PUBLIC

Green Proof for Hydrogen and Derivates

Digital Solutions to support certification

Author:

Leon Bachmann

With contributions from:

Peter Koop

Peter Schlemmer

Klaus Schimmer

Yan Yan Achdiansyah

Table of contents

Table of Figures

This report has been developed as part of the H2Uppp cooperation project with GIZ. The International Hydrogen Ramp-up Programme (H2Uppp) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) promotes projects and market development for green hydrogen in selected developing and emerging countries as part of the National Hydrogen Strategy.

Executive Summary

The relevance of green hydrogen is driven by six perspectives: environmental, political, economic, social, technological, and legal. Green hydrogen is crucial for reducing greenhouse gas emissions, particularly from hard-to-abate industries, which account for around 30% of global emissions. Political incentives and agreements, such as the Paris Agreement, have set decarbonization targets, leading 38 countries to announce hydrogen strategies. Economically speaking, rising energy costs, and fluctuating fossil fuel prices have created opportunities for investing in green hydrogen as a more secure and sustainable alternative.

In terms of market growth, the green hydrogen market is in its early stages. By 2030, green hydrogen is expected to account for around 60% of low-carbon hydrogen, rising to 65% by 2050. From a societal point of view, corporate and consumer demand for sustainability is driving the transition from fossil hydrogen to green hydrogen. Technological advancements in renewable energy and electrolysis have made green hydrogen more cost competitive.

Legal frameworks such as the European Emissions Trading Scheme and the Renewable Energy Directives are pushing the development of a green hydrogen market. Certification for low-emission hydrogen is necessary for companies to claim lower emissions and avoid surrendering emission allowances and paying carbon taxes. And of course, in the first place to have a an agreed upon process that demonstrates that the hydrogen really has the certain characteristics (e.g., low-carbon or "green").

The report discusses the role of various actors in the green hydrogen certification process and the necessity of digital solutions for improving data accuracy, accountability, and automation in the hydrogen certification process. Several software requirements are derived from the analysis of certification schemes, emphasizing the need for a comprehensive software architecture for managing the green hydrogen value chain.

The report also proposes an architecture for digital business applications that includes Sustainability Reporting, Supply Chain Transparency and Mass Balancing, Sustainability Data Exchange, Sustainability Footprint Management, Environment, Health, and Safety Management, and Intelligent Asset Management. These components aid in calculating and managing greenhouse gas emissions, ensuring traceability and transparency, sharing sustainability data securely, managing environmental, health, and safety-related activities, and optimizing asset performance.

Relevance

This chapter summarizes the most important drivers for the relevance of green hydrogen based on six perspectives. These drivers are the basis for this report and describe the initial need for digital solutions. The report prepared by Fichtner and GIZ, which examines the detailed requirements and process flows of various certification systems with the title „In-Depth Analysis of Green Hydrogen Certification Processes in the EU. Advisory Report as Guidance for the Development of Digital Solutions“, makes up the second basis for the digital solution proposal in this report.

Environmental

The hard to abate industries account for around 30% of world greenhouse gas emissions.[1] Furthermore, emissions from transportation are 16% of total world greenhouse gas emissions.[2] These emissions affect climate change and impact business activity and the economy in general. This is why reducing the emissions of the hard to abate industries is a priority in countries and regions.

Political

Cross-national political agreements such as the Paris Agreement have set decarbonization targets in almost all countries. Around 200 countries have committed to reducing their emissions. Hydrogen has enormous potential for the decarbonization of hard-to-decarbonize sectors such as heavy industry, shipping, and aviation. In addition, there are numerous incentives and government support for the development of green or low-carbon hydrogen, e.g., in the EU, Japan, Australia, and the US. As a result, hydrogen strategies have been announced in 38 countries, such as the EU Hydrogen Strategy, the Japanese Basic Hydrogen Strategy, the Australian National Hydrogen Strategy, etc.

Figure 1: Geographical perspective of hydrogen projects[3]

[1] https://www.energy-transitions.org/publications/mission-possible/#download-form
[2] https://www.weforum.org/press/2023/11/net-zero-industry-tracker-13-5-trillion-investment-needed-to-fast-track-decarbonization-of-key-hard-to-abate-industry-sectors/
[3] IEA Hydrogen Project Database

Economical

Energy costs are rising significantly due to fluctuation, CO2 taxes, price fluctuations in fossil fuels, and challenges in the supply chain. For example, in the last 3 years, the electricity price in Europe rose around 35%. At the same time the gas price increased significantly (around 85%)[4]. This creates economic opportunities to invest in sustainable activities like the production or the switch to green hydrogen, not only from an economic perspective, but also from a risk management perspective. Alternatives to replace fossil fuels with higher energy security such as green hydrogen need to be found. Companies need to find solutions to reduce their emissions to avoid high carbon costs, and one of the key solutions is the use of green hydrogen for hard to abate industries.

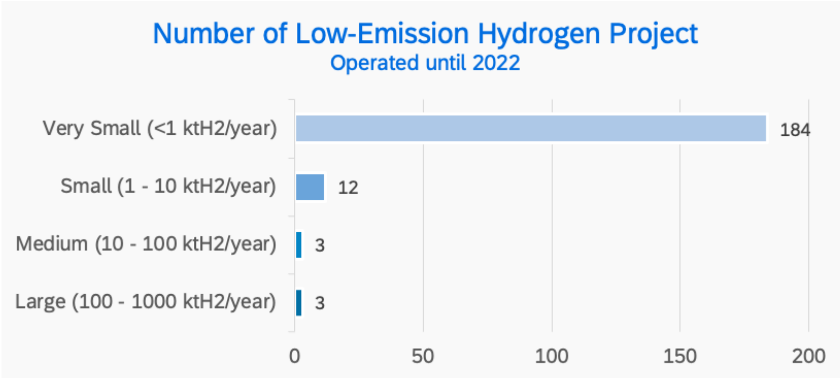

Figure 2: Hydrogen projects by their size

Currently, the cost of producing blue hydrogen is lower than green hydrogen in most parts of the world with blue hydrogen costs around \$1.8 - \$4.7/kg while green hydrogen costs being around \$4.5 -\$12/kg[5]. However, recent policy initiatives (such as the Inflation Reduction Act in the US and H2Global with contracts for difference) and higher natural gas prices in Europe and Asia have reduced this cost advantage. Assuming ambitious climate policies, green hydrogen will account for around 60% of low-carbon hydrogen in 2030, rising to around 65% by 2050.

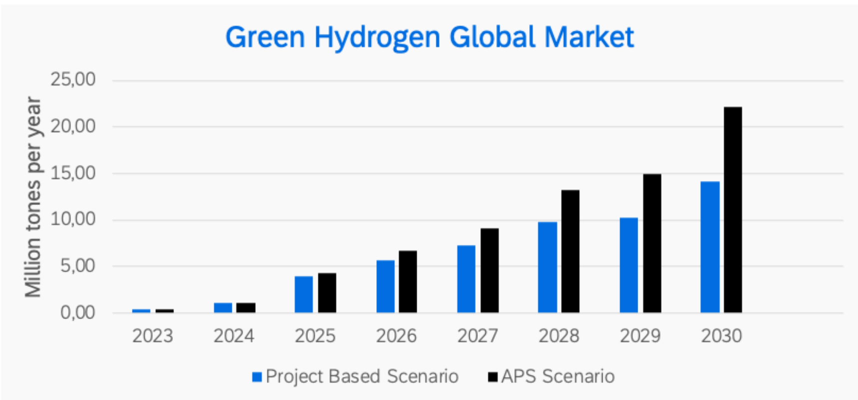

Figure 3: Outcome of Hydrogen projects predicted per year

---

[4] European Union, 2023, Electricity and gas prices stabilize in 2023.
https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20231026-1
[5] Bloomberg NEF, 2023, Green hydrogen to undercat grey sibling by the end of decade
https://about.bnef.com/blog/green-hydrogen-to-undercut-gray-sibling-by-end-of-decade/#:~:text=Blue%20hydrogen%2C%20or%20hydrogen%20produced,%244.5%2D%2412%20per%20kilo.

The nature of the hydrogen trade is likely to vary depending on the end use. For industrial use or road transportation, hydrogen is likely to be imported via pipelines from regional markets due to the high cost of transporting pure hydrogen. On the other hand, hydrogen derivatives such as ammonia and methanol will be transported by other means and at lower cost.

The green hydrogen market is still in a very early stage, as shown in figure 3. Until 2022, there are 13201[6] announced green hydrogen projects, including operated projects and future projects. The greatest number of green hydrogen plants are in Australia and Europe in 2022. However, the average size of these projects is considered as very small as shown in figure 2.

The global hydrogen market will reach 130 million tons per year in 2030 based the IEA Announced Pledges Scenario (APS)[7] including 25% low-emission hydrogen. 65% of low-emission hydrogen market will be covered by green hydrogen or electrolysis-based hydrogen with 22 million tons per year. Based on the Project Based Scenario[8], half of the green hydrogen will be produced in Europe and Australia.

Social

Business customers choose and buy based on sustainability criteria that is aligned with corporate and regional decarbonization targets, particularly in the energy and utilities sector. Consumer demand for sustainable products is therefore passed along the value chains. Companies must meet customer demands for sustainability if they want to follow the trend and mitigate risk. Both customers and end users are demanding tamper-proof certification for the reduction of emissions using green hydrogen. This is why products that contain hydrogen and its derivatives as a resource or as an energy source must be converted from grey hydrogen to green hydrogen.

Technological

There is a great advancement of renewable energy over the past years that increases the efficiency and decreases the cost of green electricity. Levelized Cost of Electricity (LCOE) of renewable energy has been decreased in the last 10 years and the price of wind and solar PV is lower than the price of fossil fuel.

Lowering the cost of electricity from renewable energy makes green hydrogen from electrolysis more cost competitive. Improvements in electrolysis and fuel cell technology increases efficiency and expands the range of hydrogen applications. Hydrogen as a fuel can be used in many applications such as transportation, industry, and power which help all those sectors to be decarbonized.

[6] Based on IEA Green Hydrogen Project Database
[7] The IEA Announced Pledges Scenario (APS) is scenario with the assumption that all climate commitments made by governments around the world, including Nationally Determined Contributions and longer-term net zero targets, will be met in full and on time.
Source: IEA Report: Global Hydrogen Review 2022, IEA Hydrogen Project Database; IRENA; Energy Monitor
[8] Project based scenario is a scenario based on the announced project that disclosed start year for operation are included in the IEA hydrogen project database.

Legal

There are several legal requirements that are driving the development of a market for green hydrogen. One is the European Emissions Trading Scheme, which limits the amount of carbon emitted by providing companies with a limited number of emission allowances. Another example is the Renewable Energy Directives, which set rules for renewable fuels of non-biological origin (RFNBO) such as hydrogen, which are categorized as renewable origin.

Companies will reduce emissions from their operations by finding alternative solutions, such as replacing fossil fuels with low-emission hydrogen fuels. They will also need to be certified for low-emission hydrogen in order to claim that the hydrogen they use has lower emissions, thus avoiding the surrender of emission allowances and the payment of further carbon taxes.

These legal requirements and implications are to be met with a larger certification framework, which is described in detail in the report presented by Fichtner and GIZ. The foundations and actors of this certification framework are described in the following chapters.

Certification Actors

"Issuing certificates for green PtX products requires going through a variety of processes that involve various elements. Recognising the importance of each element does not only help to navigate a complicated web of relationships, but also enables a more informed decision-making process."[9]

Figure 4 provides an overview of various key certification actors in the EU, their positions, and their relevance within the certification ecosystem. In a variety of cases the key driver for a certification scheme, issued and held by a scheme owner, is the regulatory framework which e.g., is set by EU commission or a country specific law. The certification body aims to ensure and assess that the requirements are met by the market participants e.g., a hydrogen producing company. The accreditation body is then in charge of ensuring that the certification body has the right competences to perform the assessment.

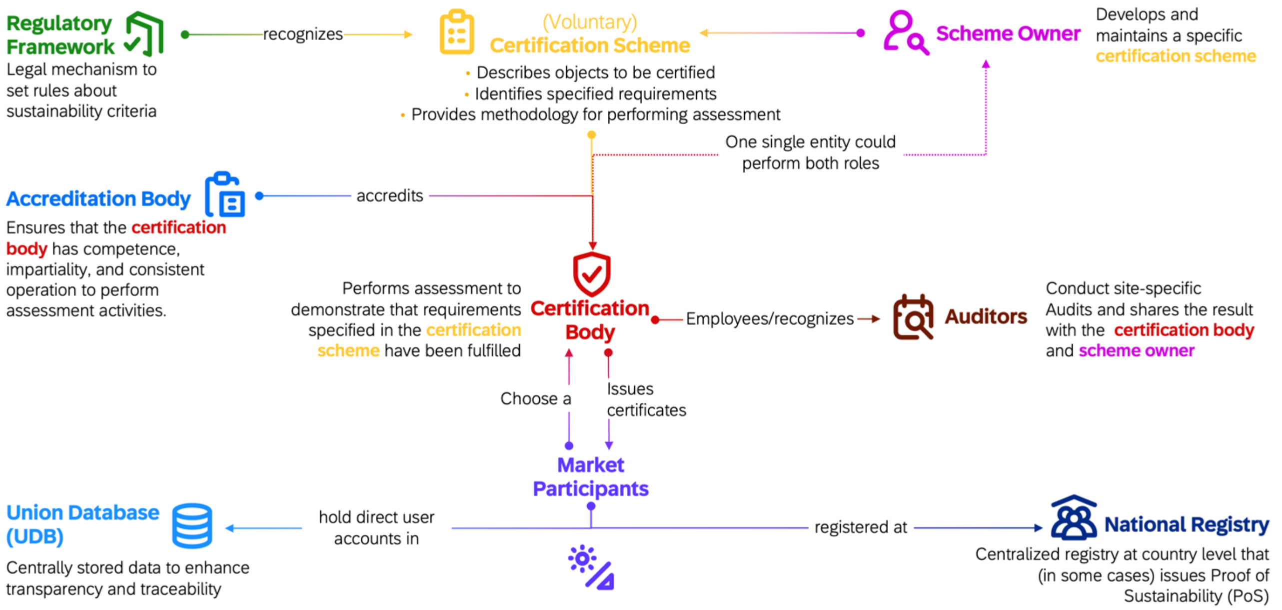

Figure 4: Relevant Actors and their relation and functions[4]

Certification bodies mostly rely on their contracted site-specific auditors that perform audits and share the results with the certification body and scheme owner. The framework for green hydrogen certification is sometimes accomplished with a union database for central transparency and sometimes a national registry.[10]

The number of relevant actors for the certification but also along the value chain with the various market participants results into a high complexity where multiple sets of data have to be shared and securely stored in local and central databases. Especially for hydrogen derivates another key challenge are the complex value chains.

---

[9] Fichtner, GIZ: An In-depth Analysis of Green H2 Certification

[10] For more, general info on certification, find publications here:
International-PtX-Hub_202305_Certification-for-green-hydrogen-and-PtX.pdf
Hydrogen Certification 101 - PtX Hub (ptx-hub.org)

Business Requirements and Digital Solutions

The market ramp-up of green hydrogen must be accompanied by digitalization, which serves as a key catalyst for the progress of the market and the standardization. Digitalization improves data accuracy and accountability, promoting a safe, efficient, and environmentally sustainable hydrogen system using data-based digital tools such as tokens and blockchain technology. Increased accountability through digitalization prevents data manipulation, strengthens stakeholder trust, and promotes security. A major advantage of digitalization is its ability to automate. The resulting scalability speeds up the hydrogen certification process, making it timelier and more cost-efficient. It also improves communication and collaboration between the stakeholders involved.

In summary, digitalization can serve as an important driver for the market ramp-up of green hydrogen. By improving accuracy, accountability, automation, scalability, safety and collaboration, digitalization supports the successful establishment of the hydrogen economy and the transition to a sustainable energy future. It plays a crucial role in ensuring that hydrogen systems remain safe, efficient, and reliable, and in monitoring the environmental impact of hydrogen production and use. Of course, it goes without saying that not everything can be fully automated, and that digitalization will not replace audits. Inspecting production sites and measuring equipment, checking processes and procedures is the basis for ensuring that the data entered or uploaded to the digital tools is correct.[11]

Software Requirements derived from the Certification Analysis

As already mentioned above, this report builds on a detailed analysis of the certification mechanism and schemes researched and written by Fichtner and GIZ with the title „In-Depth Analysis of Green Hydrogen Certification Processes in the EU. Advisory Report as Guidance for the Development of Digital Solutions". It will be in the follwing referred to as „Green H2 Certification Report". In this section these results are being translated into software requirements that will then serve as a basis for the solution proposals written below. Fichtner´s report highlights 3 certification schemes: CertifHy™ Scheme, TÜV Rheinland Standard H2.21, ISCC PLUS.

Derived Software Requirements from CertifHy™

CertifHy™ has developed two different certification schemes. The 'CertifHy™ Scheme' 16 is a GoO system that issues 'CertifHy™ certificates', and the 'CertifHy™ Voluntary Scheme' 17 is a PoS system that issues 'CertifHy™ RFNBO certificates'. The CertifHy™ Voluntary Scheme is not yet publicly available, which is why the Green H2 Certification Report focused on the CertifHy™™ Scheme for H2 GoO.

The CertifHy™ scheme requires the calculation of the product carbon footprint in accordance with ISO 14044 and 14067 and uses book and claim as the preferred chain of custody model. The underlying certificate tracking model must ensure that no certificate can be duplicated. The system includes different types of renewable electricity sources and requires greenhouse gas emissions to be considered for the calculation of the PCF.

[11] https://files.h2-global.de/H2Global-Stiftung-Policy-Brief-05_2023-EN.pdf

The information required for certification mainly relates to the electricity sources, the production facilities, and the production batches. Data is required on the type of electricity, the carbon footprint, the origin, the emission factors of substances constituting inputs and the share of renewable energy, e.g., by submitting a consumption declaration. In addition, proof of participation in a guarantee of origin system for gas or electricity is mandatory. The system requires detailed information on the production plant, as well as on changes to the plant and operating details such as fuel type and technology. Moreover, information about the production process itself is required. This includes measurement data on hydrogen output and energy input, including accuracy data. The information required for the production batches includes the quantity produced, the start and end dates and an audit trail. In addition to the production itself, data on emissions from waste, by-products and wastewater treatment is also required.

Derived Software Requirements from TÜV Rheinland Standard H2.21

TÜV Rheinland Standard H2.21 requires a Product Carbon Footprint Calculation according to RED II GHG methodology. Third-party verification of the PCF calculation must be possible. The emissions data used must contain data for CO2, CH4, N2O, HFCs, PFCs and SF6 (quantity, type, conversion to global warming potential). The emissions must also include upstream emissions from purchased goods. This includes data on other inputs (e.g., nitrogen) and their carbon footprint and energy consumption, as well as evidence of the CO2 source (if applicable). If emission factors and conversion factors are used, these must be stated, and the source must be made transparent.

The footprint includes Scope 1 and Scope 2 emissions from production as far as these are also covered by the RED II GHG methodology. The energy sources must have a green electricity certificate, a guarantee of origin or a PPA. TÜV Rheinland's certification system requires to meet the criteria for temporal and geographical correlation specified for the RFNBO category. In addition, the bidding zone of the electricity and the location of electrolysis production must be specified. Along with these, proof of additionality is required for batches produced after 01.10.2028. Facilities located in a bidding zone where the emission intensity of electricity is lower than 18 g CO2-eq/MJel do not have to demonstrate additionality. Furthermore, a temporal connection between the RFNBO (in this case the green hydrogen) and the generation of electricity from renewable energies must be proven.

ISCC Plus

The Green H2 Certification Report analyzed the ISCC PLUS with GHG Emissions Add-On. However, at the time this report was prepared, the ISCC methodology only covered the calculation of GHG emissions from biomass fuels, bioliquids and biofuels. ISCC methodology requires calculated values from a LCA which is based on an ISO 14040/44 or ISO 14067 and differentiates from the ISCC methodology need to be communicated separately and cannot be used to replace a GHG calculation based on the ISCC methodology. (see Green H2 Certification Report p. 25). It allows three tracking methods: mass balancing, physical separation, and controlled blending. The following information is required for mass balancing: Quantities of certified and non-certified materials, timeframes, individual site details, sustainability characteristics, and records of incoming and outgoing sustainable materials.

In addition, information must be available on organizational processes, subcontracting, management of service providers, and quality management systems. Evidence of transparency in reporting is also required. Relationships with stakeholders, handling of conflicts of interest, and anti-corruption measures, as well as information on the yield or conversion factors of internal processes, individual calculations of greenhouse gas emissions (if applicable), and certification history. Emission factors must also be transparent, this includes providing sources and years of publication. Material transparency must be broken down into quantities of certified and non-certified materials and transparent sustainability figures from sustainability declarations must be available once the production device has been certified. These should provide information on the sustainable share of each product.

Along with the above, records of electricity consumption in electrolysis processes must be available for the production process. For suppliers, the name and address of the supplier and the recipient with the corresponding contract number should also be presented. In addition, the shipping date, the address of the shipping point and the supplier's certificate number as well as the unique number of the sustainability declaration with product details (type, quantity, raw material) and information on the chain of custody option and "ISCC Compliant" declaration must be given.

Summary of Requirements from the three schemes

The requirements from the certification schemes presented in the three sections above are summarized in figure 5. Most of the certificate follow a footprint calculation methodology that is either derived from ISO 14067 or RED II directive or GHG Protocol. The schemes focus on direct GHG emissions and partly include indirect GHG emissions. There is a big difference in the applied tracking models and the proof for the primary energy sourcing. However, there is common agreement in the requirement to have a solid proof for green energy as well as a tracking model that prevents double counting. For proof as RFNBO, mass balancing must be used as the chain of custody model. Book and claim is used for GoO H2 certificates.

All three schemes require a clear indication for the renewable energy source, sometimes using Power Purchase Agreements (PPA´s) or Guarantees Of Origin (GoO). Another data set is required regarding the production of green hydrogen. First, regarding the production time and location which is sometimes also used to map different bidding zones. All schemes require details about the production device itself, the technology of operations, as well as modifications on the production device. Additionally, detailed measurement not only for the energy consumption but also for the hydrogen output is key to achieving certified hydrogen. The information on the production must be then combined in data sets for production batches that include amounts produced, start and end time, bidding zone, and various other information that is individual to the specific certificates.

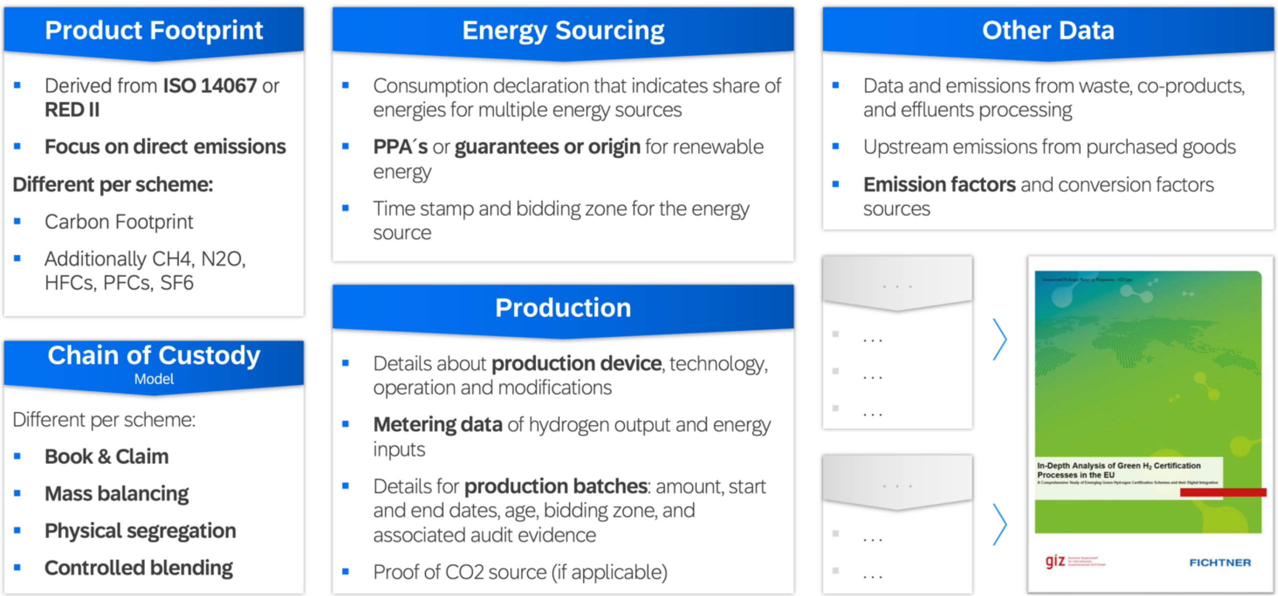

Figure 5: Summary of certification scheme requirements

Business Architecture

The requirements from business as well as certification translate into a comprehensive software architecture that significantly supports the green proof for hydrogen and other PtX products. This generalized architecture is shown in figure 6. The foundation of this architecture lays in the combination of a footprint management system with the so-called Enterprise Resource Management. These two serve especially the need of a calculated footprint in accordance with given standards, as well as the production batch data. These are two key data sets for the certification as described above. The footprint management must incorporate given standards and be open to different approaches for calculation e.g., via open access for various sources of emission factors and their databases and data providers. This solution also serves the mapping and combination of corporate footprint data with product footprint data and should include various sustainability footprint metrics besides CO2 or GHG emissions.

Especially companies that produce, trade, or use green hydrogen must report on different sustainability regulations and standards on a corporate level. That's where a solid Sustainability Reporting solution supports them significantly. But not only on the mandatory reporting, but also on the comparison between targets and actuals for various sustainability metrics in different regions and locations. Such a solution is key to achieve sustainability goals when producing green hydrogen.

The footprint management, as well as the reporting solutions pull together a complex and comprehensive set of data for each product and location. This data is partly stored in the company's own ERP system or provided by 3rd party data sources. Especially for e.g., raw materials and primary energy as it is being used a lot to produce green hydrogen. These data must be provided by the supplier of these products and materials. In this case a standardized mechanism to share sustainability data is key for ensuring the right data quality and preventing manual data exchange.

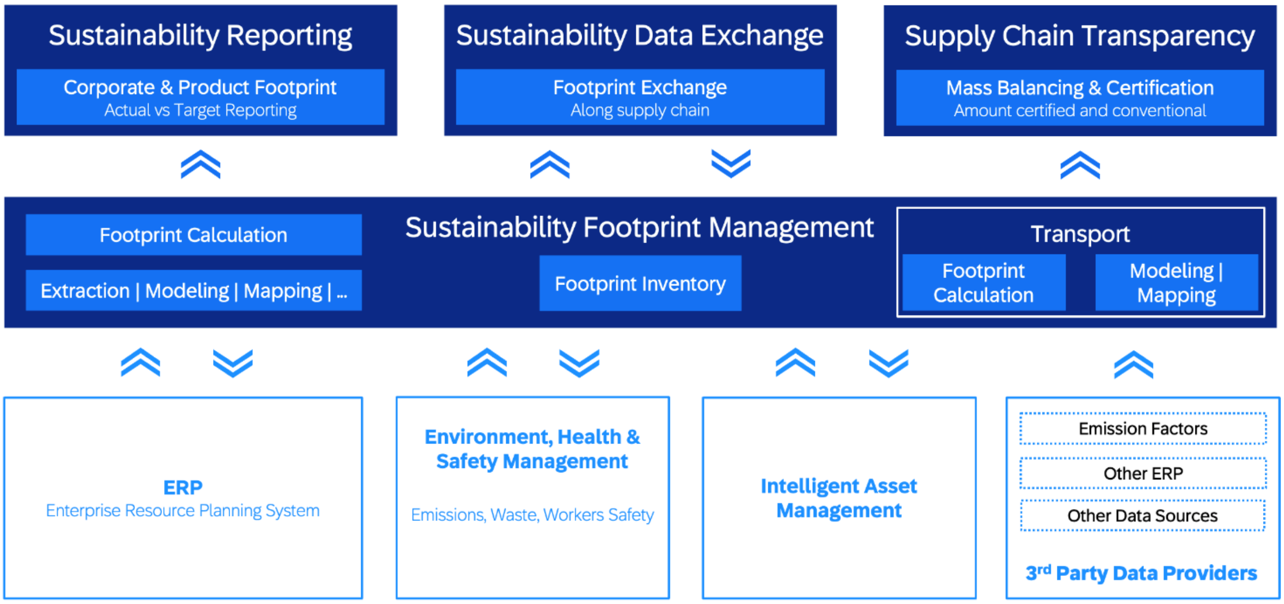

Figure 6: Simplified Software Architecture for Sustainability

The mass balancing and tracking along the value chain is one of the most important building blocks in a green hydrogen software landscape. This part is also responsible for tracking the certificates along the value chain and sharing it with relevant stakeholders. Lastly there are traditional software systems that are important for green hydrogen as well as for any other gas or energy carrier. These involve building blocks for workers' safety and health, as well as the management of assets in an intelligent manner. The sections below describe the building blocks shown in Figure 6 in greater detail.

Sustainability Reporting

Decarbonization to minimize the GHG (Greenhouse Gas) emissions and climate change forces industries to redesign their business strategies and processes. The GHG inventory, also named the Carbon Footprint, requires the analysis of sources of emissions, the collection of relevant data, and eventually implementing an effective GHG management system.

Sustainability reporting solutions such as SAP´s sustainability control tower are the center piece to get the actual emissions according to scope and asset. Providing the "corporate view" on GHG emissions, the status can be monitored, and measures derived. For green hydrogen and other PtX products this means that companies can capture their company carbon footprint in an intelligent manner. Information can be tracked based on one region or location and can be compared with their company set goals. This is not only essential for mandatory sustainability reporting but also for achieving the company's sustainability targets per region or location.

Supply Chain Transparency and Mass Balancing

Many organizations are setting ambitious objectives to transition to primarily certified sustainable material usage. Unfortunately, a lack of visibility beyond tier-1 supply chain partners and the continuous commingling and processing of raw materials and components limits organizations and supply chain networks to achieve traceability and transparency; hence slows down this transition. This is also crucial for the green hydrogen value chain where great parts of the carbon footprint might be caused by the suppliers of energy. Software like SAP´s Green Token, support their customers in creating, converting, and transferring so-called credits/tokens that represent a certain amount. For example, of green hydrogen:

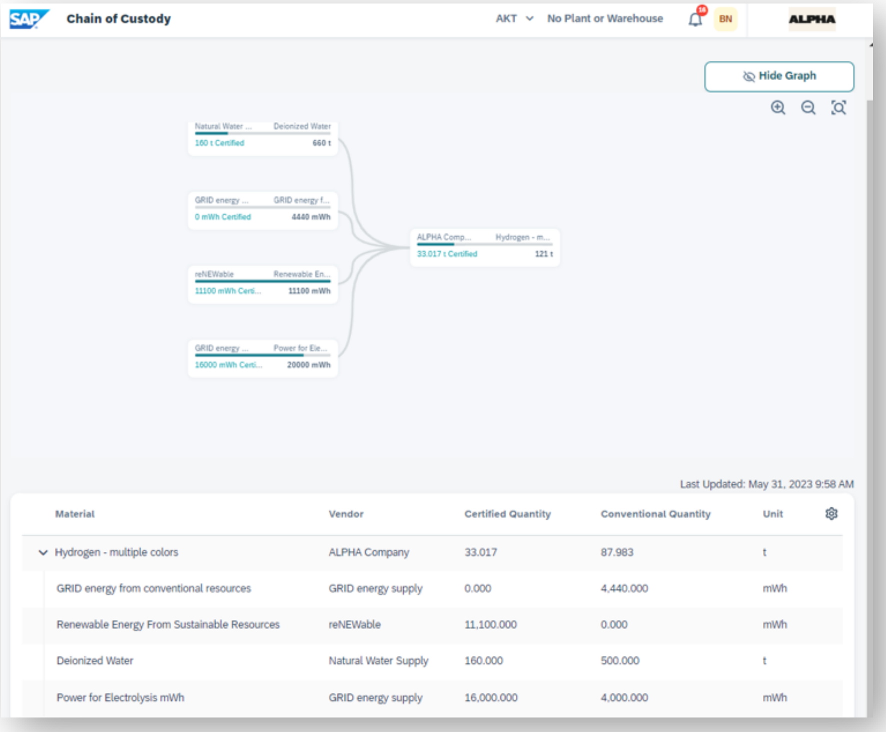

Figure 7: SAP Green Token

- **Inbound Flow:** Request and receive the transfer of credits and generate credits for certified material and assign attributes.
- **Conversion:** Configure credit conversions (input/outputs, yield loss, attributes) and allocate credits from received material to processed/manufactured products.
- **Transfer material credits:** Account for outgoing material credits and generate declarations and transfer credits and aggregated material attributes to business partners.

The Green Token solution combines the three innovative principles of mass balance, tokenization, and blockchain for chain of custody. Each token, representing a particular mass or energy content of hydrogen, carries multiple pieces of information (e.g., 60 different attributes). This enables a granular understanding of the hydrogen products' qualities at any point in the supply chain. It also results in billions of unique tokens when transporting large amounts of H2, NH3, or CH4. Token data is transferred between private blockchain wallets, representing physical locations, like production tanks, which ensures auditability and security.

Tokens allow differentiation between hydrogen products with varying environmental impact or different ESG data points. For instance, electrolysis-derived hydrogen with low CO2e emissions can achieve financial benefits in certain countries. The system also allows for a tailored approach to meet customer requirements, assigning specific percentages of green, blue, or grey tokens to different customers (just to use colors for ease of explanation). In an example, a green ammonia shipment from Australia mixes with grey ammonia in a Rotterdam tank.

Using SAP Green Token, the exact amount and specific qualities of green ammonia can be determined. Despite physical mixing, tokens allow digital distinction between the green and grey ammonia, promoting transparency and environmental consciousness.

- **Token:** A unique digital twin of the physical material capturing and tracing multi- facts attributes across the supply chain.
- **Blockchain:** An immutable and distributed ledger for validation layer for notarization and asset transfer.
- **Mass balancing:** Detailed accounting to facilitate traceability of commingled and continuously processed materials.

Sustainability Data Exchange

Controlling and mitigating scope 1 and 2 emissions is a challenging task for companies such as the ones that produce green hydrogen. However, these scopes are under control or in close control to the operation operating company.

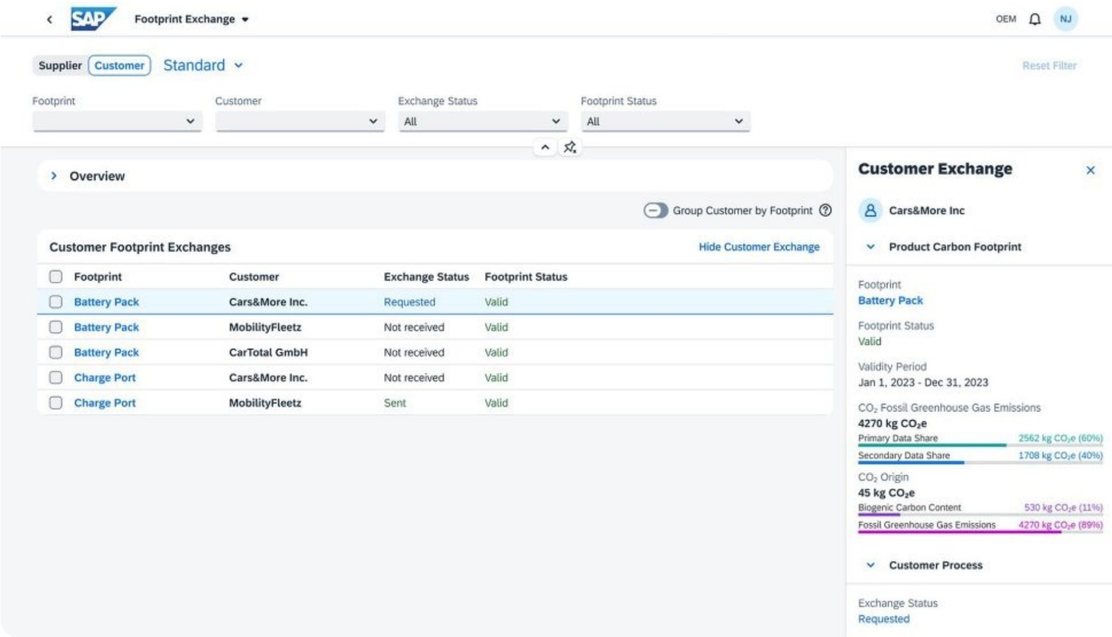

Figure 8: SAP Sustainability Data Exchange

Tackling scope 3 emissions not produced by the company or from the energy that has been used by these suppliers, is an even more complex matter. It is highly untransparent and out of control of the operating company. Collecting accurate data makes measuring and assessing these emissions difficult. And with different suppliers involved in the supply chain, there is no clarity on who exactly is accountable for reducing Scope 3 emissions. At the same time, the certificates for green hydrogen require transparent data about these emissions or at least of the carbon footprint of the used energy.

A great part of the problem is solved when sustainability data is standardized and shared securely. Built using the technical framework of GreenToken by SAP, SAP Sustainability Data Exchange allows sustainability data sharing within organizations and interoperability with other equivalent networks using WBCSD PACT standards. Companies can use SAP Sustainability Data Exchange along with SAP Sustainability Footprint Management, a single solution to calculate and manage the full range of corporate, value chain, and product greenhouse gas emissions. Alternatively, if businesses already have a solution that calculates carbon footprints effectively, they can use SAP Sustainability Data Exchange to share this data securely.

Sustainability Footprint Management

The footprint calculation is at the center of every green hydrogen certification process to ensure that hydrogen is green or low carbon. Footprint Management systems such as SAP´s Sustainability Footprint Management are designed to calculate different footprints at scale and make processes at the operating companies more efficient. Figure 9 provides a screenshot from SAP´s Sustainability Footprint Management using the example of cocoa bean production.

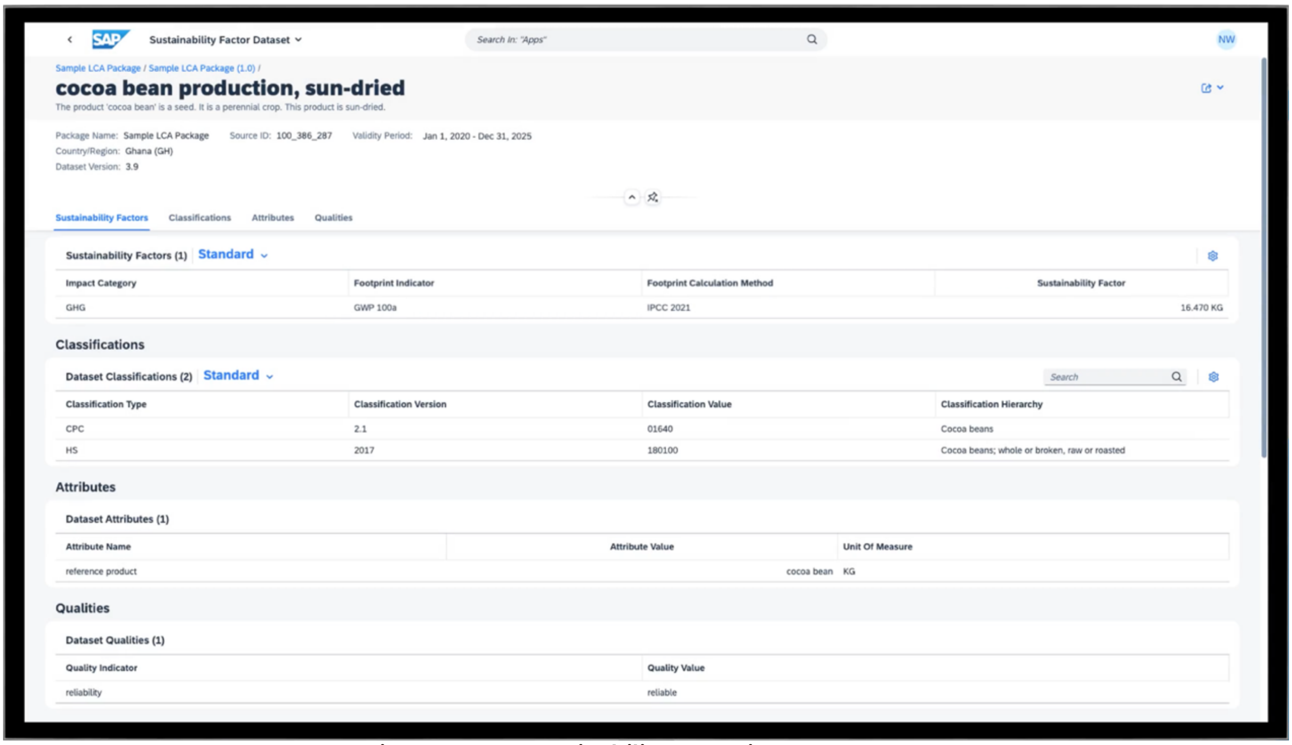

Figure 9: SAP Sustainability Footprint Management

Footprint management has four key values that enable the calculation of green hydrogen footprints and thus support green hydrogen certification processes. First, the integration of the companies ERP. Second, the emission factor management. In this regard companies can use industry averages from lifecycle assessment content providers, import footprints received directly from their suppliers, and map emission factors to business data with guided configuration.

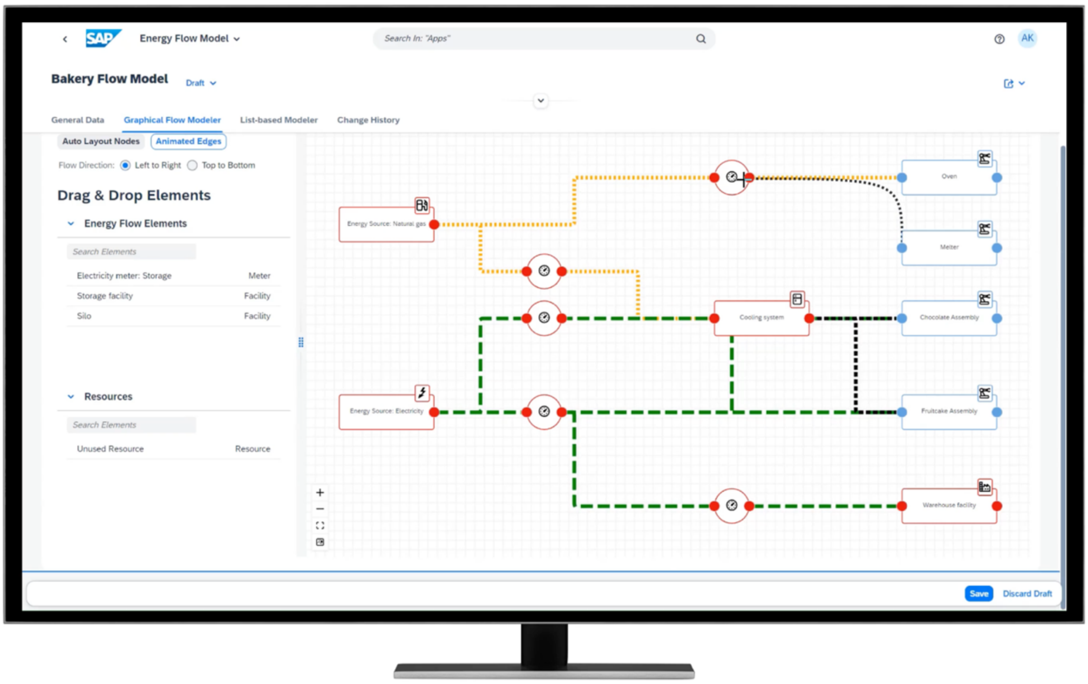

Figure 10: Energy Model in SAP´s Sustainability Footprint Management

Third, at the core of the system is the footprint calculation at scale. This lets companies calculate and monitor footprints in a graphical format, model the energy flow in their production line or facility, and manage inventory scopes and transport footprints. Last, the footprint analysis to gain full transparency and valuable insights across the company and value chain. This can be done in various dashboards, integrating footprint data into analytical applications via Application Programming Interfaces (APIs) or visualizing and analyzing all the transport routes and associated emissions on charts and maps.

Considering the hydrogen value chain there is one key element for the calculation of the green hydrogen footprint. That is the accurate modelling of energy flows in a production site including the metering. This scenario is shown in figure 10.

Ecosystem for hydrogen specific CO2 calculations

In addition to SAP solutions there are also partner solutions that support the whole certification process and more. Prologa Energy has built a cloud solution that calculates how much CO2e is on top of a mass of hydrogen that is produced in an electrolyser. This Cloud for Hydrogen Production and Supply Management uses time series of meters that measure the energy produced and consumed in 15 minutes intervals. These time series are stored in an SAP solution called Cloud for Energy.

From there, the data is used by the Cloud for Hydrogen Production and Supply Management and matched with the hydrogen produced in the same time interval. Buckets are created that consist of similar qualities (CO2e). The product management module of the Prologa Energy solution can then take a mass of hydrogen with specific CO2e attached, which is stored in various buckets, and create exactly the products that the customers want and/or the voluntary certification or mandatory regulation requires.

This data is then transferred to Green Token where tokens are created that represent a certain mass of hydrogen. On top of these tokens, attributes like CO2e can be stored and transported through the value chain.

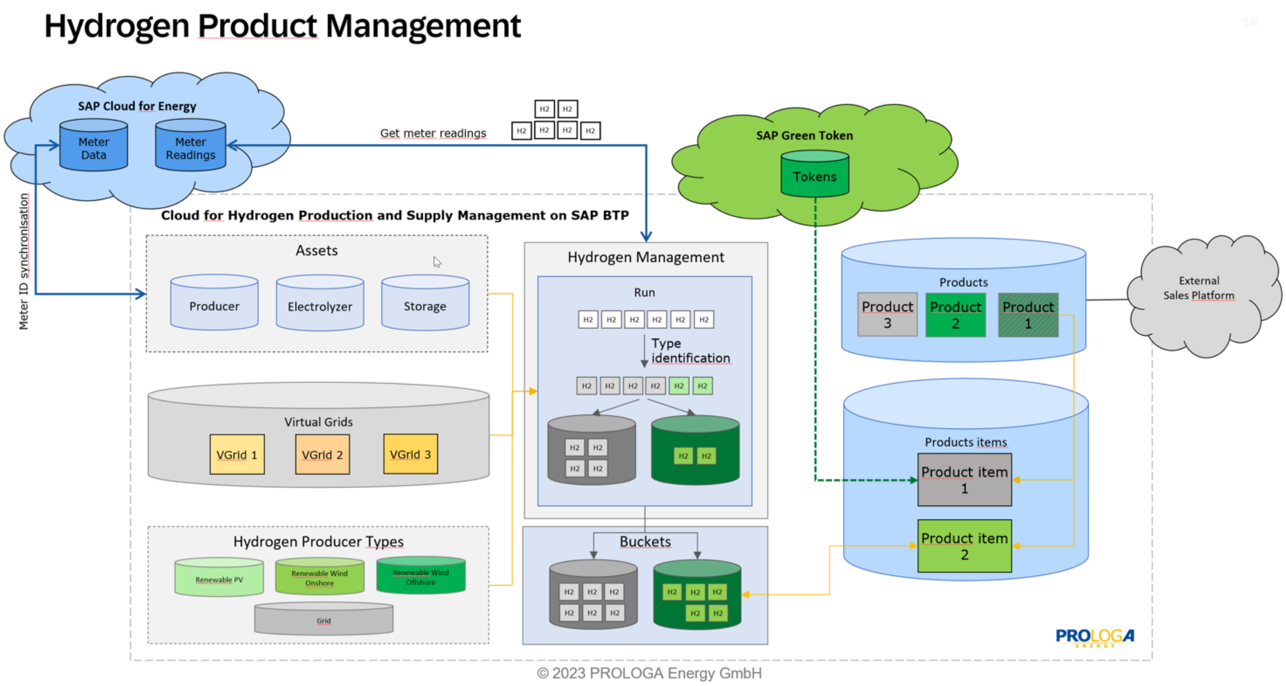

Figure 11: Product Management Module in the Cloud for Hydrogen Production and Supply Management

Environment, Health, and Safety

Managing the hydrogen value chain requires health and safety handling according to different classifications. Hydrogen is extremely inflammable and precautious manners must be in place. Customers require digital solutions to document and operate these environmental, health, and safety related activities. SAP´s ERP suite offers a deeply integrated EHS (environment, health, and safety) solution which covers all aspects in the treatment of hydrogen. Handling, storing, and transporting is seamlessly monitored and lays the basis for all logistics and commercial aspects.

Proactive incident reporting culture

The treatment of hydrogen means establishing a proactive incident reporting culture. Not only that all workers who are potentially exposed to risks and incidents should have easy access e.g., based on tablets and simplified reporting forms, but also the ease of comprehensive reports issued by safety engineers. Customers using supportive software such as SAP´s EHS can focus on incident investigation to resolve issues faster. This leads to increased health and safety awareness and a proactive incident reporting culture among the workforces.

Adopting high standards from the Oil, Gas & Energy industry

Throughout the last decades, industries exposed to hazardous materials and safety- critical environments, have implemented software such as SAP´s EHS solution to support these process frameworks in accordance with the high standards. In the future, the hydrogen economy must carefully assess these procedures and must adopt the methodology to green hydrogen production and it´s supply chains.

Intelligent Asset Management

Producing green hydrogen comes hand in hand with an increased complexity in the energy mix. Utilities must diversify their energy sources to include renewables like solar, wind, and hydro, which increases the complexity of managing these assets. Because of the potentially high production cost of green hydrogen and the overall margin focused industries, high operational efficiency is not just a goal but a necessity.

Intelligent Asset Management is a game-changing approach in the energy industry, especially as the integration of renewable energy sources is a precondition to produce green hydrogen. This approach leverages advanced technologies like data analytics, Internet of Things (IoT) sensors, AI methods, and machine learning to optimize the performance, reliability, and lifespan of assets. The key components of such an intelligent asset management (IAM) are:

- **Location-based Analytics:** combining asset data with geographic data, utilities gain insights into location-specific performance, risks, and opportunities.
- **Predictive Analysis:** IAM to utilize advanced analytics to predict asset performance, enabling proactive maintenance and reducing unplanned downtimes.

Performance Benchmarking: by, benchmarks, driving continuous improvement and operational excellence are results of continuous monitoring and asset performance analysis.

Real-time Collaboration: with integrated communication tools, utilities expect teams to collaborate in real-time, addressing asset-related issues swiftly and efficiently.

- **Artificial Intelligence:** capturing vast operational data lays the basis for automating processes based on sophisticated methods such as Artificial Intelligence.

Standardized Processes: with robust data governance, utilities aim to standardize data management processes across the organization, ensuring that all departments work with a single version of the truth.

Conclusion

In conclusion, the certification schemes for green hydrogen outlined in the certification section have several common requirements. These include a focus on direct GHG emissions with some consideration for indirect emissions, and the need for solid proof of green energy and a tracking model to prevent double counting. Additionally, all schemes require clear indication of the renewable energy source, details about the production of green hydrogen including production time and location, technology of operations, and measurement of energy consumption and hydrogen output.

To meet these requirements, a comprehensive software architecture is needed. This architecture should include a footprint management system that incorporates given standards and allows for different calculation approaches, a sustainability reporting solution to track emissions and compare them with sustainability goals, and a system for supply chain transparency and digital chain of custody model to ensure traceability and transparency of materials and components. The architecture should also include a mechanism for standardized sustainability data exchange to ensure data quality and prevent manual data exchange.

Furthermore, mass balancing and tracking along the value chain are crucial for green hydrogen certification, as is the use of tokens to represent specific qualities and attributes of hydrogen products. Overall, the software architecture described in the text provides a comprehensive solution for achieving green proof for hydrogen and other PtX products, ensuring transparency, traceability, and compliance with sustainability standards and regulations.