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Designing Hydrogen Tank Systems Holistically and Safely

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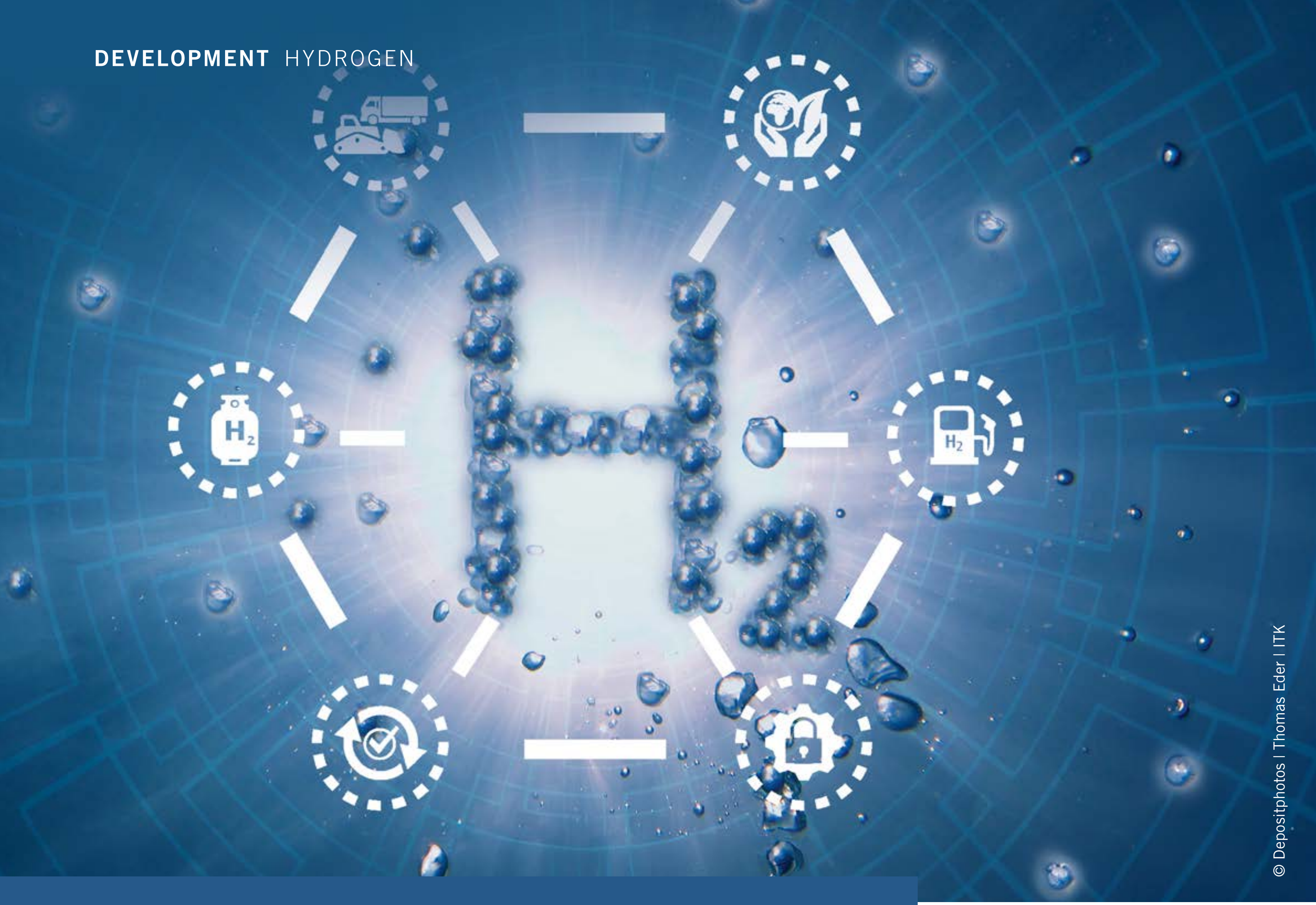

Designing Hydrogen Tank Systems Holistically and Safely

Hydrogen plays a key role in the energy transition, since battery-electric drives are not ideally suited for all areas. This applies to commercial vehicles and operating machinery in particular. The safe storage and controlled release of the highly flammable gas as well as the refueling process represent enormous challenges in the design of the hydrogen tank system. ITK Engineering shows how to optimally develop safety concepts for hydrogen tank systems.

Electric power is clearly the driving force in vehicles' transition to renewables energy sources. However, successful decarbonization requires more than just this one pillar. The use of hydrogen (H_2) therefore plays a major role and contributes to the distribution of the energy transition in transport across several energy support pillars.

H_2 technologies will have to provide an alternative and complement to electrification in the mobility sector. Fuel cells and internal combustion engines have their place with each serving different purposes: One delivers highly efficient performance at steady loads, the other robust performance at varying loads.

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No matter which of the two H_2 technologies is being utilized, the fuel path in front of the respective consumer is virtually technologically decoupled from it. This means that a fuel-cell-powered vehicle's H_2 tank system is very similar to that of an H_2 internal combustion engine vehicle. This holds true for both automotive and machine use cases. The tank's purpose can be limited to three fundamental functions: supporting the refueling process, safely storing H_2, and delivering H_2 on demand.

THE H_2 SAFETY CONCEPT

The safe handling of H_2 is a key challenge in order to utilize or prevent the chemical reaction with oxygen in a controlled manner. The aim is to utilize the resulting energy of this reaction under controlled conditions for the generation of electrical energy or for mechanical work. Any uncontrolled escape of H_2 from the tank system can have dire consequences.

The procedure for designing and commissioning an H_2 tank system is much the same as for a software application. It encompasses all aspects of development from conceptualization to implementation and testing, **FIGURE 1**.

In this context, ITK Engineering distinguishes between two types of safety: product safety and functional safety, **FIGURE 2**. To minimize risks, it is advisable to create a safety concept for the H_2 tank system that factors design, technical/functional, and organizational aspects.

Product safety is mainly about the system's structural safety in terms of wall thickness, housings to protect components, and specifications for mechanical tests. Safety requirements are usually dictated by specific Regulations, Codes, and Standards (RCS), but engineers also conduct a risk assessment to determine further safety measures.

Functional safety, as a subset of product safety, addresses the hazards associated with failing or malfunctioning Electrical and Electronic (EE) systems. Functional safety guidelines do not typically impose specific requirements on the system. Instead, they describe or specify a process to be followed. Engineers comply by making the appropriate adjustments to the system. Often, they must modify the system's architecture – for example, by adding pressure or temperature sensors and additional actuators such as valves – to bring it in line with functional safety specifications.

Another functional safety task is to monitor electrical components to detect failures and hazardous malfunctions and trigger a suitable response to protect the system and people from hazards and harm.

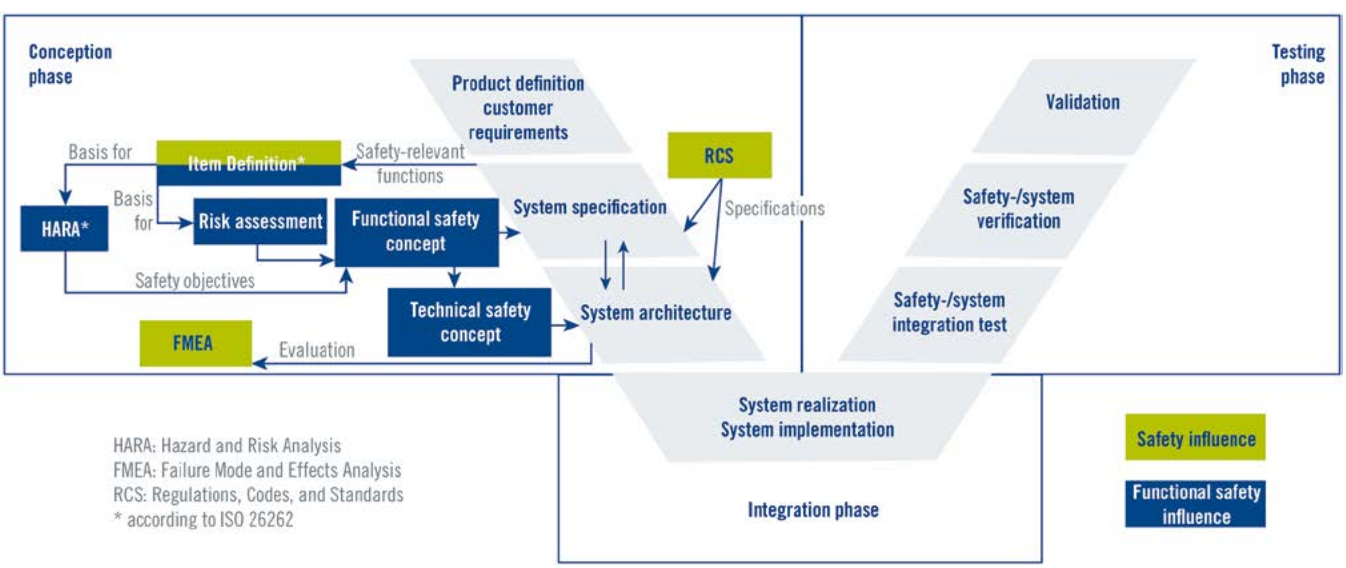

FIGURE 1 System V-model augmented with product safety and functional safety stages (© ITK Engineering GmbH)

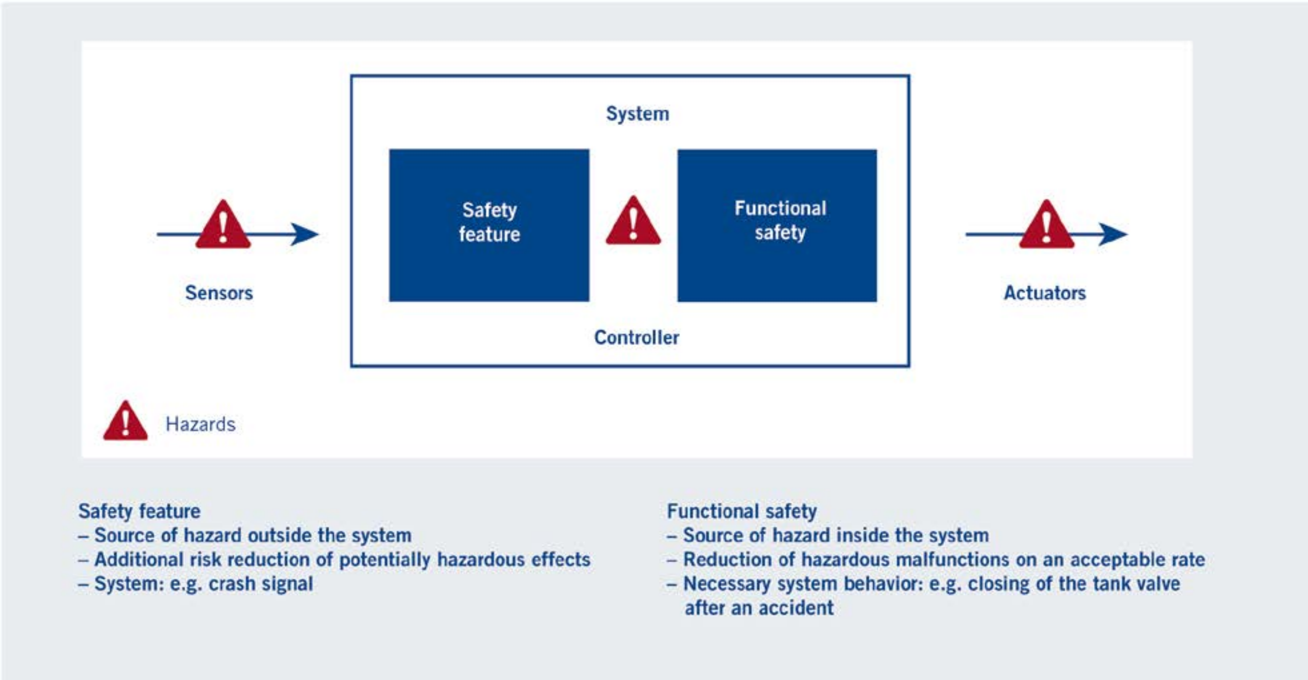

FIGURE 2 Distinctions between safety and functional safety hazards can be made by the system itself or by sensors and actuators (© ITK Engineering GmbH)

When engineers draft a functional safety concept, they base it on two points of reference – for one, the ISO 26262 item definition; for the other, a Hazard and Risk Analysis (HARA) that leads to safety objectives and the associated hazard level for the H_2 tank system, **FIGURE 1**. This results in safety goals such as these:

- prevent the formation of a hazardous, potentially explosive atmosphere
- monitor the system's operating parameters (pressure, temperature) to prevent damage that could cause a leak
- detect concentrations of H_2 outside the tanks and pipes caused by leaks
- shut down the tank system in the event of a crash or other accident scenario that could damage its components.

Engineers also examine the tank system's architecture, conducting a Failure Mode and Effects Analysis (FMEA) to assess all components and interfaces' physical and electrical properties. The functional safety concept is used to develop a strategy for achieving the safety goals. The technical safety concept includes the safety requirements and specifications for implementation in the tank system's architecture. It specifies how to put the technical safety concept into practice by defining technical data for components, such as signal sampling rates and response times. Reviews, simulations, and detailed testing procedures serve to verify both safety concepts.

In addition to the design and technical-functional aspects described, organizational measures are also derived, including the user instructions, special training, operating manuals, labels for critical parts or points of the system, and definitionof test cycles and procedures. The result of their efforts is an overall safety concept for the H_2 tank system, and a system architecture comprised of the components depicted in **FIGURE 3**.

An H_2 tank system electronic control unit is responsible for:

- monitoring and analyzing multiple pressure, temperature, and H_2 concentration sensors at defined points in the tank system and in the vehicle
- controlling and monitoring valves that release the flow of H_2 from the tank to the engine
- managing the BUS communication with other control units in the vehicle system, the filling station, and a display and operating display.

In addition, a pressure regulator, which reduces the H_2 pressure from the high to the medium pressure range before the H_2 is delivered to the engine, is part of the tank system. Also, mechanical pressure relief valves are installed at various points in the tank system.

Integrating the tank controller into the overall system is no trivial task. Getting the sensors connected to signal and communicate properly with the overall system is essential to controlling the actuators. The complex nature of this task dictates that it can be done in stages by a seasoned applications engineer who understands the system and knows how to handle specialized application tools. The final integration is verified and documented in tests covering the entire range of functions. Every sensor or actuator adjustment and software modification requires retesting.

CROSS-DOMAIN INTERPRETATION OF RCS

As already mentioned, the regulations and standards for the given industries provide the foundation for developing and promoting innovative H_2 solutions. This ensures that H_2 is used in a compliant, safe, and efficient way. But how can they be applied across domains?

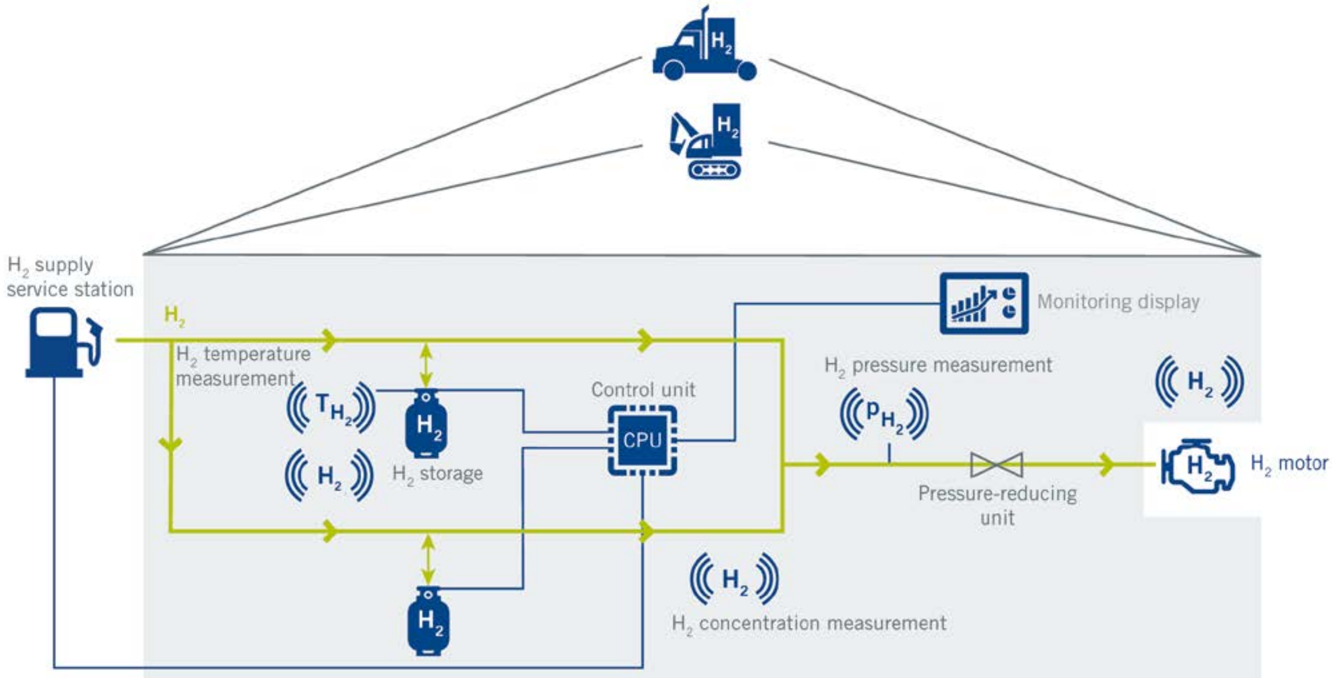

FIGURE 3 Diagram showing the flow of H_2 (green) and the tank system's control and monitoring signal path (blue) (© ITK Engineering GmbH)

The following two RCS are essential to road vehicles (automotive):
– UNECE R134: hydrogen-fueled vehicles
– ISO 26262: road vehicles – functional safety.

The priority for offhighway vehicles such as tracked construction equipment is different – the focus here is more on using the machine rather than driving the vehicle. The most pertinent RCS for this use case include:
– 2006/42/EG: machinery directive
– 2014/68/EU: pressure equipment directive
– DIN EN ISO 12100: safety of machinery, general principles for design, risk assessment, and risk reduction
– DIN EN ISO 13849-1 and -2: safety of machinery, safety-related parts of control systems.

Vehicles and mobile machinery have much in common, so there are bound to be similarities in the safety measures to be taken for their H_2 tank systems. For example, detecting H_2 leaks and protecting the tank from excess pressure and temperatures is imperative for both use cases. As a result, a part of the safety concept can be transferred from one domain to another. Automotive Safety Integrity Level (ASIL) on the vehicle side and Performance Level (PL) on the machine side can be used for this purpose. If the arguments for this transfer are persuasive, it can certainly cut development costs.

CASE STUDY: H_2 COMBUSTION ENGINE

The H_2 combustion engine WaVe project is a case study in how to develop and

FIGURE 4 The four upright H_2 pressure tanks installed in the body of the Unimog road vehicle (© Daimler Truck AG)

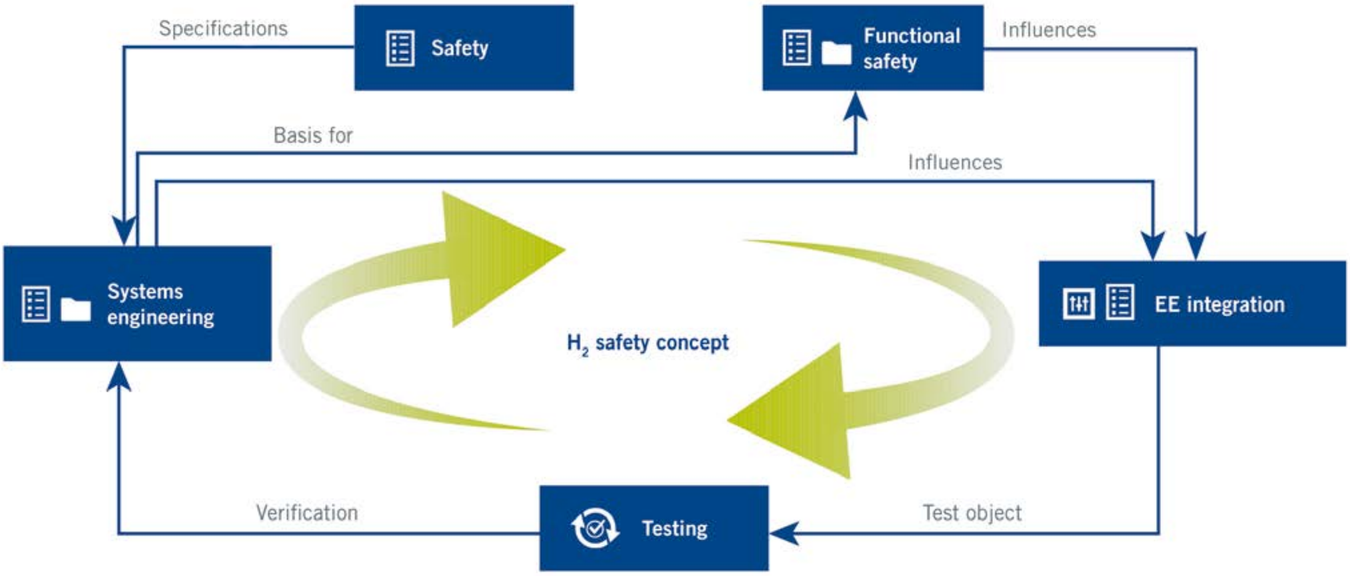

FIGURE 5 Interdependencies of individual disciplines when developing an H_2 safety concept (© ITK Engineering GmbH)

transfer a safety concept as described above. It proved the viability and merits of this procedure by successfully porting a safety concept from a Unimog prototype to a tracked vehicle, **FIGURE 4**. ITK Engineering joined forces with partners in business and industry to develop an H_2-based propulsion system for medium-duty commercial vehicles. This initiative is part of WaVe, a joint project funded by the German Federal Ministry of Economic Affairs and Climate Action. To kick off the project, the team members first defined the basic work products for the automotive and machine use cases. They then determined the requirements, conducted safety analyses, and spelled out the measures to be taken for the road vehicle. The next step was to transfer these results to the machine use case by means of delta analyses. The safety concept takes into account the requirements arising from the differences in the two vehicles' purposes and architectures. Its transfer from one use case to the other boosts efficiency in development and provides the underpinning for further vehicle spin-offs and other use cases. The result: Tailored to suit each vehicle during the conceptualization phase, this safety concept serves as basis for the integration phase.

INTERDISCIPLINARY COLLABORATION

H_2 technology is going to be a key enabler for the transportation sector's transformation. Demand for H_2-fueled vehicles is likely to grow as H_2 infrastructure takes root and branches out. Companies are gearing up to meet this demand by designing systems; others are already building prototypes. The future of H_2-powered vehicles hinges on engineers'ability to develop and deliver advanced, safe refueling systems. This requires close interdisciplinary collaboration between experts in systems engineering, safety, functionalsafety, and testing, **FIGURE 5.** These teams apply various processes and analytics methods based on applicable standards and regulations to create, document, and implement a high-quality H_2 safety concept in software and hardware, and then verify and validate the system in tests. The interdisciplinary approach minimizes the safety risk associated with H_2 use cases. Once the system's safety is assured, nothing stands in the way of H_2 seeing widespread use in the mobile sector.

IMPRINT
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ITK Engineering

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