AEROSPACE & DEFENSE

ACCELERATING HYDROGEN TRANSITION

Aviation has allowed us to travel great distances across the planet. Thanks to the existence of aircraft, we can discover new places and people in a way completely unimaginable to our ancestors. However, air travel comes at a cost: It is a contributor to global greenhouse gas (GHG) emissions [1].

2.5% of global CO2 emissions came from the worldwide aviation industry alone [2]. If left unmitigated, it can increase to 25% by 2050. Aviation experts anticipate a 3.5% compound annual growth rate (CAGR) over the next two decades that could double the number of passengers and flights today.

The industry thus faces increasing societal, environmental and economic imperatives for reinventing the way planes fly and reducing emissions. Many countries and companies have implemented ambitious targets for sustainable aviation for years, and one such target is a **50% reduction of emissions volume by 2050**, relative to 2005 levels [3].

Let's now explore the ways that the **3D**EXPERIENCE® platform and the Virtual Twin Experience from Dassault Systèmes can help accelerate the development and deployment of hydrogen aircraft technologies for either propulsive or non-propulsive energy systems.

HYDROGEN-POWERED AIRCRAFT

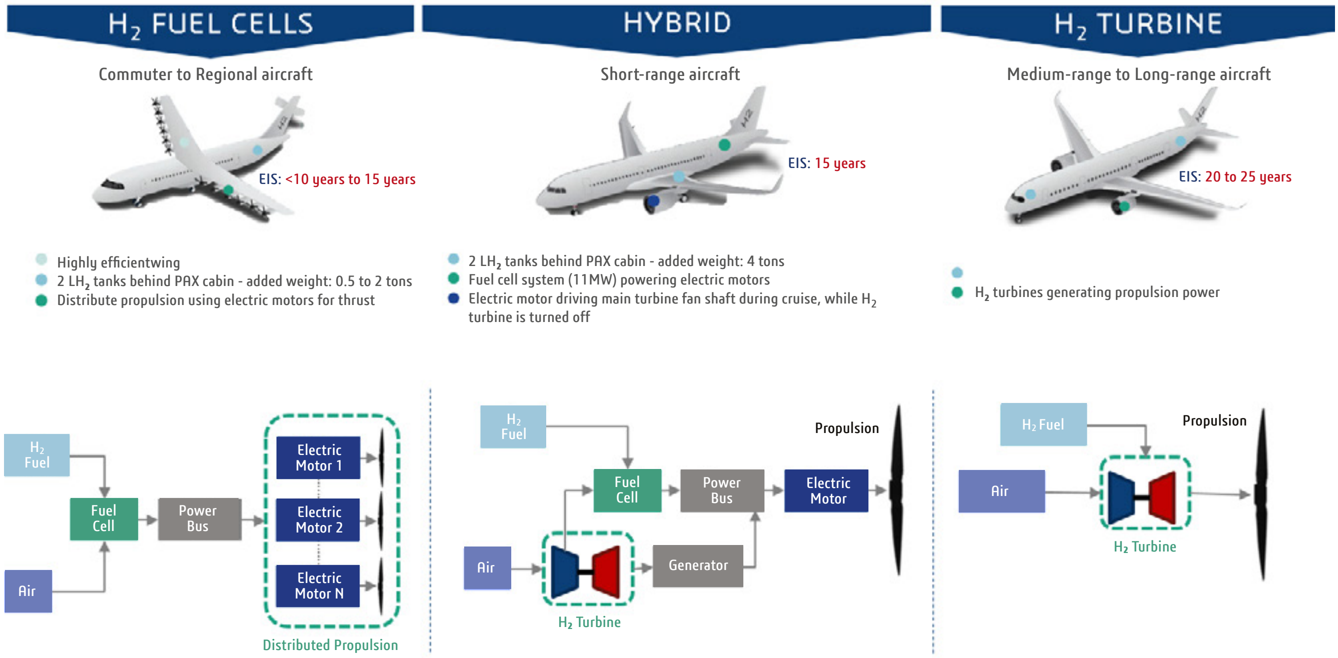

Figure 1: Planned architectures for hydrogen-powered aircraft. Adapted from [4].

Depending on their size and mission, hydrogen-powered aircraft are set to be equipped with either hydrogen fuel cells, hydrogen-fueled turbines, or a hybrid of both (Figure 1).

For smaller aircraft, hydrogen fuel cells are expected to power electric engines. Hydrogen fuel cell aircraft could potentially offer a ‘true zero’ solution for lowering GHG emissions. Similar to a battery, a fuel cell is a device that converts energy stored in molecules into electricity through an electrochemical reaction. Fuel cells that use pure hydrogen are carbon-free.

For larger aircraft, hydrogen can potentially fuel traditional combustion turbines. Hydrogen combustion has already been used to fuel the Tupolev Tu-155 in 1988[5]. The plane flew approximately 100 test flights and was later placed in storage. Today, hydrogen combustion — in either gas or liquid form — is emerging as one of the most promising options for improved environmental performance. Conversion to hydrogen combustion would require changes to the engine, fuel storage and fuel delivery elements in conventional aircraft.

Hybrid solutions are also under investigation for short to medium-range aircraft, where fuel cells can either supply non-propulsive electrical consumers or serve as a propulsive source of energy for powering electric engines.

However, this shift to hydrogen is not without some challenges. The most important concern revolves around onboard hydrogen storage. Compared to kerosene, hydrogen has approximately 2.8 times less mass per amount of energy but also 4 times more volume in a liquid state, which requires the tank size to increase [4]. Furthermore, liquid hydrogen must be maintained in cryogenic tanks at extremely low temperatures. The low gravimetric density together with the cryogenic characteristics of liquid hydrogen can result in tank shapes that are challenging to integrate into an aircraft. In order to do this, the industry must reconsider the entire aircraft architecture and integrate its sub-systems.

At the same time, the power density of hydrogen fuel cells must be improved with specific heat management to scale the solution to larger aircraft. On the other hand, if direct hydrogen combustion is utilizable for larger planes, the industry must also decrease non-CO_2 emissions that are nitrogen oxides (NOx) and water vapor in contrails.

ADDRESSING HYDROGEN CHALLENGES FOR AIRCRAFT

For hydrogen technology to become a viable solution for aviation, the industry needs to overcome a few challenges. Some challenges concern aircraft architecture and design – specifically in areas of fuselage redesign and hydrogen storage integration. As stated before, the tank layout is the key driver for aircraft configuration designs. Liquid hydrogen fuel (LH2) requires four times more storage volume than kerosene for the same energy content and must be stored under overpressure. Meanwhile, other challenges revolve around the hydrogen supply chain and infrastructure.

Stakeholder requirements, regulatory constraints, mission profile and use cases are typically skipped or considered by aircraft designers too late in the process. By the time design choices have been made, the cost of changing specifications increases dramatically. This would not be the case with early pre-production identification.

Here is where the **3D**EXPERIENCE platform is reliable. With all air transport stakeholders in a single transparent place, validating final requirements for aircraft configuration becomes easier. The platform can also help stakeholders improve intersectional collaborations in several key areas.

Here, we structure our offer in two levels. The first level carries solutions relevant to original equipment manufacturers (OEMs): The Aircraft Architecture Definition, System Integration & Aircraft Verification and Infrastructure & Logistics Planning and Market Intelligence.

The second level encompasses solutions relevant to sub-system engineers and hydrogen suppliers: Fuel Cell Development, Hydrogen Turbine Development, Storage Development and Distribution System Development. Certification and manufacturing are pillars embedded within every element of these solutions (Figure 2).

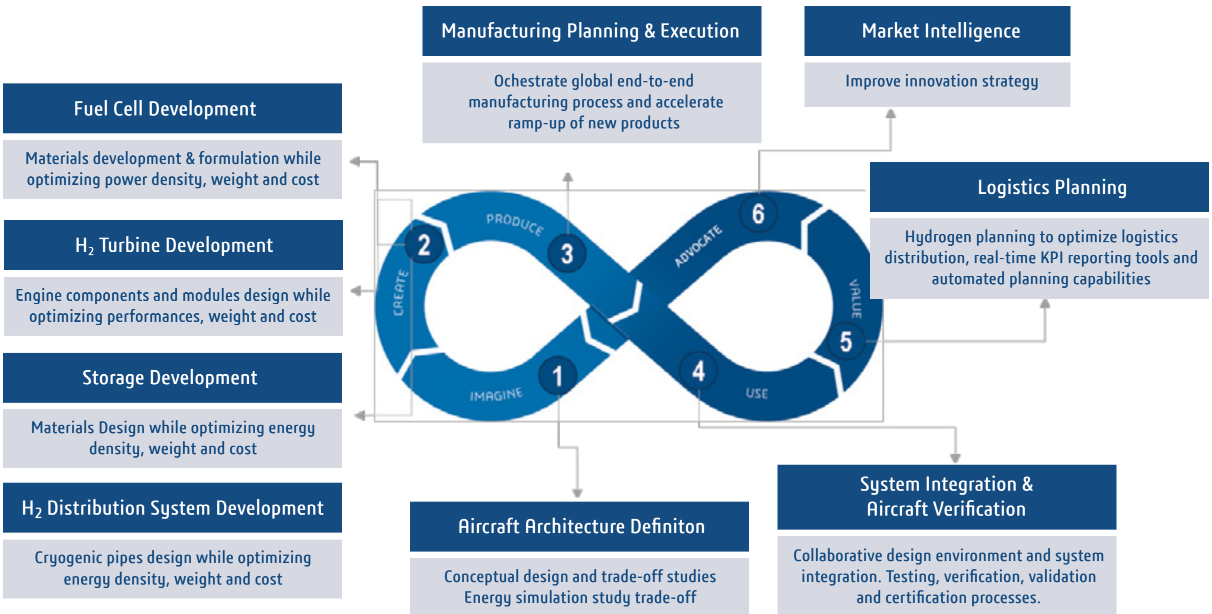

Figure 2: Our solutions portfolio.

Aircraft architecture

The aircraft design methodology utilizes existing conventionally powered aircraft. It can analyze both conventional and hydrogen fuel cell powertrains and compare the performances of current and future technologies.

With all design needs stabilized, the first step in the design process is defining aircraft architecture with the initial space allocation and arrangement of sub-systems such as the fuel tank and fuel cells.

Through trade study analysis, top aircraft configurations are identified to meet efficient and safe operation requirements. Their performances are analyzed and compared to conventional aircraft in order to select the best aircraft confirmation.

Aircraft architects can explore thousands of concept alternatives leveraging simulation capabilities offered on the **3D**EXPERIENCE platform. Then they choose the best configuration that meets the best requirements. Our Concept 3D Architecture & Simulation capabilities trace and analyze 3D concept architecture, zone and equipment space allocation against requirements (Figure 3) and safety constraints around a mock-up that integrates all disciplines (including structure, electrical, fluidic and equipment). The chosen configuration is optimizable using Multi-Discipline Optimization (MDO) techniques leveraging the platform's built-in capabilities.

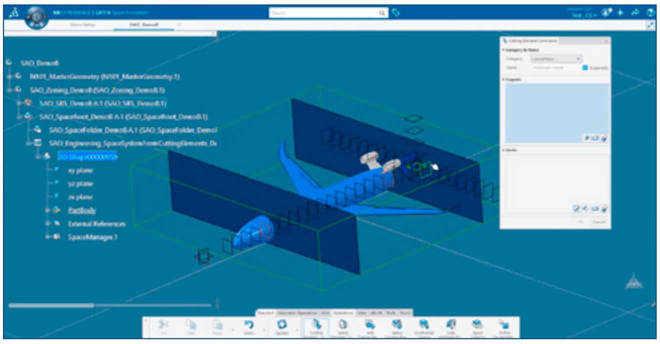

Figure 3: Space and zone allocation.

Defining next-generation hydrogen aircraft requires strong collaborations between all stakeholders. Cooperation with suppliers, in particular, is crucial in ensuring seamless sub-systems integration within aircraft architecture.

OEMs and strategic innovation partners can access up-to-date crucial information when they leverage total value network visibility and single-source data models on the platform. Updates relating to safety and efficiency progress are consistently streamlined, accessible and verifiable.

The Platform's Virtual Twin Experience capability can accelerate aircraft prototype testing. By simulating advanced 3D designs based on real-life scenarios, stakeholders can virtually test, validate and accurately predict an aircraft feature's performance well before production. This way, they can easily obtain critical validation right at the design stage while reducing emissions, costs, waste and use of resources (Figure 4).

As the authoritative source of truth, the **3D**EXPERIENCE platform prevents rework during the transition from the concept phase to the preliminary design phase.

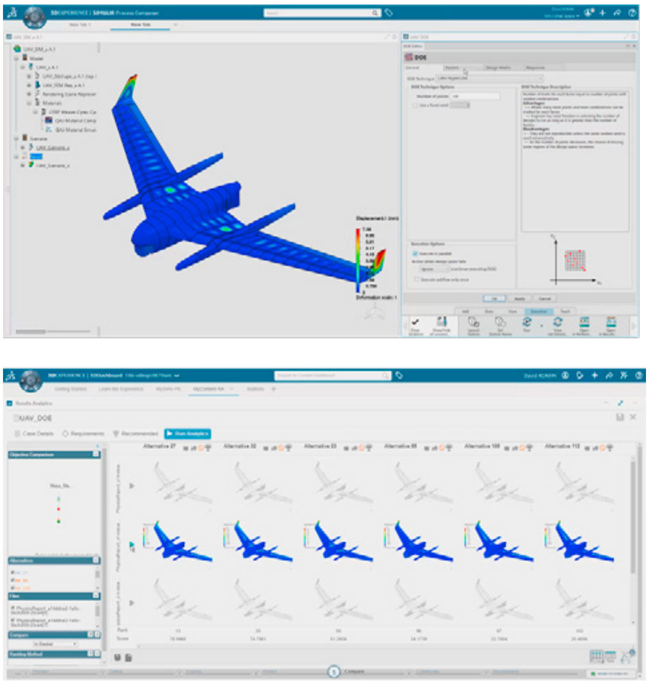

Figure 4: Trade-off analysis workflow applied to an aircraft architecture.

Storage

A main challenge in hydrogen-powered aircraft architecture is its low volumetric density. The aircraft requires four to five times the volume of conventional fuel to carry the same onboard energy. Providing hydrogen in gas form also requires a lot of storage volume. The compression required by the storage volume can then increase costs and energy needs. As a result, storage can get heavy.

At the same time, the mass of liquid hydrogen tanks must decrease by 50%. There are various levers to reduce it, including a lightweight material with a strong interaction with hydrogen one without any reaction. From here, it is clear that hydrogen storage is a materials science challenge. A better understanding of its interactions with other elements (such as metals or composites) is therefore crucial.

The utility of the **3D**EXPERIENCE platform – from 1D analysis for systems engineering to 3D assessment that focuses on materials – enables manufacturers to observe and experience aircraft design in different operating conditions. In the case of liquid hydrogen tanks, the platform's unique solutions allow them to evaluate the pressure and temperature stratification within the tank right at the design stage. Doing so can ensure that liquid hydrogen does not ever evaporate (Figure 5).

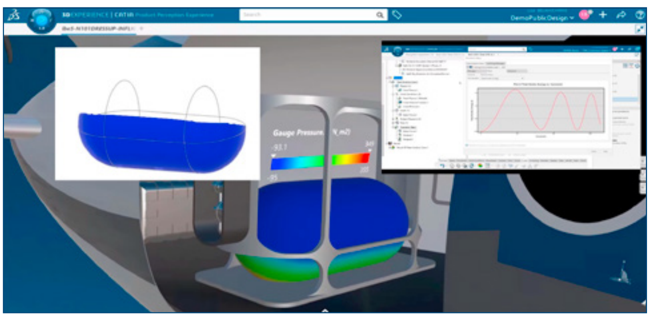

Figure 5: Sloshing simulation of a liquid hydrogen storage system.

Hydrogen fuel cells

A hydrogen fuel cell uses hydrogen's chemical energy to produce electricity. Adding energy storage (such as a battery) to this system helps ensure fast load following and power peak shaving, and in turn, these two outcomes will optimize the sizing of the fuel cell system. The most advanced and suitable option for aviation today comprises low-temperature proton-exchange membrane (PEM) fuel cells.

To design fuel cell systems for passenger aircraft, it is necessary to specify the aircraft's system requirements. Its fuel cell design must incorporate these crucial functions: Waste heat management, fuel cell durability, increased system power and energy densities (e.g. fuel storage) and reliable power quality (Figure 6).

The **3D**EXPERIENCE platform supports accurate sourcing and testing at component, sub-system and system levels. Working on it allows manufacturers to simulate polymer electrolyte membrane (PEM) fuel cells and cell stacks for pre-design, control strategy evaluation or loss analysis. As a result, they can predict a complete fuel cell's performance at scale (Figures 6, 7).

Manufacturers can also capture the multiscale nature of materials, such as the PEM fuel cells' membrane component, with the Material Excellence solutions. For instance, the characteristics of water-immersed protons pathways at the nanoscale can be part of the multiscale analysis that facilitates in-depth fuel cell performance assessment.

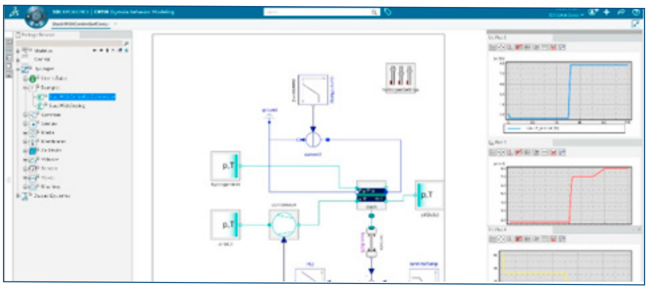

Figure 6: 1D simulation of a plane's fuel cell and battery system.

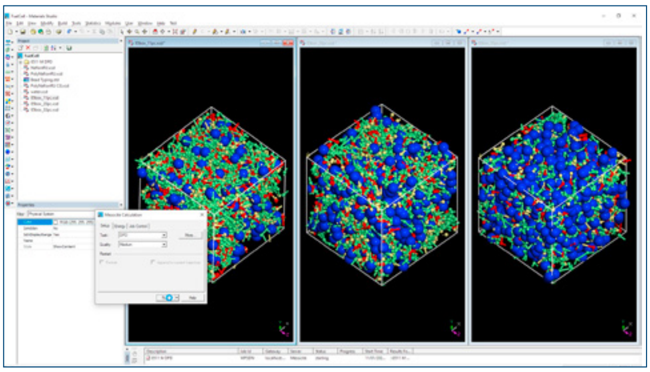

Figure 7: Nanoscale simulation of the fuel cell membrane.

Hydrogen-fueled engines

Hydrogen engines will have to be more efficient and emit only non-CO_2 emissions like nitrogen oxides (NOx). All development stages managed by engine manufacturers must be accelerated to ensure entry into service within the decade.

The **3D**EXPERIENCE platform helps manufacturers define design details with precision. What's more, they can easily focus on specific hydrogen-related engine sub-systems such as fuel injectors and experience their design via integrated modeling and simulation. For instance, they can perform a fluid-mixing simulation incorporating both hydrogen and air to understand the regions of inefficient mixing that can produce nitrogen oxides (Figure 8).

Thanks to the full continuity between the platform's CAD and simulation capabilities, DOE can be realized to identify the best fuel injector architecture. This ensures efficient mixing within the aircraft's combustion chamber (Figure 8).

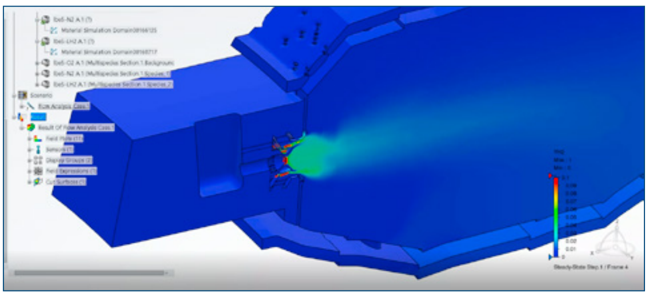

Figure 8: CFD simulation of gaseous hydrogen-air mixture in the combustion chamber.

Certification

To obtain type certificates enabling them to fly, , OEMs must demonstrate their aircraft safety to certification authorities. The existing certificates for conventional rotorcraft or fixed-wing aircraft currently do not match the particularities of hydrogen configurations. Therefore, companies must first accelerate the development and deployment of new technologies. After all, time is of the essence: Commercialization and aircraft certification can take more than ten years to complete, while substantial fleet replacement would require an additional decade.

To meet the standard level of performance, OEMs can leverage virtual simulation to iterate aircraft design at a lower cost. They can explore several solutions before finalizing tests on a real physical prototype. Specific tests are required around safety and reliability. The traditional method of testing comprises multiple trials and errors involving a limited amount of configurations while not achieving optimum results. With simulation, the iteration is automatic and the principles of multi-physics can be applied to it simultaneously.

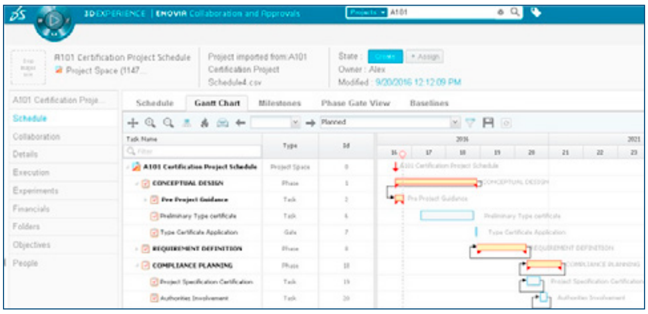

Figure 9: Management of certification engineering efforts.

It is not only necessary to prove the fulfillment of all performance-related requirements but also mandatory to justify how the conclusion was built. Therefore, regulations, requirements and design solutions must be traceable as soon as aircraft engineering activities commence. A single source of truth helps companies benefit from digital data continuity and enables certification authorities to see manufacturers' design intentions from the get go.

Companies can seamlessly plan, execute and monitor their type certification strategy when their stakeholders can easily produce and approve supporting deliverables (Figure 9). Failing to have the deliverables in place and accessible at the right time could incur unwanted certification delays.

The **3D**EXPERIENCE platform helps OEMs build a regulations pipeline and crawl airworthiness authorities' websites easily. It enables them to create a transparent scientific pipeline that manages means of compliance, virtual models, methods, mathematical formulas and previous results.

The platform also aids OEMs in areas of decision-making. They can easily provide summarized information on dashboards and effectively communicate tasks via certification project statuses, tests campaign monitoring, submissions and issuances.

ADDRESSING SUPPLY CHAIN AND INFRASTRUCTURE CHALLENGES

A shift to hydrogen will require airports to reinvent their existing infrastructure and logistical systems.

For one, hydrogen is highly explosive at ambient temperatures. As such, storage tanks must stay outside of the airfield to reduce the chances of chain-reaction explosions. Following this, a significant increase in overall storage space must be expected. These tanks must also be kept at -253°C to keep hydrogen in its safe-to-use liquid form, which generates a new level of safety management and logistical complexities.

Meanwhile, hydrogen must be transported from its producer to the airport at the most minimal cost possible. Doing so prevents overall hydrogen adoption costs from increasing [6].

Therefore, a strong collaborative system needs to exist among energy suppliers, OEMs, airports and airlines worldwide to tackle these challenges successfully. Building a global and cooperative aviation ecosystem with all value chain players involved is likely the key to achieving a truly competitive and sustainable hydrogen-fueled industry (Figure 10).

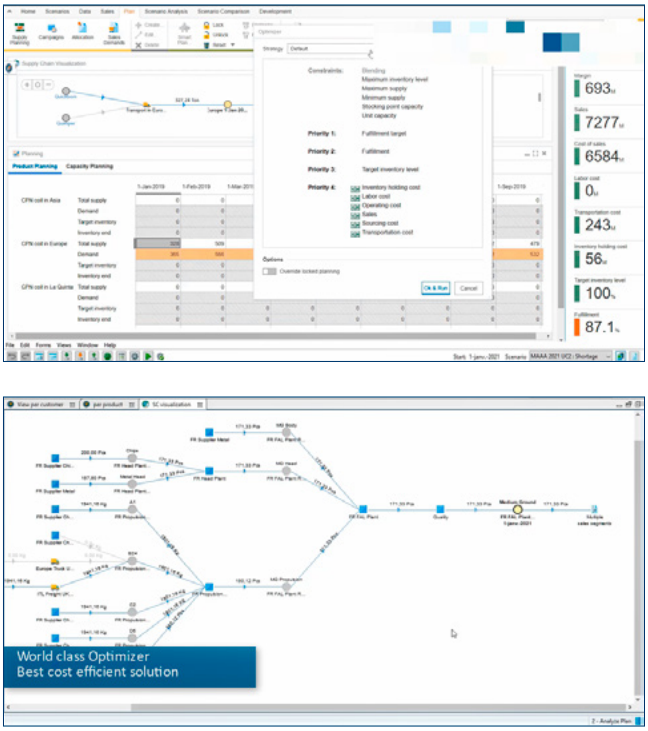

Figure 10: Supply chain management for hydrogen delivery.

ADDRESSING HYDROGEN MARKET INTELLIGENCE

Hydrogen's future will be driven by technology investment decisions. As such, hydrogen stakeholders must continuously monitor their hydrogen business environment.

Technical, HR, strategy and marketing teams, for one, can utilize the **3D**EXPERIENCE platform's multi-lingual and multi-channel semantic analysis software to transform information into applicable knowledge and detect emerging trends and weak signals.

This unique information intelligence tool covers more than 30 languages and multiple source of information such as:

- Investigations (e.g. NPS, CES, CSAT)
- E-mails, contact forms and chat
- Web and social networks
- Requests for proposals (RFPs) and contracts
- Scientific papers
- Technical documentations and maintenance logs

The teams can utilize the tool to distribute relevant information throughout their company. Doing so ensures all departments – from operations and logistics to product design and customer service – can quickly identify enterprise-wide problems and best practices. At the same time, they can monitor the evolution of relevant topics and create their action plans based on the most important themes.

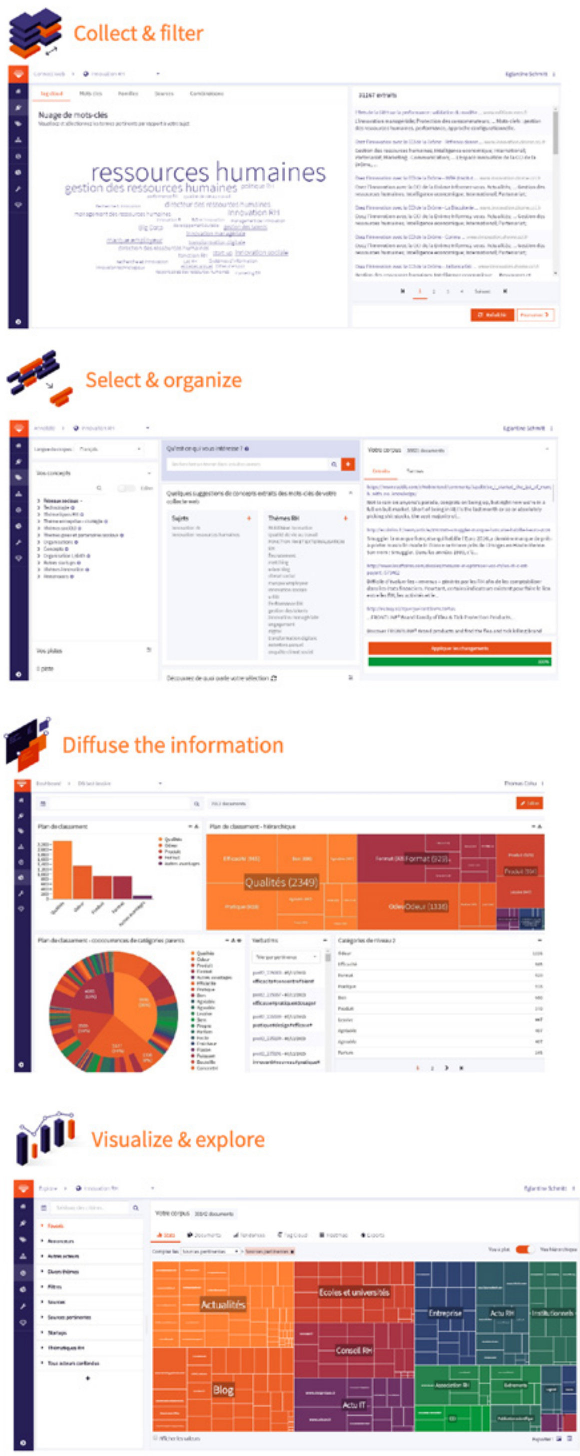

Figure 11: Information intelligence tool for sharing, collecting, analyzing and monitoring hydrogen-related information.

CONCLUSION

Decarbonizing aviation can be complex and challenging – but it does not have to be. With the right solutions, low-carbon possibilities are endless.

Using the advanced digital capabilities powered on the **3D**EXPERIENCE platform, aviation companies can deliver better fuel systems, better planes and a better value network – and seamlessly achieve aviation decarbonization targets.

On the platform, companies can create and optimize Virtual Twin Experiences of hydrogen-powered aircraft technologies for either propulsive or non-propulsive energy systems before deploying them in real time. Simulating advanced 3D data models with real-time insights enables them to redefine new and existing aircraft architecture and safely accommodate their adoption of fuel cell-electric systems.

Companies can further utilize the Virtual Twin Experience to test, verify and validate the resilience of aircraft materials and designs.

The same solution can also help them accurately verify the safety, efficiency and performance of hydrogen aircraft designs and systems at all scales before taking them to production. This way, they can upskill operators in a safe environment while minimizing the risks of upscaling to new technologies.

Besides accelerating hydrogen aircraft design, the platform also enables companies to improve daily operations. Companies can easily optimize the supply chain and airport operation while accelerating hydrogen technology adoption and aviation decarbonization efforts at the same time.

With the right digital support, the aviation industry's vision for a carbon-neutral future can become a reality.

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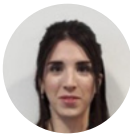

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