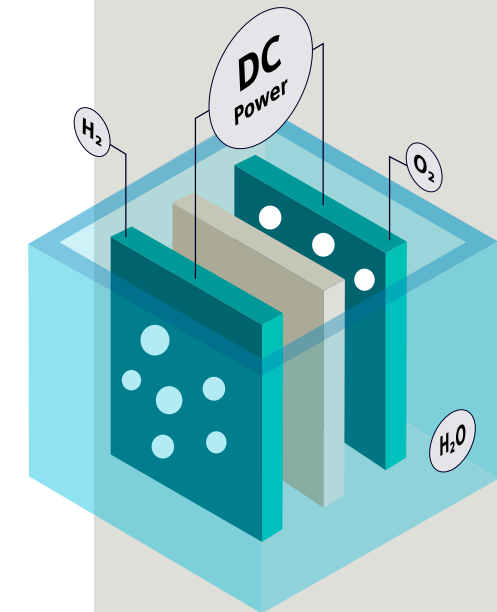
Green hydrogen production relies on electrolyzers to enable electrolysis. Key types include:

- **Proton exchange membrane (PEM):** It is highly efficient for small-scale, high-purity hydrogen production, well suited for automotive fuel cells, but it is expensive and unsuitable for large-scale operations
- **Alkaline electrolyzer (AEL):** A low-cost, scalable option for industrial use, though it requires more space and infrastructure and is slower to adapt to power changes
- **Solid oxide electrolyzer (SOE):** Offers high efficiency and scalability with lower energy consumption, but demands extremely high operating temperatures, challenging material durability



Read blog on simulation of SOFC (solid oxide fuel cell)<sup>3</sup>

The Simcenter computational fluid dynamics (CFD) simulations model provides critical processes in electrolyzers like fluid dynamics, gas bubbles and heat transfer, helping engineers optimize electrolyte flow, electrode efficiency and system scalability for green hydrogen production.

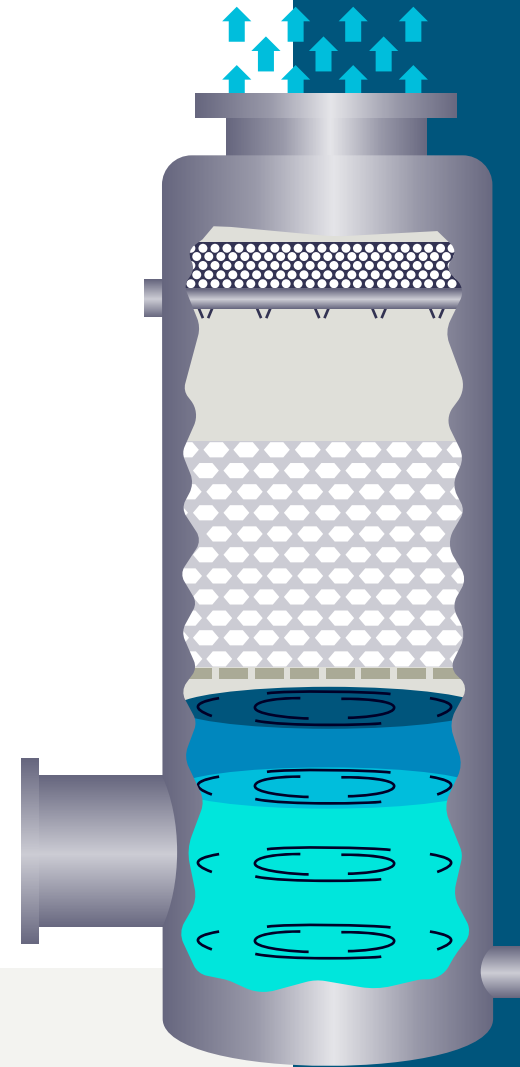
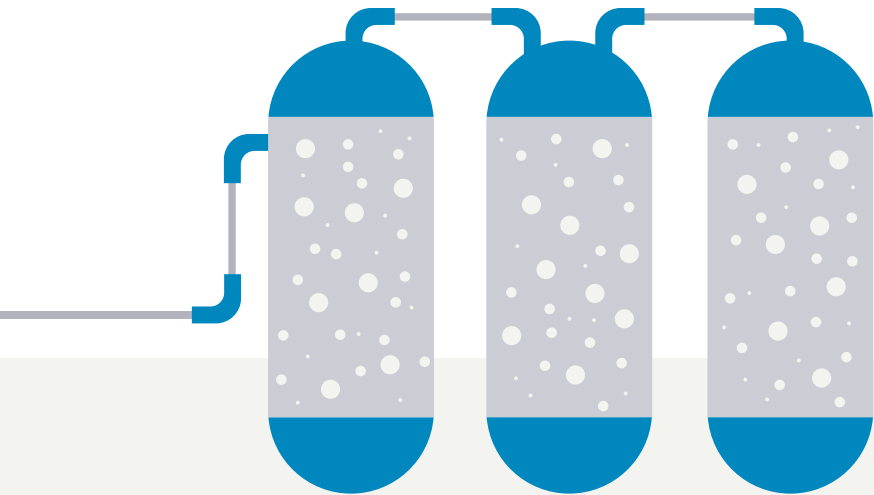


# Simulation for hydrogen production

## Simulation for blue hydrogen production

Blue hydrogen production from methane releases CO<sub>2</sub> emissions, which are captured and stored using key CCS methods, such as:

- **Amine washing:** Solvents absorb CO<sub>2</sub> from gas streams, which is then released, compressed and transported for storage after heating the CO<sub>2</sub>-rich solution
- **Scrubbers:** Uses chemical reactions to absorb and separate CO<sub>2</sub> from gas streams, also removing pollutants like sulfur dioxide (SO<sub>2</sub>) in industrial applications
- **Cryogenic separation:** Uses extremely low temperatures to liquefy and isolate CO<sub>2</sub> based on its higher boiling point compared to hydrogen



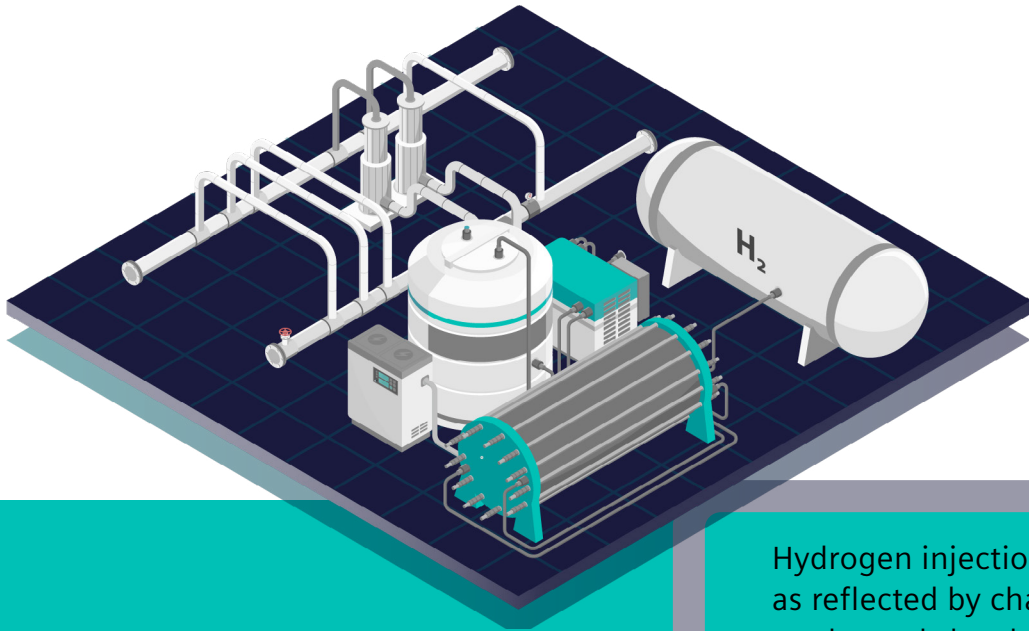
The Simcenter multiscale, multiphysics simulations optimize equipment like scrubbers by modeling processes such as multiphase flow, absorption reactions and differing timescales.

With scrubber 3D simulation, engineers can track the slurry's volume fraction and the mass fraction of SO<sub>2</sub> in real time, providing insights into how efficiently SO<sub>2</sub> is absorbed and neutralized over time.

# Simulation for hydrogen storage and transport

Hydrogen's low density necessitates storage via pressurized tanks for short-term needs or cryogenic liquefaction for large-scale, long-term transport. Temperature fluctuations during operations pose challenges that system simulation software can address by analyzing refueling times, pressure changes and safety factors.

For hydrogen transport, retrofitting natural gas pipelines is essential, requiring engineers to address critical challenges such as material embrittlement and maintaining flow stability.



**Simcenter system simulation software** optimizes storage and transport by:

- **Pressure management:** Simulating pressure dynamics in refueling and defueling to predict and control temperature spikes and tank performance
- **Thermal effects:** Modeling heat transfer to reduce material stress during tank cycling
- **Safety:** Analyzing leaks, venting times and flame lengths for enhanced operational safety
- **Pipeline design:** Modeling fluid dynamics in pipelines and identifying optimal pipe size and material
- **Compressor optimization:** Determining ideal compressor size and number for hydrogen compression
- **Flow regulation:** Simulating valve behavior under varying conditions to ensure stability and proper valve sizing

Hydrogen injection into natural gas feeds for gas turbines can significantly alter fuel properties, as reflected by changes in the Wobbe Index. Such variations can lead to combustion instability, unplanned shutdowns, and potential asset damage. Recent studies have used simulation of hydrogen dosing to predict shifts in the Wobbe Index, demonstrating how factors such as pressure, line-pack, and mixing dynamics influence fuel stability and operational reliability.<sup>4</sup>



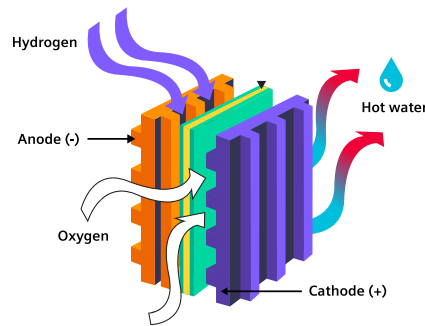
# Simulation for hydrogen consumption

Hydrogen's versatility and emissions-reducing potential make it vital for both stationery and mobility applications.

## Stationery applications

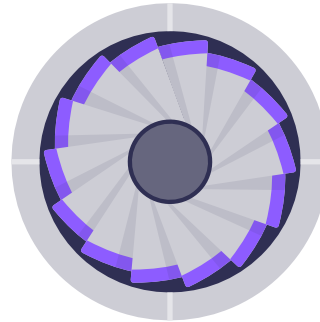
### Fuel cells

Generate zero-emission electricity for homes, businesses and critical facilities with only water vapor as a byproduct



### Gas turbines

Blend or replace natural gas to provide high-temperature heat and power for industries like cement, steel and chemicals, enabling immediate decarbonization



## Fueling infrastructure and challenges

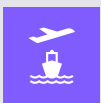
Hydrogen refueling stations (HRS) are critical for hydrogen vehicle adoption, storing and compressing hydrogen at high pressures (700 bars). However, challenges include high infrastructure costs and technical barriers like managing hydrogen's low density and safety concerns.

- Simcenter system simulation software models can be used to fuel cell electric vehicles, predicting interactions across subsystems like the fuel cell stack, air supply and recirculation loop
- Simcenter CFD tools also simulate flow, chemistry and heat transfer in gas turbine combustion systems, optimizing performance and emissions under varying conditions. It can also be coupled with intelligent design exploration to further improve combustor performance.

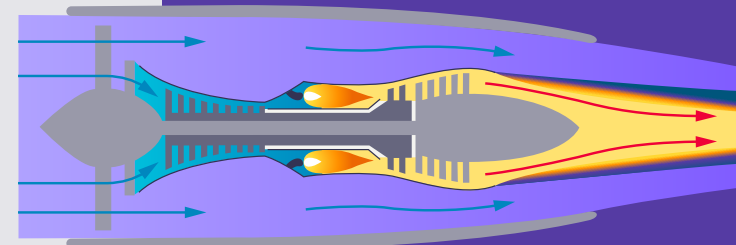
## Mobility applications



**Hydrogen vehicles:** Ideal for long-haul trucks due to fast refueling and extended range.



**Maritime and aviation:** Hydrogen is emerging as a sustainable alternative for shipping and aviation, since emissions can be reduced with hydrogen-fueled jet engines and hybrid systems



# Customer spotlight: Open Grid Europe



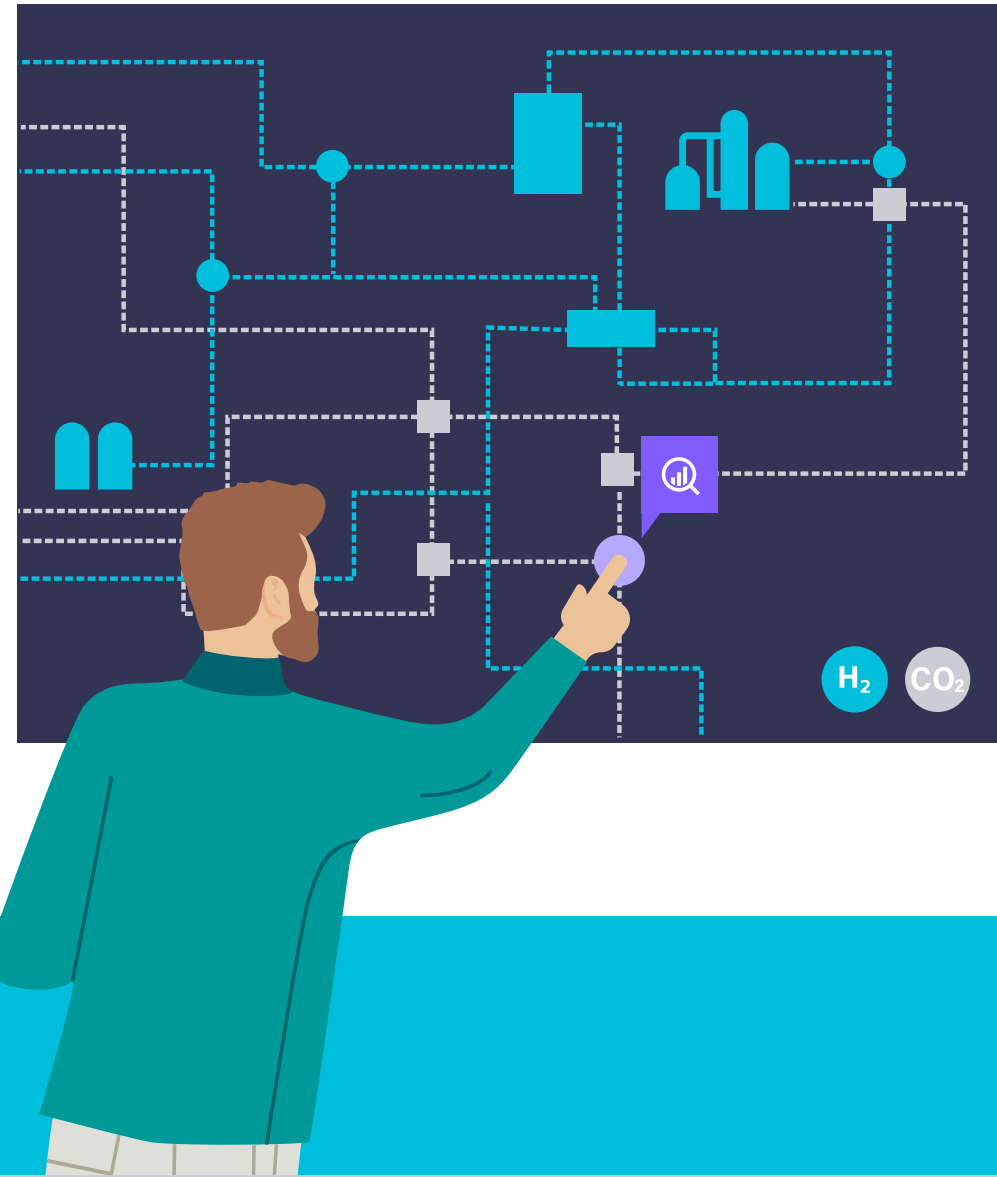
**Challenge:** Open Grid Europe (OGE) needed to ensure the safety and reliability of its gas distribution systems while adapting to energy transition demands. Challenges included managing complex pipeline networks during emergencies and retrofitting infrastructure to handle supercritical CO<sub>2</sub>, which differs significantly from natural gas.



**Solution:** The Simcenter multiphase, multiphysics CFD tool enabled OGE to analyze gas flow dynamics, model critical parameters like phase splits and heat transfer, and deliver system efficiency under new operating conditions.



**Outcomes:** OGE minimized downtime, reduced risks and ensured safe, future-ready operations by assessing and retrofitting infrastructure for hydrogen and CO<sub>2</sub> transport.



OGE has relied on Simcenter system simulation software for detailed engineering of gas flow networks for over a decade to improve safety, and reduce the risk of unplanned downtimes, thereby increasing overall operational efficiency.<sup>5</sup>

# Customer Spotlight: B&B-AGEMA



## Challenge

Developing a 100 percent hydrogen-fueled dry low-emission (DLE) combustor required overcoming challenges like hydrogen's high flame speed, flashbacks and the need for robust, cost-effective designs meeting stringent performance targets.



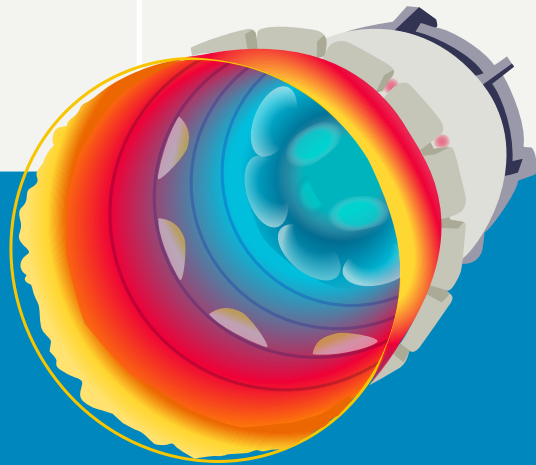
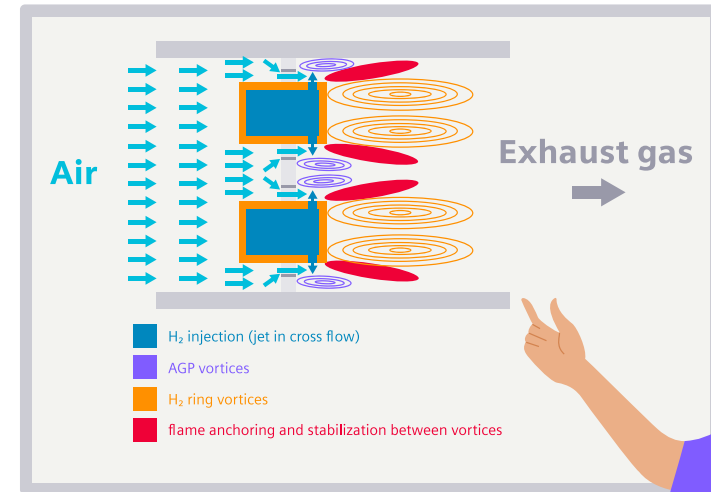
## Solution

Simcenter CFD simulations enabled analysis of combustion behavior, flame shapes and burner configurations. Conjugate heat transfer (CHT) analysis evaluated how different fuel types affected the burner's thermal load.



## Outcomes

Delivered the world's first 100 percent hydrogen combustor, reducing flashbacks and NOx emissions, setting a new standard in hydrogen combustion.



*The Simcenter CFD simulations have shown a new flame shape with very low NOx properties, which was never considered before.*

**Jens Dickhoff, Technical Manager, Combustor Design, B&B-AGEMA**

# Future trends and opportunities



Simultaneously, advances in simulation technology are accelerating the adoption of hydrogen by overcoming traditional barriers associated with its production, storage, transport and usage.



The global shift toward decarbonization offers unprecedented opportunities for hydrogen to play a transformative role in reducing emissions across some of the most energy-intensive sectors. The development of hydrogen-compatible technologies such as advanced burners, fuel cells and hydrogen-ready furnaces will be critical in achieving this transition.

# Why Simcenter

Using Simcenter integrates multiscale and multiphysics tools with cross-platform, hardware, software, and AI integrations to provide model-based insights from design to operations. Simulation-led processes accelerate better design development while ensuring operational performance and safety. It enables the simulation of complex systems across industries such as process equipment, nuclear reactors, heating, ventilation and air conditioning (HVAC) systems, wind turbines and emerging technologies like BESS, hydrogen and carbon capture.



## Model the complexity

To model the complexity of energy systems, it is essential to capture all the physics of a system, from quantum to production scale. With the widespread use of simulation to model multiphysics cases, companies in the energy sector are better placed to reduce costs, while improving operational safety and efficiency.



## Explore the possibilities

With the rise of AI and AI-led simulation solutions, there are countless opportunities for design space exploration and process optimization. This will produce streamlined workflows with tailor-made solutions for specific challenges in the energy sector.



## Go faster

While scaling renewable energy and improving energy infrastructure are priorities, it is crucial not to neglect process optimization. Simulation insights support both faster design space exploration and enhanced system performance in an increasingly competitive market.



## Stay integrated

Integrations across existing systems and data transfer between scales and assets enable a more holistic view of energy operations. This remains a key area where simulation and the digital twin can provide real insight into production facilities and energy infrastructure.

# For more information

## References

1. [Hydrogen usage with Simcenter System Simulation: Mobility and stationary applications – Part 3](#),” Siemens blog, July 11, 2024.
2. [“Renewable Energies: Boost your Battery Energy Storage Systems with Simcenter System Simulation](#),” Siemens blog, March 4, 2025.
3. [“Technical and economical assessment of a Solid Oxide Fuel Cell \(SOFC\) Combined Heat and Power residential system using System Simulation](#),” Siemens blog, October 10, 2023.
4. [“Don't let fuel transitions derail your operations”](#),” Siemens white paper, March 4, 2024.
5. [“OGE leverages 1D CFD to design safe gas infrastructure and assess readiness for energy transitions](#),” Siemens case study, December 9, 2022.
6. [“Developing a completely hydrogen-fueled gas turbine](#),” Siemens case study, June 4, 2021.

[Contact us](#)

## Resources

1. [Hydrogen usage with Simcenter system simulation: Part 1 | Part 2](#)
2. [Green hydrogen production simulation with Simcenter Amesim™ software](#)
3. [Green energies and hydrogen](#)
4. [Siemens hydrogen solutions](#)