QUANTRON

Unlocking New Possibilities

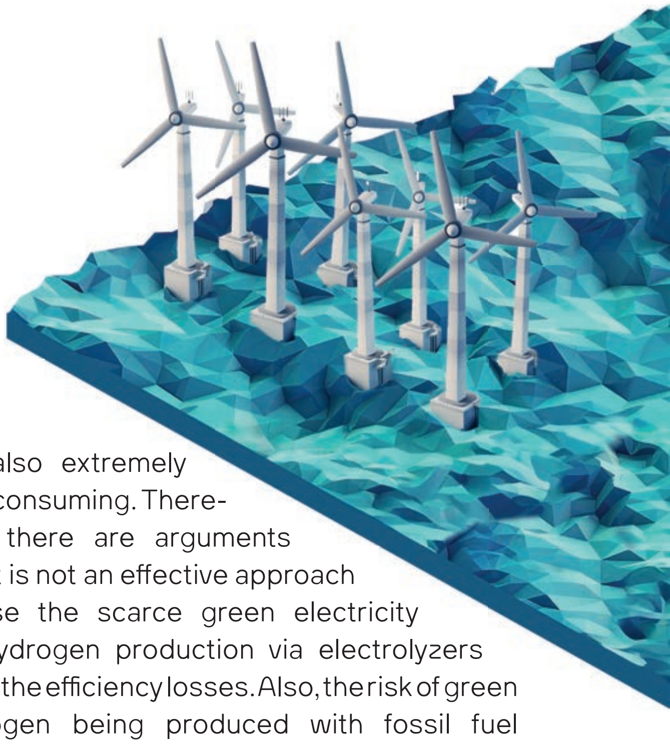
Waste-to-hydrogen as an energy source
for fuel cell vehicles

Empower the Future

Have you heard about the new normal?

Zero Emission. Full Power. Better Future.

Contents



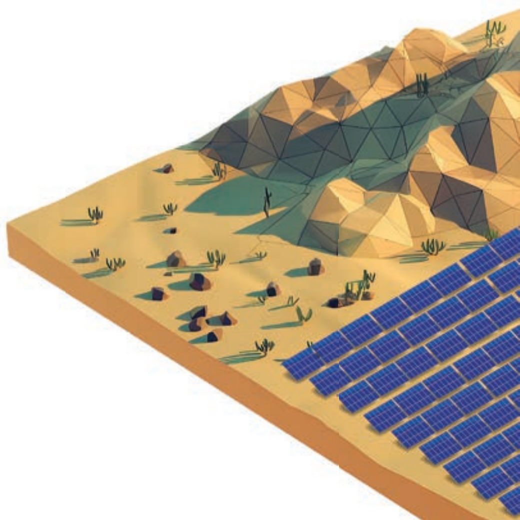
Executive Summary

The projection of hydrogen demand is growing fast as hydrogen is playing an important role for decarbonization in various sectors. Governments worldwide are actively fostering this growth through diverse regulations and incentives, aimed at boosting green hydrogen production, enhancing transportation infrastructure, and ensuring its application in efforts to reduce carbon emissions. The main obstacle to adopting hydrogen in the most demanding sector however lies in producing enough carbon-free and low-carbon hydrogen at prices that are competitive.

Unlike conventional energy resources, hydrogen production offers greater flexibility in terms of scale and location, presenting a unique advantage. However, current hydrogen production methods are facing some substantial challenges. Green hydrogen production is contingent on renewable electricity availability, the demand for which is already growing tremendously. Many industries are switching their energy sources from fossil fuels to green electricity to lower their carbon footprint. As a result, the renewable electricity demand will soon surpass the available supply, especially during the peak hours. On the other hand, the geographic and temporal variations in wind or solar installations' output poses an additional challenge. It is estimated that the global gird network needs to be doubled to meet the 2050 demand of electricity. Expanding the electricity grid is not only costly but also extremely time consuming. Therefore, there are arguments that it is not an effective approach to use the scarce green electricity for hydrogen production via electrolyzers given the efficiency losses. Also, the risk of green hydrogen being produced with fossil fuel generated electricity from the grid cannot be ignored. Ultimately, for a smooth energy transition, the color of the hydrogen is not the key but that the hydrogen ultimately has a low-carbon intensity and is affordable.

Rather than exclusively emphasizing green hydrogen, the key to unlocking hydrogen's full potential lies in diversifying its production methods. In this regard, waste-to-hydrogen (WtH) stands out as an efficient and eco-friendly potential solution. With increasing population and growing urban economy, waste management is a critical aspect of sustainability development. Waste to energy (WtE) is recognized as one of the effective approaches to reduce waste ending in landfills. WtH, as a subset of the WtE concept, offers a promising pathway for producing hydrogen from waste which could not only contribute to decarbonization, but also promote a circular economy in local and regional ecosystems.

Localized hydrogen production, as exemplified by WtH, brings multiple benefits. It reduces costs associated with waste management,



Every End can be a new Beginning: Benefits of WtH

Economic

Cost effectiveness of Hydrogen
- Waste as raw material has lower to negative cost
- Production cost of WtH can be lower than electrolyzers

Extra revenue for players
- Hydrogen produced can be sold as energy source
- Byproducts can be sold for industrial applications

Local economy
- Creates employment opportunities
- Strengthens regional waste management systems

Environmental

GHG reduction
- Avoid the emissions associated with landfilling or incineration
- Reduce waste ending up into landfill

Enhance Circularity
- Recovery of energy from waste
- Extraction of valuable materials from WtH residue
- Reduce raw material acquisition

Support energy system
- WtH as energy carrier with Integration of renewables
- Energy storage for excess renewable electricity to support grid stability

Figure 1

bolsters energy independence, and stimulates local economic development. Complementing large-scale green hydrogen production, WtH introduces an alternative, efficient pathway for decentralized hydrogen production. Moreover, locally produced hydrogen has the potential to replace conventional energy sources in industries and to fuel hydrogen-powered vehicles. The reduction in the fuel transportation distances achieved through on-site production translates into significant savings, not only in operational costs but also in the investment required for conversion and transportation infrastructure.

Diverse WtH technologies have the capability to convert a broad spectrum of waste types, including industrial by-products, biological refuse, plastics, and municipal waste into hydrogen. The variety of waste types demands the development and commercialization of assorted WtH technologies, a challenge actively pursued by innovative companies in this field. For these enterprises, ensuring a steady and reliable market for the hydrogen produced is essential.

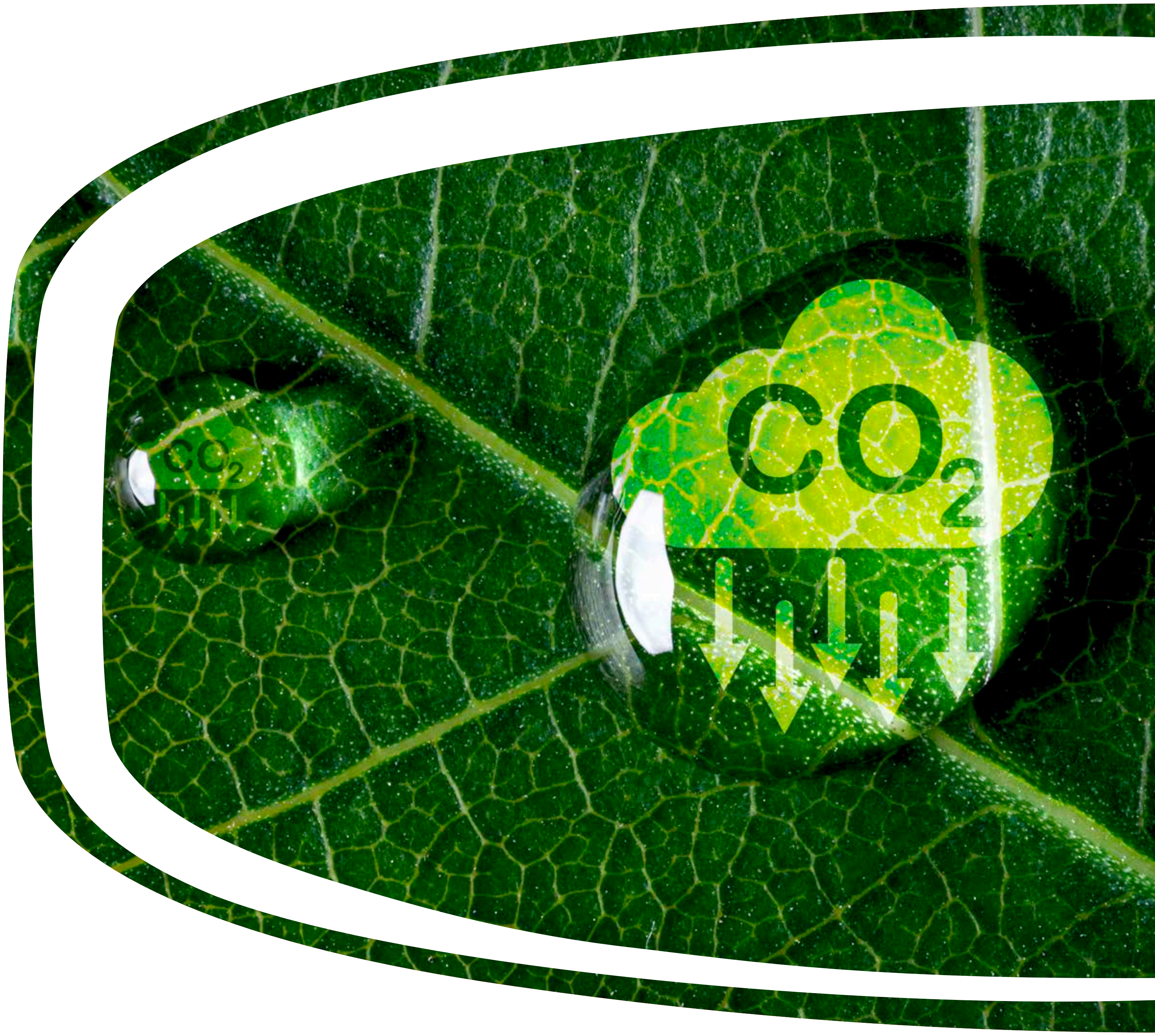
QUANTRON recognizes the potential to incorporate WtH into a zero-emission commercial vehicle ecosystem. The hydrogen harnessed from these WtH processes is versatile, with applications extending far beyond just industrial use. It is ideally suited to power various logistic vehicles, ranging from community garbage collection trucks and forklifts at industrial sites, to public transport vehicles like city and regional buses.

Having WtH companies as a part of QUANTRON's Clean Transportation Alliance (CTA)

> "Every **End** can be a New **Beginning**"

enhances the ecosystem for zero-emission commercial vehicles under our Quantron-as-a-Service (QaaS) model tailored to equip customers with fuel cell-powered trucks and buses.

Furthermore, collaboration with CTA partners can lead to the development and implementation of comprehensive solutions encompassing both the transportation of hydrogen and the creation of necessary refueling infrastructures. Such an approach not only complements and extends the hydrogen supply chain but also reinforces sustainable energy infrastructure, a critical element for future progress.



Introduction

Hydrogen is expected to play a pivotal role in decarbonization efforts globally. As an energy source, hydrogen is very versatile. Its high energy density positions it as a promising candidate to replace coal in many carbon-intensive industries. Examples range from environmentally friendly steel production to applications in heavy-duty transportation, shipping, and aviation. It also has immense potential as a long-duration energy storage medium.

Consequently, it has been attracting substantial interest from public institutions and private stakeholders, evidenced from a growing number of investments, incentives, and support. Countries like US, Germany and Japan have adopted ambitious hydrogen strategies aimed at decarbonizing heavy industries and transport. Projections suggest that by 2050, hydrogen demand across various applications will exceed 500 Mt, accounting for 10% of the global energy mix. As a result, a recent report from Deloitte projected that the global hydrogen market could reach $199 billion by 2025, with investments exceeding $70 billion in hydrogen-related projects.

Taking the US as an example, the Biden-Harris administration signed the Bipartisan Infrastructure Law (BIL) to provide $550 billion in investments for the transportation sector. This includes support for the deployment of charging stations and hydrogen refueling stations (HRS). In October 2023, the US DoE announced $7 billion in funding seven selected regional clean hydrogen hubs (H_2Hubs) across America as part of the BIL. More recently, the government also announced $750 million, funded by the BIL, to support 52 projects across 24 states as a part of the Investing in America agenda. Additionally, the Inflation Reduction Act (IRA) supports hydrogen production facilities and renewable electricity projects to benefit the dispensing of green hydrogen and renewable energy. The US Department of Energy (DoE) has also released its Clean Hydrogen Strategy and Roadmap recently. This entails a target for production of 10 million metric ton per annum (MMTpa) of hydrogen in 2030, rising to 50 MMTpa by 2050. It also targets reducing the cost of electrolyzers by 50-70% and other initiatives creating over 100,000 jobs by 2030.

Hydrogen hubs in Europe and USA

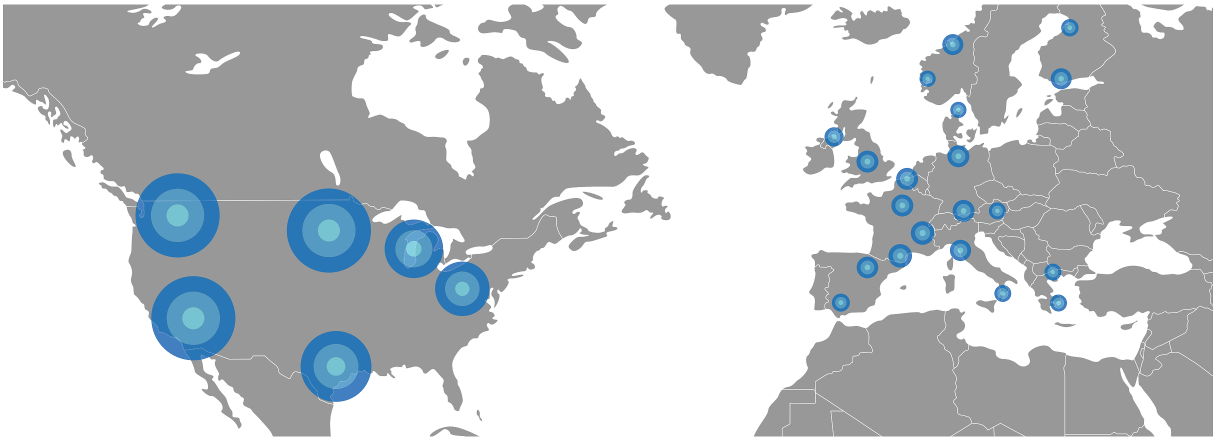


Figure 2

Similarly, the European Union (EU) has also been making significant and concerted efforts to aid the growth of the hydrogen economy. The EU strategy on hydrogen was adopted in 2020 including various policy actions, while the REPowerEU plan helped shape comprehensive frameworks to support hydrogen uptake. The revised Renewable Energy Directive in 2023 included new binding renewable energy targets for 2030. The EU estimates that it will need about 20Mt of hydrogen by 2030, with about 50% produced domestically and the rest imported from energy partners. In other words, this means that the EU targets to produce 10 million tons (Mt) of renewable hydrogen domestically by 2030, coupled with an additional 10 Mt of imports. There are over 300 hydrogen projects in Europe and over 30 Hydrogen Valleys have been established as large-scale flagship projects. Further initiatives like setting up the Clean Hydrogen Partnership, the European Hydrogen Bank, and investment support through funding various IPCEI projects have further provided momentum to the sector.

Talking specifically about the transportation sector, the EU recently adopted the cornerstones of an infrastructure package under the Fit-for-55 program. The Alternative Fuel Infrastructure Regulation (AFIR) sets out a target of one hydrogen refueling station in all urban nodes and every 200km of the 'trans-European transport (TEN-T) core network' by 2030. Establishing mandatory deployment targets for recharging and refueling stations will alleviate consumer worries regarding the challenges of refueling zero-emission vehicles. This initiative also paves the path for a convenient and economically viable refueling experience throughout the European Union.

Concurrently, the latest forecasts from BloombergNEF on the levelized cost of green hydrogen production indicate that prices could drop below $4 per kg of hydrogen by 2030 in major focus markets. Demand-side measures, like the US DoE reportedly planning $1bn in subsidies for clean hydrogen users (as a part of its $7bn H_2Hubs program) and the setting up of the European Hydrogen Bank, will surely accelerate the adoption of zero emission fleets.

> **38 Mt** per year clean hydrogen supply announced globally until 2030, less than **1 Mt** deployment is available today.

Clearly, a lot of investment and effort is necessary to ramp-up hydrogen supplies to meet this explosive demand growth. A lot of focus of governments, regulators, investors, and industry participants has been on "green" hydrogen (i.e., carbon neutral hydrogen produced from renewable energy sources), given that currently most hydrogen today is produced through the carbon-intensive and expensive steam methane reforming (SMR) process. Similarly, "blue" hydrogen, wherein the carbon emissions in the process are captured and stored and/or utilized, is another touted solution, though these technologies remain relatively expensive and face implementation challenges (e.g., potential CO_2 leakages).

To fully tap into hydrogen's potential though, it is crucial to consider all cost-efficient production methods while minimizing the carbon footprint. One key advantage of hydrogen, which is often overlooked, is that it has diverse production pathways, enabling flexibility in where and how it is produced. This whitepaper explores the potential of one such approach of producing cost-efficient hydrogen with a minimal carbon footprint, namely the waste-to-hydrogen (WtH) technology. But before diving into that, it is necessary to understand the current challenges in green hydrogen production and its transport to the points of consumption.

Focus on (Green) Hydrogen

A recent study by the consulting firm, Roland Berger, estimated that the value pool of green hydrogen could reach €500 bn by 2030, buoyed by incentives in the US, Europe, and Asia, as well as declining costs. This momentum is expected to establish hydrogen as a self-sustaining business post-2030. However, there are also some factors and challenges associated with the ramping-up of green hydrogen that must be recognized.

The first is the availability and usage of renewable electricity. In the EU, for example, annual electricity demand is forecast to more than double from 3,000TWh today to 6,800TWh by 2050. Peak demand could be even greater, as the electricity system increasingly supplies winter heat. The scale of infrastructure to be built up is massive, even though it has been facing some headwinds in the last months – factors like cost increases, high inflation, structural supply shortages, and strained supply chains brought many wind and hydrogen project constructions to a halt in Europe and US. These factors are largely expected to ease out in the coming months.

Conventional electricity generation based on fossil fuels has historically been located in close proximity to demand centers like cities and industrial hubs. On the other hand, renewable electricity generation is temporally and geographically constrained and often at remote locations. For example, some large-scale wind farms are currently being developed on offshore locations. Similarly, the best economics and efficiencies in generation of solar power are offered in sun-rich locations, typically in regions like southern Europe or US, middle East/north Africa, or Australia.

As the transition gains momentum, there is also an increasing awareness to the limits and realities of today's electricity grids. Building new power lines and reinforcing existing infrastructure is an enormous undertaking, necessitating substantial time and investment. BloombergNEF estimates that the global network of cables needs to be doubled by 2050, spanning a staggering length of 152 million km and requiring a $21 trillion investment. Additionally, transmission losses in bringing the generated electricity to the point of consumption also need to be factored into the efficiency calculation from a system-level[1].

In contrast, one key advantage of hydrogen molecules as an energy carrier is that they are easier and cheaper to transport over long distances compared to transmission of electrons. For low volumes and across short distances, it could be cheaper to produce hydrogen locally, potentially with imported renewable electricity. However, for distances of over 500 km, pipelines are better suited to import hydrogen economically and with larger volumes. Repurposing existing natural gas pipelines can decrease the infrastructure investment costs to

1. Transmission losses estimated to be between 6 to 10 percent per 1,000 km in high-voltage alternating-current grids and about 4 percent per 1,000 km in high-voltage direct-current grids (which are subject only to ohmic losses).

as low as one-third of building new dedicated pipelines. This mode is well suited for moving hydrogen within Europe or for importing from neighbouring regions with pre-existing infrastructure. For import routes across much long distances (3,500 km or more), maritime shipping is emerging as the preferred option when hydrogen pipelines may not be possible.

On the other hand, critics rightly point out the efficiency losses entailed in the conversion of electrical energy into hydrogen molecules in the electrolysis process and in re-generating electricity again from these molecules at their point of consumption, for example in the fuel cell in a vehicle. Each step in this value chain also accrues costs and amortization of heavy capital expenditure (e.g., for large scale electrolyzers). Another criticism levelled at green hydrogen production is the potential hidden carbon costs in the process. Green hydrogen is only truly green if it is produced using electricity from renewable energy – using electricity drawn from existing grids having a significant share of coal-powered electricity would be counterproductive in this regard. At the same time, if utilizing the electricity generated from renewable sources for manufacturing hydrogen leads to the electricity being replaced in the grid by fossil fuel powered energy plants, that would also have a negative impact overall. These examples make it difficult to really justify how "green" the hydrogen is at a system-level, and has led to speculative criticisms in concert with the factors like the lower efficiency and higher costs of making green hydrogen available at scale.

In a net zero economy, the large-scale clean energy production (at remote locations) must also be complemented with a myriad smaller-scale renewable developments such as onshore windmills and local solar panels. However, grid capacity constraints have already led to frequent instances where windmills have to be turned off and windfarms have been com-

pensated hundreds of millions to do so. In such cases too, there is an increasing recognition that green hydrogen will have an important role to play in balancing[2] renewable intermittent electricity production, electricity demand, and grid stability. However, there is still a lot of work to be done before the economics of such smaller scale installations become favorable to allow the end users to use the hydrogen thus produced at competitive prices.

Given these challenges, it is critical that the scope of discussion of hydrogen production pathways is not limited to only "green" or "blue" hydrogen. This does a disservice to one of the major advantages of hydrogen, that it can be generated in many different ways. These have been visually distinguished by assigning various colors to the hydrogen depending on how it is produced, in addition to the "green", "blue", or "gray" hydrogen.

It must be stressed here that at the end, what is important and relevant is not what color label is applied to the production approach, but what is the cost of producing the hydrogen and the associated carbon footprint of the process employed. For instance, consider green hydrogen again: currently, the electrolysis process is prohibitively expensive for widespread commercialization. Numerous studies suggest that for green hydrogen to become dominant and to reduce the current dependance on hydrogen generated from steam methane reforming by 2050, it is critical to improve electrolyzer manufacturing technology and the cost of the renewable electricity used as input.

On the other hand, as explained earlier in the text, the environmental credentials of hydrogen can be questionable if an electrolyzer claims to produce green hydrogen but relies on a grid with intensive GHG emissions. The differences in grid emissions play a significant role in how hydrogen is categorized.

For the industrial transition to cleaner energy, the carbon intensity and affordability of hydrogen should become the primary consideration. This underscores the need to prioritize the production and use of low carbon hydrogen, no matter what its production pathway or respective color classification is. One particular pathway of generating hydrogen from various types of waste is especially interesting as an emerging technology for producing it locally or decentrally, and merits further exploration as a part of the decarbonization technology mix.

2. Grid storage is currently largely done through pumped-storage hydropower, especially in China, but batteries are also increasingly playing a role according to the IEA. In the future, they are projected to account for the majority of storage growth worldwide, typically employed in sub-hourly, hourly and daily balancing. Hydrogen offers an option for longer-term storage and balancing as a complementary solution.

The Colors of Hydrogen

Grey hydrogen, the most widely used form, is produced from fossil fuels, predominantly natural gas, through a process called steam methane reforming (SMR). It involves extracting hydrogen from natural gas by reacting it with high-temperature steam, resulting in the release of carbon dioxide (CO_2) as a by-product.

Blue hydrogen is a cleaner alternative to grey hydrogen as it incorporates carbon capture and storage (CCS) technology. Blue hydrogen is also produced through SMR, but the CO_2 emissions generated in the process are captured and stored underground or utilized for other purposes, such as enhanced oil recovery.

Green hydrogen is currently defined in different ways, the most common being electrolysis from renewable sources, such as solar or wind, to split water molecules into hydrogen and oxygen. As a result, green hydrogen is entirely clean, emitting no CO_2 or other harmful pollutants during its production. Common certificates (e.g., CeritfHY, CMS 70) title hydrogen as "green" if it achieves at least 70% GHG reduction compared to diesel as a fuel, often listing technology choices of electrolysis or the use of biogenic residues. Green hydrogen offers a truly sustainable solution for achieving a carbon-neutral future. In some instances, the hydrogen produced by using solar power for electrolysis has also been termed **yellow hydrogen**.

Turquoise hydrogen, also known as low-carbon hydrogen, is produced through a process like electrolysis but utilizes methane instead of water as a feedstock. The process, called methane pyrolysis or methane cracking, generates hydrogen and solid carbon as by-products. The solid carbon can potentially be utilized as a valuable material in various industries, such as construction or as a component in advanced materials.

Brown or black hydrogen is produced by coal gasification, a process that converts brown or black coal into a gas mixture containing hydrogen, carbon monoxide, and other gases. While brown hydrogen has been used historically, it is considered the least environmentally friendly form of hydrogen due to its association with carbon-intensive fossil fuel coal.

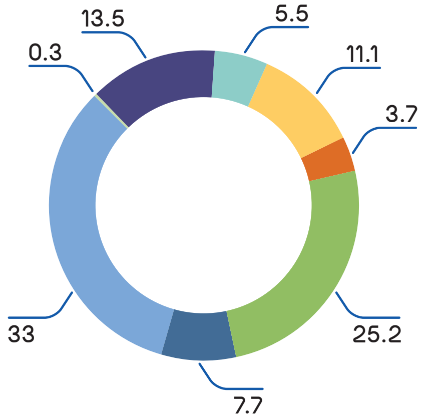
Pink hydrogen, also referred to as light-duty hydrogen, is produced using renewable energy sources, particularly solar power, in combination with biomass gasification. Biomass feedstock can include organic waste or specially grown crops. The process releases hydrogen while capturing and storing carbon, resulting in a low-carbon or even carbon-neutral outcome. Pink hydrogen holds potential for various applications, including transportation and power generation.

In some regions, **pink hydrogen** is also used to refer to the use of nuclear energy for producing hydrogen through electrolysis. Others refer to this as purple or red hydrogen. Naturally occurring hydrogen, though very rare, has been termed as **white hydrogen**. Now, people are discovering the places where the hydrogen is fluxed and with high concentration to extract. Finally, some have referred to the hydrogen produced from waste as **orange hydrogen**.

From Waste to Energy

The world generates over 2 billion tons of municipal solid waste each year, and this is expected to continue increasing. According to the World Bank, global waste production is anticipated to surge to 3.4 billion tons by the year 2050. However, on a global scale, only around 19% of the waste produced by humans is salvaged through recycling and composting efforts, while 11% undergoes incineration as a means of final disposal. The predominant approach to handling waste entails its disposal in landfills or open dumpsites, which puts tremendous stress on the environment and poses significant threats to wildlife habitats, especially in developing nations.

Global treatment and disposal of waste (in %)



- Composting
- Incineration
- Controlled Landfill
- Landfill (unspecified)
- Sanitary landfill (with landfill gas collection)
- open dump
- Other
- Recycling

Figure 3

It is worth noting that the IPCC's 4th assessment report highlights that the waste management sector contributes to 5% of the global greenhouse gas emissions. This figure is projected to rise significantly to 2.38 billion tons of CO_2-equivalent per year by 2050 if substantial improvements are not implemented within the sector. While global waste management has made some progress in recent years, it is evident that the world still faces pressing challenges that demand urgent attention and action. Given this growing problem, it is essential to think about how technological advancements can be applied to generating value, even from waste, and reducing their environmental impact in the process. In this pursuit, waste-to-energy (WtE), and especially waste-to-hydrogen (WtH), processes offer a promising avenue.

The most effective approach to reducing waste is to mitigate the generation of waste at its source, but achieving zero waste is unattainable in reality, as long as the current economic and social models persist. Against this background, practices such as reuse, sorting, and recycling have made significant contributions to reduce the environmental impact of waste. However, it must be acknowledged that these methods will also eventually encounter limitations and reach a level of saturation.

The next best approach in the waste management hierarchy, once the “reduce-reuse-recycle” strategies are no longer feasible, is the

> **200 Mt** of waste incinerated on landfill every year in Europe.

recovery of energy from the waste, whereby non-recyclable wastes are burnt in the WtE plants to recover the energy in the form of steam, electricity, or hot water. From a system perspective, WtE is a clean and safe waste treatment method. It serves the dual objectives of reducing the amount of waste that ends up as landfill, while also producing useful energy from it. The process promotes a shift to a more sustainable and circular economy as it keeps the resources within the economy when the product has reached the end of its life. Typically, one ton of waste can generate about 500 to 600 kWh of electricity or around 900 kWh of heat. Until 2022, 5,134 MW capacity of municipal waste energy plants have been installed in Europe which produce enough electricity to supply almost 20 million people per year. Germany has the largest installed capacity (1,068 MW) of WtE plants, and this number is growing. The global WtE market size is projected to surpass over $ 88 billion by 2035 with WtE Plants, expected to produce 189 billion kWh of useful energy per year.

Waste Hierarchy

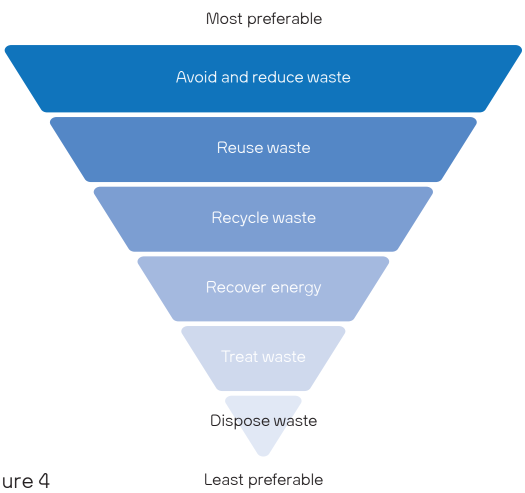


Figure 4

Modern WtE plants are different from the old trash incinerators that were energy intensive, endangered the environment and people's health. The modern, properly run WtE plant sorts waste material before burning to ensure the items burnt are not hazardous. Also the WtE plants co-exist with recycling to recycle materials from the waste and residues. Though some have challenged the CO_2 emissions associated with waste combustion in WtE processes, it is worth noting that a substantial portion of the waste processed in these plants is biogenic in nature. This encompasses materials such as paper, food, and other biomass waste that have absorbed carbon throughout their lifecycle. According to EU legislation, the biodegradable portion of municipal and industrial waste is considered as biomass, and as a renewable energy source. In other words, the energy output from WtE plants is estimated to be about 50% renewable. WtE facilities thus play a pivotal role in reducing greenhouse gas (GHG) emissions – not only by substituting traditional fossil fuel-based energy production with partially renewable electricity and heat generation, but also through their capacity to recover raw materials (e.g., metals) and divert waste away from landfills. Hence, the approach provides another way towards sustainability and clean energy supply.

Hydrogen from Waste

Interest in hydrogen as a clean alternative to fossil fuels has spurred the exploration of its potential for various applications, driven by both industry and government support. As an energy source itself, hydrogen's big advantage is its versatility. Hydrogen's high energy density positions it as a promising candidate to replace coal in environmentally friendly steel production and has applications in heavy-duty transportation, shipping, aviation. It also has immense potential as a long-duration energy storage medium. Given the massive growth expected in the demand for hydrogen as a fuel and its crucial role in decarbonizing hard-to-abate sectors, a lot of debate has been triggered about employing any green hydrogen produced in sectors which really need it. A recent study from the Boston Consulting Group even emphasized that given its high production prices, there is credit to the arguments of green hydrogen being the "champagne of decarbonization technologies". To ensure its availability for the decarbonization of process industries and power systems, there must be an impetus on supporting the industry to scale green hydrogen production through subsidies for early projects, instruments that incentivize demand, and an acceleration of renewable infrastructure build-out. This highlights the critical need to supplement the production of green hydrogen with other low carbon production pathways and competitive costs.

One ton of waste to estimated amount of hydrogen

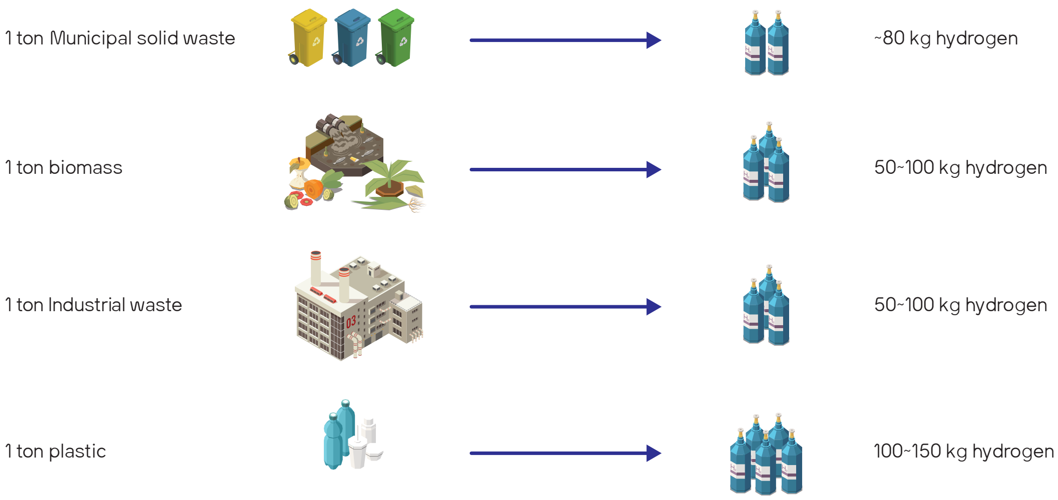


Figure 5

Note: indicative estimates from industrial players

Against this background, WtH as a specific subset of the WtE concepts is emerging as one of the potential solutions. WtH entails the decentral production of hydrogen from various waste streams including municipal solid waste, industrial waste, plastic waste, sewage sludge, and agricultural waste. This can be achieved by integrating a combustion based WtE facility with electrolyzers, or through other methods such as gasification, pyrolysis, and anaerobic digestion to produce hydrogen from waste.

In comparison to other hydrogen production methods, the WtH technology offers some distinct advantages. While the current focus of low-carbon hydrogen production is largely on water electrolysis, this process is heavily reliant on the availability of freshwater (an increasingly stressed resource globally) and of large-scale renewable electricity at cheap prices (buffeted by grid and infrastructure challenges discussed earlier). This skews its viability primarily towards regions with excess wind, solar, geothermal, hydropower or other renewable energy sources.

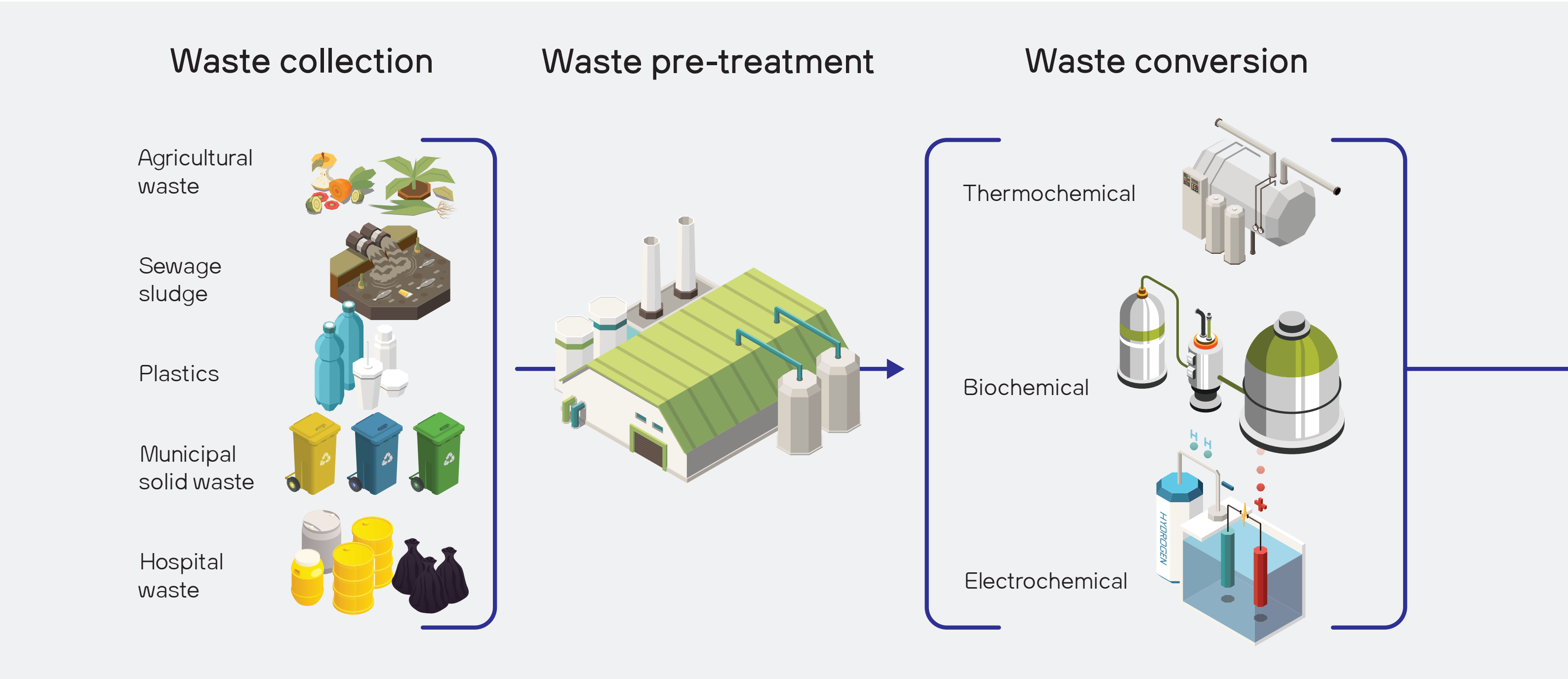
On the other hand, WtH provides a more efficient use of "waste" resources locally and in close proximity to the point of energy requirement, bolstering the overall supply of hydrogen while promoting cleaner energy sources. The application of WtH approach transforms wasted assets into marketable products and enhances operational efficiency within facilities. Before we dive into the advantages offered by the process though, let us understand what it entails from a technological perspective.

Jump out of the "Stereotype" of Energy: make the leap!

Conventional energy or non-renewable energy has been used for centuries. Since the last industrial revolution, conventional sources of energy have been widely used to generate electricity, fuel vehicles, and manufacture products. We have a great and well-developed infrastructure to exploit and transport fossil fuels. Meanwhile, we also have established a "stereotype" of energy. For many people, energy would be centrally produced, transported to the end-users, and with "cheap" price. However, the realm of energy is evolving. Under the urgency of global decarbonization, we should shift our interests on energy away from its stereotype.

Green energy really seems more expensive than conventional energy. But a comprehensive analysis of the entire energy supply chain reveals that renewables are often more cost-effective than traditional energy sources. Importantly, this assessment considers not just the price tag of energy but includes overall cost to the society. Our environment is burdened with liabilities, such as land degradation, global warming, radioactive pollution caused by using nuclear energy and CO_2 emissions from coal. Yet, the use of zero-emission energy protects air, water, soil, flora, and fauna from pollutants, saves resources and uses land efficiently.

Unlike fossil fuel, many renewable energies do not require a centralized massive exploitation such as a mining site. A localized approach of production can be more economically feasible to use on-site, which can also save substantial transportation/ transmission costs. This also applies to WtH technologies, whereby the distributed production of hydrogen can be realized close to the point of end use, thus reducing the need for building new supply chains or repurposing existing infrastructure like gas pipelines. The urgency of global decarbonization compels us to jump out of this old mindset and embrace a new paradigm of sustainable energy.



The process of producing hydrogen from waste typically entails the following steps:

1. Waste Collection

Different types of waste, including organic waste, biomass, municipal solid waste, or wastewater sludge, can serve as feedstocks for hydrogen production. Standard operating procedures are established for sorting wet, dry and other waste in most countries, with municipal waste collection facilities and operators handling the logistics for bringing the waste to the WtE plants, where they are further sorted if needed.

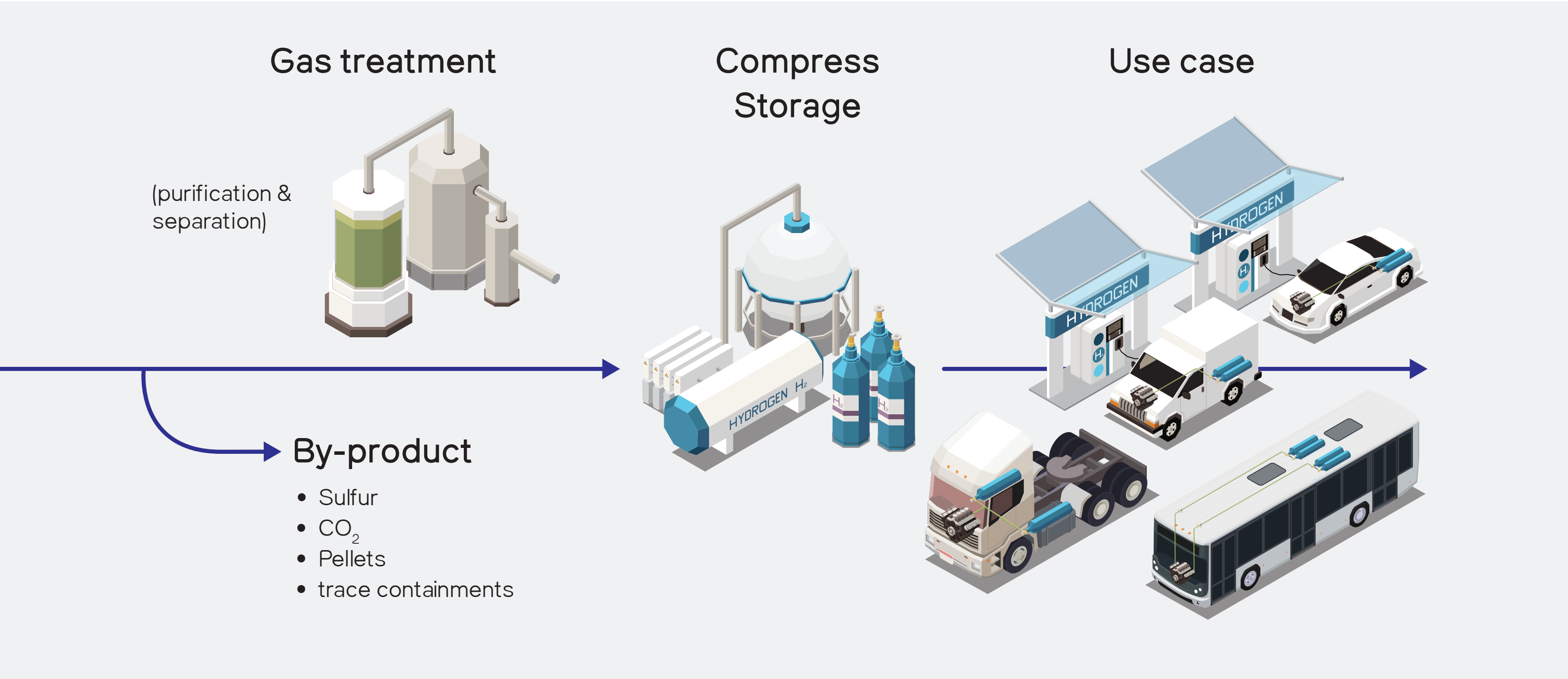
2. Waste Pre-Treatment

After collection and sorting, the waste undergoes pre-treatment to remove contaminants such as non-organic materials or hazardous substances. It is crucial to ensure that the waste feedstock is clean and free from any materials that could interfere with the conversion process.

3. Waste Conversion

Once pre-treated, the waste is subjected to a specific conversion process to extract hydrogen. Several technologies can be employed for waste-to-hydrogen conversion, including:

a. **Thermochemical conversion** technologies such as steam reforming of biogas, gasification, or pyrolysis, utilize high temperatures to break down the organic components of the waste. These processes produce a synthesis gas (syngas) consisting of hydrogen, carbon monoxide, and other gases. A water-gas shift reaction can be further applied to the syngas, which will increase the hydrogen content and reduce the CO content. The water-gas shift reaction involves reacting the syngas with steam over a catalyst to produce more hydrogen and CO_2. The syngas ultimately needs to be separated to recover and purify the hydrogen.



b. **Biochemical conversion** involves the use of microorganisms or enzymes to break down organic waste materials, such as biomass or wastewater sludge, through fermentation or anaerobic digestion. This biological activity produces biogas, which primarily consists of methane and carbon dioxide. Biogas can undergo a reforming process, such as steam reforming or dry reforming, to convert methane into hydrogen-rich syngas.

c. **Electrochemical conversion,** specifically through processes like electrolysis, utilizes an electric current to split water molecules into hydrogen and oxygen. In this case, the waste-derived electricity is used to power the electrolysis process directly, resulting in the production of clean hydrogen.

4. Gas Treatment

Regardless of the conversion technology employed, the produced syngas or hydrogen-rich gas stream requires purification to remove impurities and contaminants. In the application of steam reforming, this is done before the synthesis gas generation with the raw biogas. Gas purification processes may involve methods such as pressure swing adsorption (PSA), membrane separation, or catalytic reactions to eliminate undesirable components like sulfur compounds, carbon monoxide, or trace contaminants.

5. Hydrogen Compression and Storage

Once separated, the hydrogen is typically compressed to increase its density for efficient storage and transportation. Compression methods, including piston compressors, diaphragm compressors, or centrifugal compressors, are employed to achieve the desired pressure levels. The compressed hydrogen can be stored in gaseous form or liquefied through cryogenic processes for higher storage capacity. Finally, the hydrogen thus produced may be used as an energy source for various applications.

Economic benefits of WtH approaches

Conventional methods of hydrogen production, such as steam methane reforming, have limitations in terms of high carbon emissions and their reliance on fossil fuels. There is consequently a lot of impetus being placed on scaling up green hydrogen, but the demand for hydrogen is far outpacing the foreseeable supply and it will take time and investments to reach cost parity. In comparison, innovative WtH approaches are emerging as economically competitive and environmentally sustainable solutions.

From an economic perspective, the potential advantages of WtH arise from using waste streams as an input resource to generate additional revenues in support of local economies. As mentioned earlier, conventional hydrogen production relies heavily on fossil fuels, contributing to carbon emissions and dependence on limited resources. On the other hand, WtH utilizes various organic waste materials, including biomass, landfill waste, and organic industrial waste. By converting these waste streams into hydrogen, it creates a circular economy approach, reducing waste disposal costs and providing a renewable resource for hydrogen production.

The cost-effectiveness of waste-to-hydrogen technology compared to conventional methods is a crucial factor. While initial investments in waste-to-hydrogen facilities may be higher, the long-term benefits outweigh the costs. Waste materials are often available at low or even negative costs, as they would otherwise require expensive disposal processes. This availability significantly reduces the feedstock costs for hydrogen production, leading to a more economically viable solution. According to the information provided by our partners and key industry participants in the WtH sector, it is observed that the production costs are anticipated to fall within the range of 1.5~4 € per kg of hydrogen. This cost projection is more economical compared to the estimated cost for hydrogen generation via electrolyzers powered by renewable sources, which currently stands at approximately €2 to €7 per kg.

This also presents opportunities for revenue generation through multiple channels. First, the hydrogen produced can be sold as a valuable energy source. Second, the process generates by-products such as biochar, vitrified slag and metal mixes, as well as pure carbon dioxide or other valuable chemicals that can be sold or utilized in various industries. Further, the thermal energy generated may also be used for heating applications. These additional revenue streams contribute to the overall economic viability of WtH facilities.

Further, implementing such WtH projects creates employment opportunities that can stimulate the local economy. The construction and operation of WtH facilities require a skilled workforce, leading to job creation and income generation in the region. Additionally, the utilization of waste materials from local sources strengthens regional waste management systems, reducing dependence on external resources and fostering local economic development.

Hydrogen transportation cost

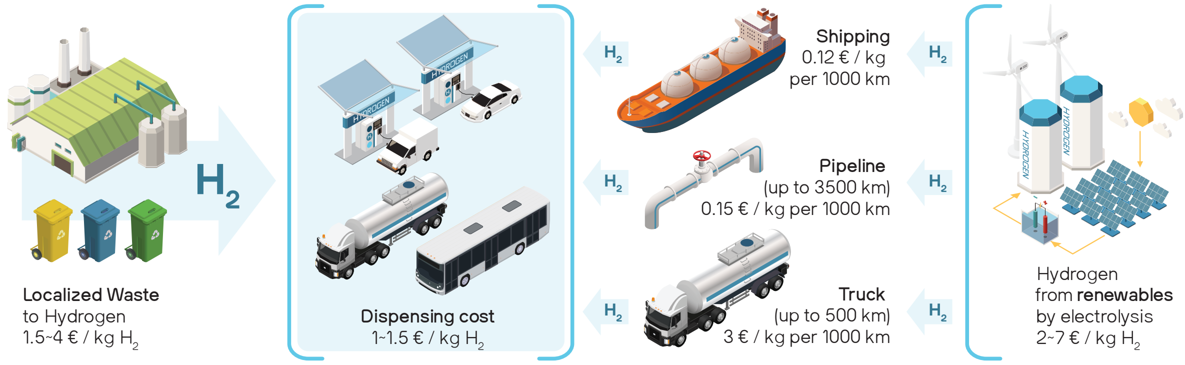


Figure 6

Note: Costs are estimated range from industrial players

Hydrogen Transportation Challenges

In the rapidly evolving landscape of sustainable energy, the transportation of hydrogen brings a unique set of challenges and opportunities. Currently, hydrogen transportation is primarily conducted through two main avenues: pipelines and through tankers of gaseous/liquid hydrogen or its derivatives in ships, trains, or trucks. For shorter distances, under 300 km, the industry predominantly relies on compressed gas trailer trucks. For longer journeys, the transportation of hydrogen requires a more intricate approach. Pipelines are recognized as a key component to support hydrogen economy. It can constantly move hydrogen in a large volume for a long distance. Although pipelines are an optimal long-range solution, the construction and maintenance of pipelines are associated with high capital costs. Liquid hydrogen, suitable for extended distances, requires special containers designed to maintain the hydrogen at -253 degrees Celsius. This requirement not only adds complexity but also significantly increases the cost. These expenses have been a consistent barrier to the wider adoption of these technologies, with projections suggesting that they will remain costly until at least the mid to late 2020s. In addition, the process of converting hydrogen into a transportable form, through liquefaction or compression, adds to the overall expense, highlighting the importance of considering the entire supply chain when evaluating the feasibility and cost of hydrogen transport.

Studies by the International Energy Agency (IEA) and the Hydrogen Council shed light on the economic aspects of these transportation methods. They have identified pipelines as the most cost-effective means for transporting hydrogen over long distances, particularly for routes up to 3,500 km. For instance, within Europe or to its neighboring regions, the cost of transporting hydrogen through new or repurposed pipelines is estimated to be around 0.15 €/kg per 1,000 km. On the other hand, ammonia is another favorable method of shipping hydrogen. Comparing to liquid hydrogen, ammonia has higher energy density 121 kg of hydrogen per cubic meter as carrier and requires less energy to convert and transport. The cost to transport ammonia by ship is around 0.12 €/kg per 1,000 km without considering the cost of converting. A study by McKinsey shows that converting hydrogen to ammonia for transport and then back to hydrogen could result in an additional cost of 2.28-2.74 €/kg H_2 by 2030. In contrast, transporting hydrogen by truck, whether as a gas or a liquid, is substantially more expensive – around 3.3 €/kg per 1,000km. Furthermore, when considering the additional costs of extracting and purifying hydrogen at the point of use, this is normally required for fueling a FCEV, the total distribution cost for trucking increase to approximately 8.5 €/kg for a 1,000 km journey.

These numbers paint a clear picture: while pipelines currently offer an efficient and cost-effective solution for hydrogen transportation, the allure of localized production – with its potential for cost savings and energy independence – cannot be ignored. By producing hydrogen closer to where it will be used, consumer industries can potentially bypass the transportation costs.

Hydrogen production localization is not free from challenges. It demands investment in local infrastructure (e.g., WtH facilities with onsite HRS) and technological advancement, yet offers the attractive prospect of greater control, reduced transportation costs, enhanced self-reliance, and a boost to local economies.

Environmental benefits of WtH approaches

WtH technologies are also emerging as a promising solution from an environment and sustainability perspective. It can aid in the reduction of GHG emissions, the enhancement of air quality, and a mitigation of the negative impacts of inefficient waste disposal methods.

By transforming waste, WtH helps avoid the emissions traditionally associated with conventional waste disposal methods like landfilling and incineration. By diverting waste from landfills and utilizing it for hydrogen production, methane emissions emitted from landfills can be decreased and in turn lead to a smaller carbon footprint. The mitigation of methane emissions can be regarded as a CO_2 sink, for example, when agricultural residues like manure or dung are used as feedstock.

Converting waste to hydrogen minimizes carbon dioxide emissions since hydrogen usage produces only water vapor as a byproduct. Further, this technology serves to reduce the release of pollutants such as nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM) when compared to the combustion of fossil fuels. Utilizing waste-derived hydrogen produces negligible pollutants, benefiting air quality and reducing associated health risks.

Simultaneously, the recovery of energy from waste promotes a circular economy approach, reducing the environmental impacts of inefficient waste management and extracting value from materials that would otherwise be disposed as waste.

Finally, the usage of hydrogen produced from waste as an energy carrier enables the integration of renewable energy into the grid. Excess renewable energy, including that generated from WtE plants, can be stored for a longer duration as hydrogen to ensure a stable energy supply during low generation periods too, i.e., grid balancing. This enhances grid stability and supports the viability of renewable energy systems.

Partner Spotlights from the Clean Transportation Alliance

The Clean Transportation Alliance (CTA), backed by QUANTRON, represents a collaborative effort among technology firms, industry experts, and energy suppliers united in their mission to achieve decarbonization. This alliance emphasizes the importance of forming partnerships to foster a supportive ecosystem for Quantron-as-a-Service (QaaS), a unique and comprehensive solution for fleet operators to decarbonize. Concentrating on zero-emission mobility, the CTA supports QUANTRON to adopt a technology agnostic approach, incorporating both battery electric and fuel cell vehicles tailored to specific end-use applications and customer requirements.

By collaborating with WtH technology companies, the CTA will aid in accelerating the establishment of hydrogen infrastructure as part of regional industrial initiatives. Such partnerships enable local hydrogen production, significantly reducing the costs related to hydrogen transportation, and thereby enhancing the overall efficiency and sustainability of the hydrogen supply chain.

UNIWASTEC

Location:
Rotkreuz, Switzerland
Technology:
Evaporation electrolysis
Resource:
Wastewater or seawater
Output: Up to 15,000 t H_2 p.a.

UNIWASTEC, a Swiss WtH technology company, offers comprehensive services to help industries transform waste into green energy. Their approach involves converting municipal and industrial waste into green electricity, utilizing an innovative method to generate purified, climate-neutral hydrogen. What sets their technology apart is the use of seawater or wastewater for hydrogen production, significantly reducing water consumption by eliminating the need for precious drinking water and lowering energy requirements compared to traditional electrolysis processes. This approach ensures sustainable and efficient hydrogen production.

FusionOne Energy Corp. is an innovative leader in the clean energy sector, pioneering the conversion of plastic waste into valuable hydrogen and electricity. The proprietary technology, including the advanced HydroPlas Reactor™, sets the company apart as they create a zero-emission future by diverting plastic waste from landfills and converting it into clean, sustainable energy. Committed to the commercialization of this technology, FusionOne is leading the charge towards a greener planet and a sustainable energy landscape. Company efforts align with global initiatives to lower energy bills, achieve climate goals, and electrify homes, businesses, and transportation. FusionOne is dedicated to advancing clean power solutions and investing in the future of energy, creating a circular economy that benefits both the environment and society at large.

FUSIONONE

Location:
Toronto, Canada, USA
Technology:
thermal decomposition
Resource:
Plastic.
Output: Up to 2,000 t H_2 p.a.

Location:
Gothenburg, Sweden
Technology: High temperature conversion
Resource: All types of waste
Output: Up to 12,000 t H_2 p.a

Plagazi AB aims in fostering a circular economy, advancing renewable energy sources, and enhancing waste management practices. Their core business revolves around designing, developing, and building plasma gasification facilities aimed at converting diverse waste materials into green hydrogen. Their approach places a strong emphasis on energy efficiency, environmental sustainability, and their contribution to a circular economy.

BtX Energy, born from a research and development initiative by WS Wärmeprozesstechnik GmbH, stands at the forefront of direct steam reforming technology for biogas. They specialize in sourcing biogas from pure residual materials such as liquid manure and plant residues, resulting in high-purity hydrogen production without the need for further processing steps. Their expertise lies in tailoring bespoke energy solutions to suit various needs, be it a farm with a biogas facility or a production facility, aligning these individualized energy concepts with their greenhouse gas reduction objectives.

Location: Hof, Germany
Technology: High temperature conversion
Resource: Biogas (existing biogas plant)
Output: pilot system 100kg H_2 per day

Location:
Peißenberg, Germany
Technology: Patented carbonization process with thermal gasification
Resource: sewage sludge, organic waste, digestate, liquid manure, farmyard manure, tree cuttings and green waste (= input materials).
Output: Up to 600 t H_2 p.a.

blueFLUX Energy AG is a German high-tech company that specializes in transforming organic waste into green hydrogen and other sustainable energy sources. The focus is on the development and construction of H_2 generation plants that use a patented carbonization process to produce green hydrogen, synthesis gas, synthetic lignite substitutes and biochar from organic residues. The technology solves two main problems. The utilization of organic residues and the generation of sustainable energy. The blueFLUX technology is a decentralized solution that uses the residual material flows from the region to generate energy for the region. The first demonstration plants have been running for four years and several demonstration projects are currently being built and installed.

Green Hydrogen Technology (GHT), a German technology provider, offers an innovative solution for industries seeking to convert non-recyclable plastic waste and biogenic materials into climate-neutral hydrogen. Their decentralized approach encourages industries to utilize local infrastructure, reducing transportation costs and promoting safe, residue-free energy production, ultimately facilitating climate-neutral hydrogen production on an industrial scale.

Location: Augsburg, Germany
Technology: High temperature conversion
Resource: Sewage sludge, plastic and wood waste
Output: Up to 5,000 t H_2 p.a

Uniwastec

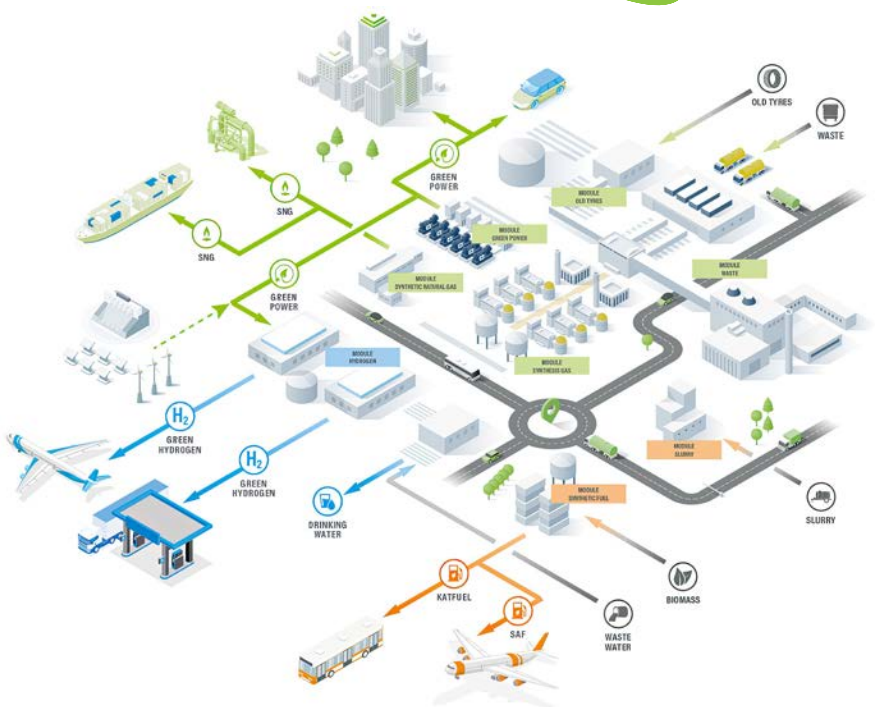
UNIWASTEC, a Swiss start-up, has emerged as a pioneering system provider in the domain of sector coupling, thanks to its innovative Waste-2-Energy systems. These technologies are capable of processing almost any type of solid and liquid waste, converting it into green, emission-free energy and valuable raw materials. This approach not only addresses waste management issues but also contributes to energy production, thereby promoting sustainable cycle closure.

A key feature of UNIWASTEC's technology is the thermolytic conversion of municipal and industrial waste into green electricity. This electricity powers a novel process that employs seawater or wastewater to generate highly purified, climate-neutral hydrogen. This method stands out for its minimal water consumption, as it does not rely on freshwater resources. Additionally, it is more energy-efficient compared to traditional electrolysis methods, making it a sustainable solution for hydrogen production suitable for various uses.

Further enhancing its portfolio, UNIWASTEC offers synthetic natural gas, green electricity, synthetic fuel, and high-purity green hydrogen derived from diverse waste materials like used tires, sewage sludge, manure, biomass, and wastewater. The company's patented technologies stand out for being emission-free and more energetically efficient than existing market solutions. These technologies do not

UNIWASTEC

depend on membranes, filters, or chemicals and produce high-quality materials and energy products. UNIWASTEC's comprehensive services range from project planning and engineering to financing and plant operation, offering an all-inclusive solution for clients. Under the leadership of CEO Urs Pelizzoni, UNIWASTEC has formed a strategic partnership with QUANTRON. This collaboration aims to revolutionize the future of transport and energy sources, integrating UNIWASTEC's waste-to-energy expertise with QUANTRON's sustainable mobility knowledge.



Urs Pelizzoni, CEO of UNIWASTEC, explains:

The future of transport is carbon neutral and includes new, smarter energy sources. The cooperation between QUANTRON, a world-class mobility provider and its innovative QaaS transport model, and UNIWASTEC, a global provider of climate-neutral hydrogen that offers market-leading waste-to-energy solutions based on outstanding patented technologies, facilitates a unique strategic collaboration. We are very pleased to engage in this partnership. Together with QUANTRON, we are now able to offer customers the entire end-to-end solution while simultaneously realising our shared vision of a carbon-neutral green future.

FusionOne

FusionOne Energy Corp., a leader in technological innovation, is revolutionizing the hydrogen production industry by converting one of the most problematic waste products, plastics, into clean energy. The world is now producing the equivalent weight of nearly 25,000 Empire State Buildings of plastic waste in a year, and almost 80% of them ended up in landfill. FusionOne's groundbreaking HydroPlas™ reactor not only addresses this environmental crisis by reducing plastic waste but also generates zero-emission energy, marking a significant step towards ecological sustainability.

The company's technology efficiently produces fuel cell-grade pure hydrogen and zero-emission electricity, positioning the HydroPlas™ System at the forefront of advanced Thermal Decomposition Technology. Optimized specifically for processing plastic waste, FusionOne's system also handles multiple carbon-based feedstocks, yielding a variety of sustainable commercial products, including high-grade hydrogen and clean electricity.

FusionOne has been actively working towards commercializing its technology. They are focused on securing a sustainable supply chain within North America and fostering solid partnerships with vital suppliers of components. The company has successfully operated its initial system since the first half of 2022, and this system is located at Detroit, Michigan. This project serves as FusionOne's technical demonstration, showcasing their technology in a phase prior to full commercialization. Here, they will pull together all of the individually proven technologies and combine them into a fully operational system. The selected location has been granted conditional use as a recycling site, including all the required waste handling permits. FusionOne will process multiple waste streams and optimize the integration of the Hydrogen Production facility to prove the system is ready before commercial operations commence on-site.

The strategic choice of FusionOne's initial site will derisk the typical two-year timeline required for site sourcing, infrastructure development, and operational permitting by utilizing a facility with a history in multi-stream waste handling. Equipped with truck and rail docks, plus a rail freight terminal, the site ensures

swift feedstock delivery and efficient dispatch of products. This infrastructure paves the way for hydrogen-powered local transport, fostering partnerships with local governments for green transport solutions.

FusionOne and Quantron AG are synergizing their expertise to forge a sustainable path forward in the transportation sector with sustainable hydrogen fuel derived from recycled plastics. The proprietary HydroPlas™ technology is part of the driving force behind this venture, processing waste plastic streams into zero-emission hydrogen fuel, and targeting feedstock-rich, fuel-hungry warehouses, distribution centers, and ports.

This initiative is more than an advancement in clean energy —It's a unifying mission that brings together the pioneering technology of FusionOne with the robust hydrogen fuel cell vehicle portfolio of QUANTRON.

The CEO of FusionOne Elliott Talbott states:

We're embarking on an exciting journey with QUANTRON, leading to a comprehensive, zero-emission solution for heavy goods mobility. This collaboration will accelerate the deployment of our HydroPlas™ system across North America, converting waste to clean fuel and powering a new generation of QUANTRON class 8 trucks. Our joint efforts will significantly amplify the impact of each mile driven by QUANTRON's trucks, turning waste plastic into energy and clearing the path towards a more sustainable future.

As we join forces with QUANTRON and other partners in the Clean Transportation Alliance, FusionOne is excited to contribute to a greener future, where every mile traveled by a fleet is a step towards reducing plastic waste and promoting zero-emission transportation.

Plagazi

At Plagazi, the vision is clear: to contribute to a circular economy and build a better future for our planet. By focusing on cost-effective and large-scale green hydrogen production, they are addressing two crucial challenges simultaneously. Firstly, they tackle the issue of non-recyclable waste by treating various waste types such as auto-shredder residue, contaminated plastics, industrial waste, hazardous waste, and even difficult biomass. Secondly, they offer a sustainable solution to reduce the carbon footprint by producing green hydrogen.

Plagazi's patented Swedish technology is the key to their success. Through plasma gasification, they are able to convert waste into green fuel cell grade hydrogen with an exceptionally high purity level. This clean fuel can be utilized across a wide range of applications, from fuel cells to industrial processes, providing a versatile and sustainable energy source.

Torsten Granberg, CEO of Plagazi, strongly believes that the technology aligns perfectly with the requirements of sustainable mobility.

PLAGAZI
GREEN HYDROGEN FROM WASTE

12'000 tons of green hydrogen / year

51 MW green hydrogen / year

10 MW district heating / year

66'000 tons non-recyclable waste / year

KÖPING HYDROGEN PARK BY PLAGAZI™

The shared vision of Quantron AG on the future of sustainable, zero-emission road transport in Europe as well and its synergy with waste-to-hydrogen as a hydrogen-supplying technology and enthusiasm between the two companies make this collaboration even more exciting.

Plagazi, converts all types of waste into green hydrogen through plasma gasification. The production process is highly energy efficient self-sufficient and environmentally friendly by not producing any dangerous by-products. We work towards a circular economy and for a better future.

Plagazi is the solution to cost-effective and large-scale green hydrogen production by treating non-recyclable waste types and is the solution to a reduced carbon footprint. Plagazi's green hydrogen has a very high purity and can be used for everything from fuel cells to industrial processes.

Gustav Granberg, CEO of Plagazi:

Establishing a strategic cooperation agreement with a leading and forward-thinking mobility developer such as QUANTRON creates an exceedingly interesting and promising outlook on the future of sustainable, zero-emission road transport in Europe as well and its synergy with waste-to-hydrogen as a hydrogen-supplying technology. We believe that our technology caters excellently to the location flexible requirements of sustainable mobility, and it is exciting to see that QUANTRON shares that sentiment. We very much look forward to working with them.

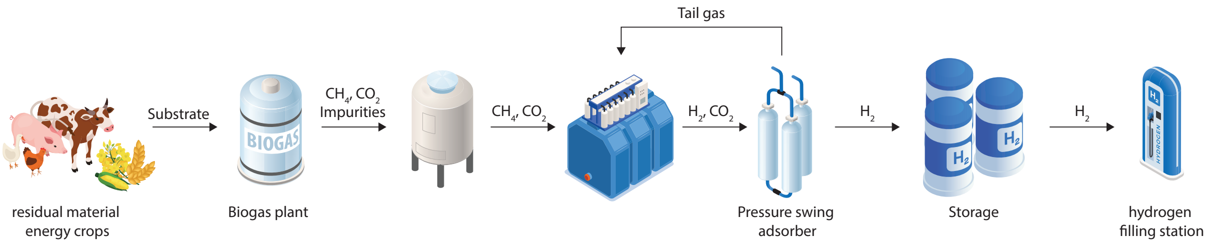
BtX Energy

BtX energy is the product of a research and development project of WS Wärmeprozesstechnik GmbH. The process patented by Dr. Joachim Alfred Wünning (founder of WS) for the clean gasification of biomass by adsorption of tars on in-process activated carbon was able to set standards for gas purity of wood gases in the accompanying dissertation by Dr.-Ing. Andy Gradel. Together with WS Reformer GmbH and eflox GmbH, the idea of upgrading biogas through steam reforming was further developed in parallel at WS. The two applications now represent the pillars of BtX energy GmbH as a project planning office and the youngest start-up with roots in WS.

The company is currently considered the technology leader in the direct steam reforming of biogas. At best, the gas is obtained from pure residual materials such as liquid manure, dung, or plant residues that are not part of the feed chain. The biogas is desulfurized and then used directly in the steam reformer without any further upgrading steps. This produces a synthesis gas that is processed directly on site into high-purity hydrogen by means of a water gas shift stage and separation.

The company currently operates a pilot plant in Krefeld, Germany, which produces green hydrogen from 100% residual materials and

Bio-to-X - Hydrogen from Biogas



Source: btx-energy

has its own on-farm filling station. The resulting fuel has a footprint of -17 kg CO_2 per kg hydrogen due to the avoided methane emissions, even without further CO_2 capture. This means a GHG-reduction of around 270 % in comparison to diesel. The technology is CCU-ready, so another CO_2 capture unit can be added for its use, which would move the footprint even more into negative ranges. By-products without additional CO_2-Capture are clean and carbon-neutral exhaust gas and a small water only.

Thanks to this outstanding CO_2 footprint, the technology can quickly become economical via GHG quota trading; in the best case, the quota revenues exceed the production costs of the fuel. The plants produce between 100 and 400 kg of hydrogen per day per unit, the technology is market-ready and available today.

For the reforming process, any kind of biogas from all substrates can be used, such as:

- manure / sludge
- biowaste
- plant residues
- landfill Gas
- energy Crops

The waste-to-hydrogen conversion depends on the biogas yield of the substrate. The overall efficiency of the process is around 80 % (60 % hydrogen, 20 % heat). Therefore, 10 Nm^3 of usual biogas (55 %) is needed for the production of 1 kg of hydrogen. the investment costs of a plant are between 1.5 (100 kg/d) and 3 mio. € (400 kg/d). Due to the high number of full load hours, a project with an appropriate residual material ratio achieves a payback period of between 5 and 10 years.

QUANTRON's vision of a zero-emission transportation sector can thus be rapidly implemented in regional value chains by BtX reformers.

Dr.-Ing. Andy Gradel, CEO of BtX:

Quantron is setting milestones in the road transport of the future. We want to support the energy transition in the transportation sector with our biohydrogen through reliable production and best economics and are very pleased to be a strategic partner of such an innovative player.

blueFLUX Energy AG

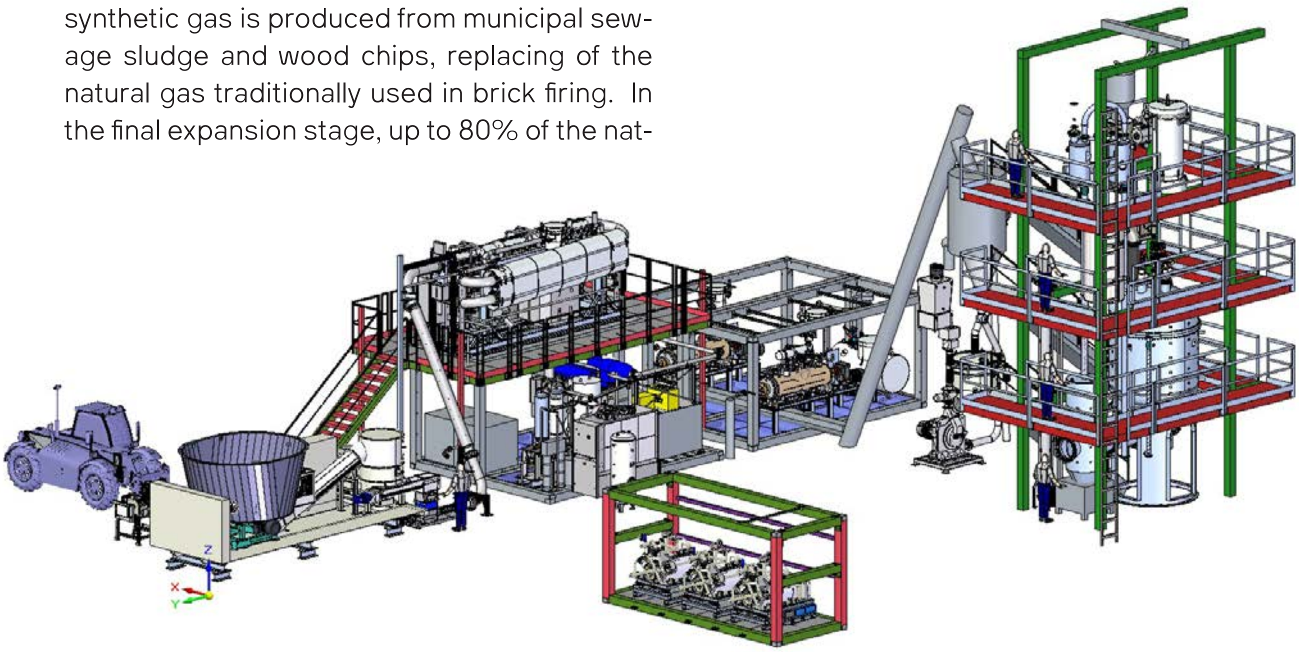
The decentralized production of sustainable hydrogen is increasingly becoming the focus of attention. blueFLUX technology exemplifies this shift by transforming materials, often viewed as waste, into valuable energy resources. This approach harnesses regional material flows to produce local energy, thereby playing a pivotal role in developing a localized hydrogen infrastructure.

At present, several demonstration projects are underway, highlighting the practical implementation of this technology. The first step is to set up the H2 model region in the district of Weilheim-Schongau, where integration in agriculture, at the sewage treatment plant and at the waste disposal company will be demonstrated and thus serve as beacons for decentralized and regional energy transition.

A key large-scale implementation project involves a brick manufacturer, where the blueFLUX process is innovatively applied. Here, synthetic gas is produced from municipal sewage sludge and wood chips, replacing of the natural gas traditionally used in brick firing. In the final expansion stage, up to 80% of the natural gas used today will be substituted, paving the way for not only a new era of sustainably produced bricks but also aligns with the broader goals of sustainable construction.

In agriculture, the 'Almwirtschaft Windkreut' project is another testament to the versatility of blueFLUX technology. Here, Agricultural residues are converted into green hydrogen for mobility, distributed via a mobile H2 gas filling plant. This project takes circularity a step further by utilizing biochar as a fertilizer substitute and soil enhancer, while the residual process heat is used in a small decentralized local heating network. This initiative exemplifies a full-circle approach, effectively linking agricultural by-products to hydrogen-powered transportation.

Both projects, currently in their construction or implementation phases, are set to connect to the grid in 2024.



blueFLUX Energy AG

The blueFLUX process offers a high degree of input flexibility, capable of processing both wet and dry materials. This adaptability allows for the mixing of different inputs to achieve an optimal dry substance content of 30%. The process begins with a patented carbonization technique, which efficiently extracts two forms of energy from the input material: steam and coal. This coal has a calorific value on par with lignite and a dry matter content exceeding 95%. The carbonization process eliminates the need for added water since the input materials naturally contain the required amounts.

Following carbonization, the coal undergoes grinding and is then converted into synthesis gas. This transformation occurs in an entrained-flow gasifier, where previously separated water vapor is reintroduced. The resulting synthesis gas, with a hydrogen content of approximately 45-55%, is further processed through a CO shift stage. Here, additional water vapor from the first process step is added, boosting the hydrogen concentration to around 65%. The final steps involve the separation, purification, and compression of the hydrogen, preparing it for use in mobility applications.

Addressing the classic 'chicken-and-egg' dilemma in hydrogen infrastructure, the blueFLUX system incorporates a mobile H2 filling station within the Almwirtschat Windkreut project. This innovative solution provides flexibility in hydrogen delivery, ensuring that hydrogen fuel is accessible and readily available at varying locations. These initiatives are not just technological achievements; they are beacons of a circular economy, where waste is not an endpoint but a new beginning, contributing to energy independence, environmental sustainability, and local economic resilience.

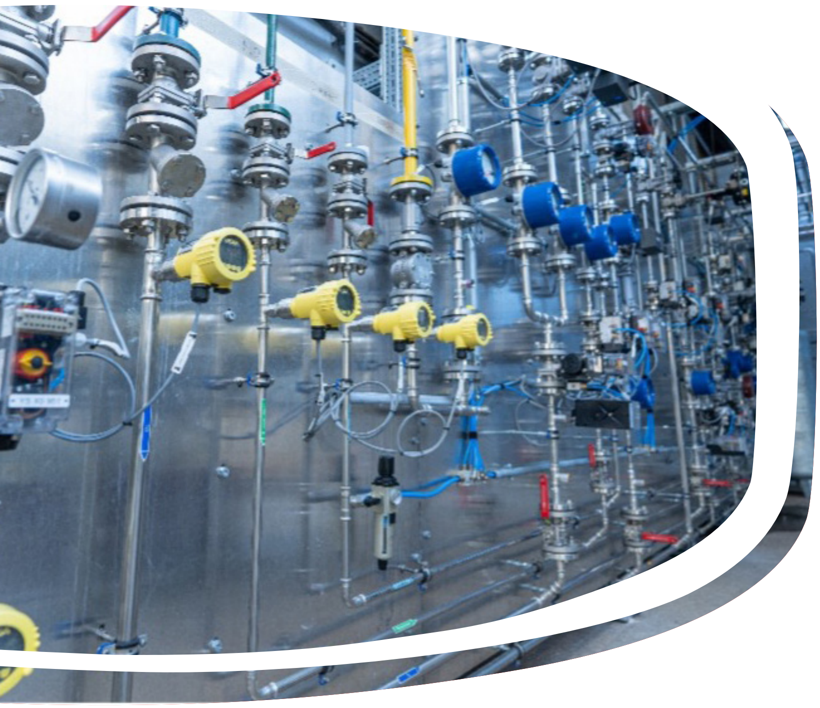
“*Dr.-Ing. Uli Mach, COO General Manager of blueFLUX Energy AG:*

Quantron's approach combines well with blueFLUX Energy AG's decentralized approach to building an H_2 infrastructure. We are all the more pleased to be able to contribute to the solution with blueFLUX technology. The mobility sector in particular will become increasingly important in the coming years due to the issue of quota revenues. blueFLUX is an expert in the materials that generate particularly exciting quota revenues for the introduction of sustainably produced hydrogen into mobility. In combination with low production costs and the decentralized approach, this results in exciting business models for operators.”

Green Hydrogen Technology (GHT)

CEO of Green Hydrogen Technology Robert Nave emphasizes the importance of a circular economy in their vision to disrupt traditional waste incineration and revolutionize decentral hydrogen production. The company presents an innovative solution to generate climate neutral hydrogen or synthetic fuel by utilizing non-recyclable plastic waste or biogenic materials (digestate, wood waste, straw, organic waste, etc). By combining upcycling, energy production and climate protection, GHT helps solve the global waste crisis but also actively contributes to the transition to climate-neutral energy sources.

GHT's production process is designed to produce large amounts of renewable hydrogen without relying on fossil fuels. The company invented a patented high temperature gasification process that effectively converts non-recyclable plastic waste or biogenic materials into a synthetic gas without producing any residuals such as tar, soot or slag and avoiding harmful substances such as dioxins or furans. Thus, the process represents a safe and reliable method for energy production. The synthetic gas can be purified to hydrogen gas (H2) and ultimately replaces fossil fuels in the mobility sector or industrial processes.



One of the key advantages of GHT's technology is its flexibility. The production plant can be adapted to accommodate locally available resources, making it suitable for diverse locations. The high production capacities of GHT plants will enable a significant number of QaaS trucks to be powered by this sustainable energy source, further promoting the circular economy.

Green Hydrogen Technology combines upcycling, energy production and climate protection. This is how truly clean hydrogen is produced from non-recyclable plastic waste or biogenic materials. With our patented technology, we actively and sustainably shape the transformation to climate-neutral energy sources.

The GHT process offers an alternative method to waste disposal and to waste incineration for many companies. Instead of paying for the disposal, the companies can use the waste as a valuable resource and locally produce the en-

ergy carrier of the future – hydrogen. A company might use hydrogen to transport their products to the end customers using QaaS trucks, thus decarbonizing a substantial part of their value chain.

Green Hydrogen Technology demonstrated the functionality of its technology with a pilot plant in under 2 years. The pilot plant is substantially above laboratory scale and can produce around 400 kg/h of synthesis gas, which contains up to 15 kg/h of hydrogen. GHT has entered a strategic partnership with ETG, a family-run waste disposal company from Baden-Württemberg with more than 800 employees, to further develop its technology and produce 100 tons of hydrogen per year starting from 2024.

Robert Nave, CEO of GHT:

Energy transition is a team sport. We are delighted to have QUANTRON, a great partner for the decarbonization of the transport sector, at our side. Our technology allows cost-effective production of green hydrogen - and with such production capacities which means many QaaS trucks can be powered with it in the future. At the same time, GHT production facilities can be supplied with these trucks in a climate-neutral manner. This is how we envision circular economy.

An Ecosystem Perspective

Ecosystems, in general, capitalize on the interconnectedness of companies. From an ecosystem perspective, WtH technology engages various communities on board for value creation and value capture. Embracing WtH unlocks the potential for forging new partnerships. Companies specializing in waste management, energy production, transportation, and various other sectors can be brought into an ecosystem to create a more comprehensive value chain around innovative WtH technologies.

The successful integration of WtH into an ecosystem demonstrates the ability of the technology and the concept of decentralized hydrogen production. With the added expertise of WtH partners on QUANTRON's zero-emission commercial vehicle platform, we broaden our portfolio of solutions to cater to customers seeking to reduce their carbon footprint. The diverse application potential of hydrogen from industrial processes to powering zero emission vehicles means that WtH approaches can cater to that wide range of end users.

For example, the hydrogen thus generated can be used to power the vehicles used to meet the logistical needs of the waste management companies as well as the waste producers. This could include applications in municipal areas such as refuse collection vehicles as well as inbound/outbound and intralogistics operations of industrial clients. Waste-derived hydrogen can thus play a vital role in decarbonizing transportation. Adopting hydrogen from waste provides another avenue to reduce the transportation sector's carbon footprint and accelerates the transition to sustainable mobility. As more companies adopt this technology, there is a greater likelihood of building a robust infrastructure for hydrogen production and distribution network locally. This will be an advantage for platform players to attract more partners on the platform, and ultimately benefits both businesses and the local economy.

To illustrate the synergy between WtH facility and an ecosystem, let's consider QUANTRON and its potential partners as an example. Imagine Company A, a logistics company, is keen on reducing the carbon footprint of its fleet and reaches out to QUANTRON for Fuel Cell Trucks (FCTs) with bundled hydrogen solutions. As QUANTRON begins to provide pricing options, it becomes apparent that Company A has a partner, Company B, which operates an on-site industrial production facility and generates waste.

In this scenario, QUANTRON, as an ecosystem orchestrator, can introduce a WtH partner into the mix. It can offer Company B the benefits of WtH technology as a waste management solution. The hydrogen produced through this process can then be utilized to refuel Company A's FCTs without the need for additional route planning or added logistical complexities.

Moreover, if there are other FCTs operating in the same area, they too could benefit from this WtH-generated hydrogen, creating an additional economic advantage.

In this way, QUANTRON, as the ecosystem orchestrator, plays a pivotal role in assisting both Company A and Company B in their efforts to reduce carbon emissions.

Simultaneously, the WtH technology gains new customers, further enhancing its reach and impact. This symbiotic relationship showcases how ecosystems can bring together different stakeholders with WtH technology on board, creating a win-win scenario that fosters sustainability and business growth.

Example: Ecosystem built around industrial waste

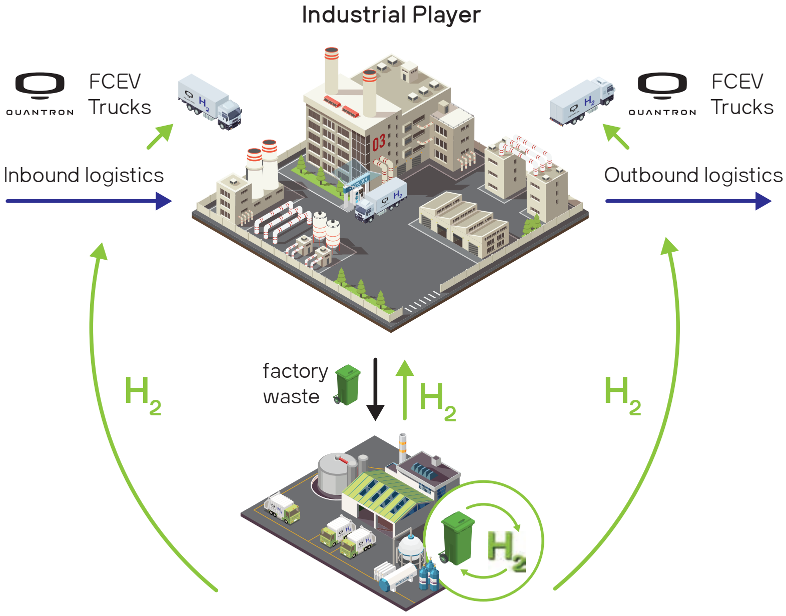
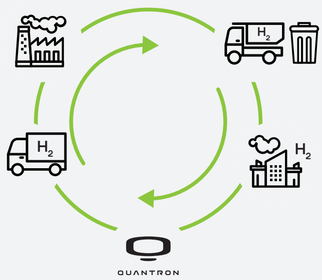


Figure 7

Innovative Partnership



- Logistic company decarbonize their transport business with QUANTRON FCEVs
- Building waste-to-hydrogen plant to collect waste from factory to produce hydrogen
- QUANTRON delivers FCEV trucks to guarantee uptake of hydrogen
- Potentially bundled in QaaS

Conclusion

Waste-to-hydrogen (WtH) technology as a complementary to the green hydrogen produced by electrolyzers offers a compelling proposition from multiple standpoints. From an environmental point of view, WtH contributes to sustainability by significantly reducing greenhouse gas emissions and air pollution compared to traditional waste disposal methods, such as landfilling or incineration. Furthermore, it diverts waste from landfills, extending their lifespan and reducing environmental risks. From an energy perspective, hydrogen, produced through WtH, serves as a versatile and clean energy carrier, supporting various applications and aiding in the transition to cleaner energy sources. It can also be used to balance energy grids and store excess renewable energy. Economically, it generates job opportunities and opens new revenue streams, while also attracting investments due to its alignment with sustainability goals. Additionally, it enhances energy resilience at the local level and benefits from regulatory support, making it a holistic and attractive solution for both the environment and businesses. WtH aligns with the principles of the circular economy by recovering valuable resources from waste streams and reducing resource depletion.

Several countries around the world have already been exploring and implementing various waste-to-hydrogen technologies. For example, three major Japanese corporations — car maker Toyota, industrial gases giant Iwatani and JGC Holdings – agreed to explore a joint hydrogen production business using waste plastic gasification facilities in the Nagoya Port area. The target of this project is to produce 11,000 tons of hydrogen from 80,000 tons of waste plastics per year. Also, Egypt and Oman chosen by WtH company to develop a $1.4 billion waste-to-hydrogen plant will initially convert one million tons of municipal solid waste each year. In America, Raven SR Inc., a leader in renewable fuels, together with Chevron New Energies, a part of Chevron Corporation, announced their collaboration to advance the commercial operations of a sustainable WtH production facility located in Richmond. This initiative is aimed at providing hydrogen fuel to transportation sectors across Northern California, emphasizing the commitment to green energy and sustainable fuel solutions.

From a company point of view, WtH technology fosters partnerships among various sectors, from waste management to energy and transportation. It creates a comprehensive and interconnected value chain. Its successful integration demonstrates the viability of decentralized hydrogen production, significantly expanding service providers' portfolios and offering diverse applications, from industrial processes to fueling hydrogen-powered vehicles. In addition to supporting the decarbonization efforts for these applications, scaling up waste-to-hydrogen facilities also provides tangible benefits to the local economy and promotes sustainability and circularity.

QUANTRON, as an ecosystem builder and orchestrator, is committed to connecting partners from various backgrounds in pursuing our vision of decarbonizing commercial vehicle transportation. Together with the partners in our Clean Transportation Alliance, including the ones working on promising WtH technology approaches, we are convinced that we will contribute to reducing carbon emissions and expanding its reach together. This synergy and integration of multiple hydrogen production and distribution technologies and pathways into local, regional, and global ecosystems will further promote growth and sustainable development of all partners.

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EDITORIAL TEAM

Lead Authors & Editors: Dr. Srinath Rengarajan, Jiaen Li

Experts & Contributors: Andreas Haller, René Wollmann, Jörg Zwilling, Martin Lischka, Donato Azarone, Lucas Schubert, Julia Schreier, Pranav Jaju, Julia Weber

Design & Digital Production: Andreas Peake, Carolin Risinger, Koorosh Shojaei, Nadine Otremba, Ataman Özölçer

We would like to thank our partners from Clean Transportation Alliance for their contributions.

For further information, please contact info@quantron.net

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First Print: March 2024

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QUANTRON

Quantron AG
Koblenzer Straße 2
86368 Gersthofen/Augsburg, Germany
Phone: +49 (0) 821 78 98 40 - 0
Fax: +49 (0) 821 78 98 40 - 99
Mail: info@quantron.net
www.quantron.net