WHITE PAPER

Turning the European Green Hydrogen Dream into Reality: A Call to Action

Without additional regulatory support, European green hydrogen may remain the fuel of the future

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The Dream of Green Hydrogen to Become Reality?

Green hydrogen is a critical element to achieving net-zero emissions

As we stated in our 2019 publication *The Real Promise of Hydrogen*, low-carbon hydrogen and associated synthetic fuels like methanol and ammonia are indispensable to decarbonizing large sectors of the global economy.

While a broader range of low-carbon hydrogen colors will be needed during the decarbonization journey, a fossil-free target state will require green hydrogen. To be able to enable the continent's ambitious climate targets, Europe's green hydrogen market finally needs to scale within this decade.

Europe's hydrogen market is beginning to take shape …

After a decade of much debate, a meaningful hydrogen market and a multibillion-euro market for green hydrogen now seems to be emerging on the horizon. A good deal of this is driven by a flurry of **regulatory activity across the hydrogen value chain:**

- Subsidy schemes are emerging to support investments in **hydrogen production**, such as the Dutch SDE++ for domestic projects or the European Hydrogen Bank and H2Global for imports.
- **Infrastructure** access is starting to become clearer, as the development of first elements of the European hydrogen backbone is being expedited in several countries—with the support of the EU IPCEI scheme.
- **Hydrogen demand** is being stimulated by investment subsidies (such as for the thyssenkrupp DRI steel plant) and by ongoing discussions on consumption subsidies (such as the German carbon contracts for difference for potential industrial offtakers). Germany is also planning auctions for its first hydrogen-only backup power plants.
- The recently agreed **RED III** imposes the mandatory use of RFNBO (including green hydrogen) for EU industry consumption by way of quotas.[1] Further, a combined subtarget of 5.5% for advanced biofuels and RFNBOs was agreed upon, with a minimum requirement of 1% RFNBOs supplied to the transport sector in 2030.

Meaningful demand is expected to emerge if planned regulations come into effect. Several industrial sectors, primarily current gray hydrogen consumers, may be willing to pay around or above €6/kg for green hydrogen by the end of the decade.

Refineries will contribute significant volumes to this demand. Despite some uncertainty regarding RED III implementation details,[2] oil players are already taking action. For instance, BP and Total are willing to pay a €12.6B premium for 7 GW offshore wind power generation that secures them green hydrogen at a cost above €6/kg.

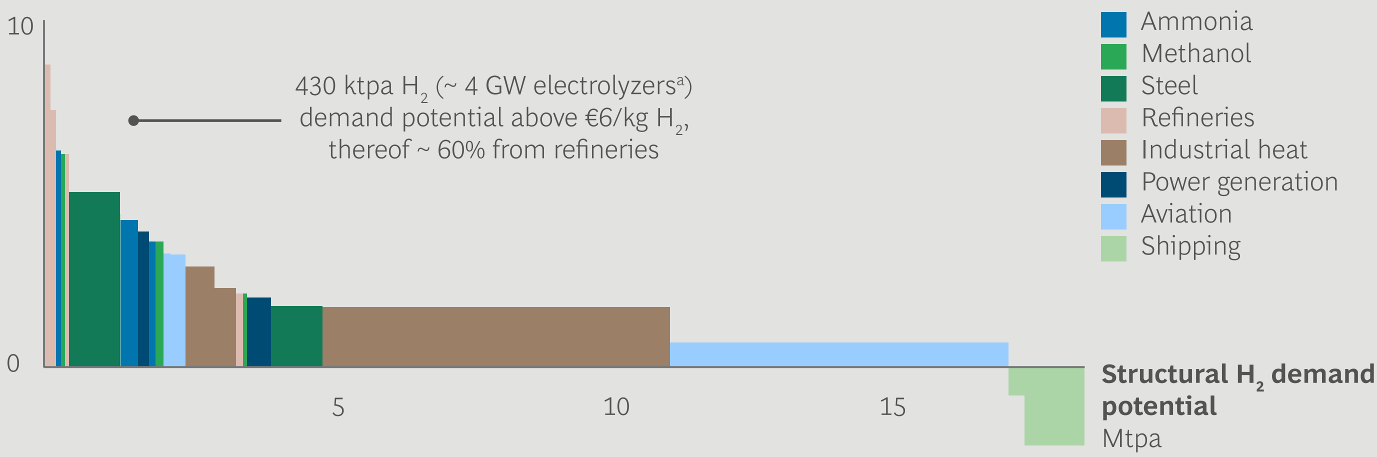
Additional sectors such as ammonia and methanol production are also relevant, along with the portion of Europe's steel industry capable of selling premium green steel. In Germany and the Netherlands alone, this "**high-price plateau**" could drive approximately 1 Mt of green hydrogen demand annually by 2030, equivalent to over **10 GW of electrolyzer capacity**.

And as demand is taking shape, so is hydrogen supply. A number of project developers are currently driving industrial-scale green hydrogen projects to final investment readiness. Again in Germany and the Netherlands alone, a total pipeline of 23 GW in electrolyzer capacity by 2030 is currently in planning, with 4 GW already at least in the FEED phase.

Germany 2030: ~ 0.4 Mt green hydrogen demand potential above €6/kg

Exhibit 1: Hydrogen demand merit order for Germany in 2030

German green hydrogen offtakers' willingness to pay in 2030
€/kg H_2 (base case)



a. Assuming 65% electrolyzer efficiency (LHV) and 5,000 full load hours

Source: BCG analysis

… but it is not yet taking off

And yet, **investment decisions are still pending**. Europe's hydrogen market still needs to overcome several major barriers to reach its actual potential.

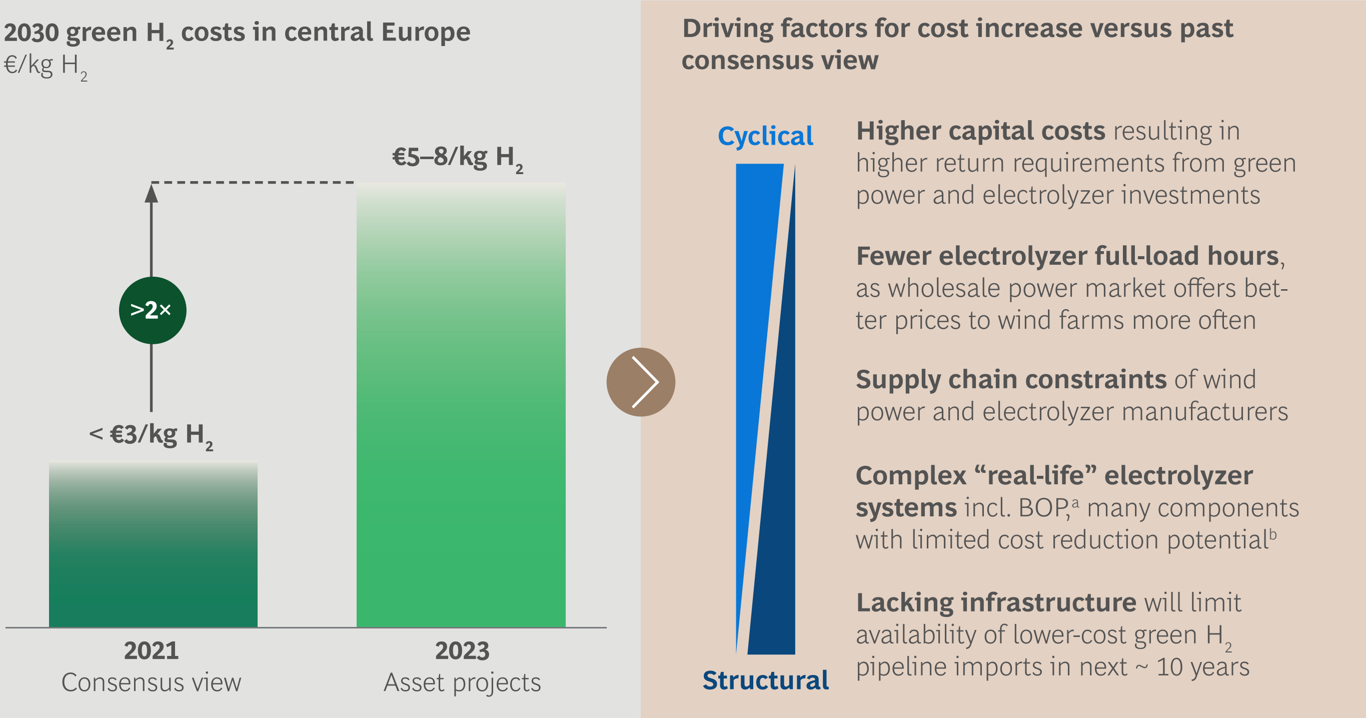
Optimistic cost projections are not materializing. Just a few years ago, the consensus view expected green hydrogen production costs below €3/kg; see exhibit 2. Meanwhile, a deteriorated macroeconomic context, higher energy market prices, and structural challenges in the wind power and electrolyzer supply chains prove these costs unrealistic, at least for the coming decade. As a result, real hydrogen asset projects currently in development suggest green hydrogen production costs in the range of €5–8/kg in 2030 for central Europe.

Even at the lower end of these costs, green hydrogen is not competitive with alternative decarbonization technologies for most potential consumers. At the higher end, green hydrogen producers would struggle to find offtake at all.

1. The RED III quota requires the mandatory use of at least 42% RFNBO—effectively green hydrogen—of EU industry's total hydrogen consumption by 2030 and 60% by 2035.
2. It is not yet clear to what extent refineries' hydrogen consumption will be considered within RED III industry versus transport sector quotas and how relevant multipliers for the transport sector quota will be set in the future.

Real asset projects reveal much higher green hydrogen costs than past consensus views

Exhibit 2: Green hydrogen wholesale price projections in Europe in 2023



a. BOP = balance of plant

b. Such as power electronics or gas conditioning, which are already standard components in utility-scale applications

Source: BCG analysis

Cost sensitivity to green hydrogen production

The cost of **delivered green electricity** still remains the largest factor determining overall green hydrogen economics. As a result of a higher cost of capital and structural supply chain challenges of wind power system manufacturers, the levelized cost of power has significantly risen in recent years and is likely to remain above pre-crisis levels during this decade. Also, given that green hydrogen in most European countries has to be produced from additional non-subsidized renewables, electrolyzers are competing for green power with skyrocketing wholesale prices on the captured-power market.

High **electrolyzer utilization** can be a major lever for decreasing hydrogen production costs—but will come at a trade-off with green power costs in most locations. However, by following an **integrated approach** to location choice, renewable electricity production, electrolyzer configuration, and power market situation, hydrogen project developers can achieve significant production cost advantages over their competitors.

Electrolyzer system costs have not dropped yet and are not likely to fall as fast as expected a few years ago.

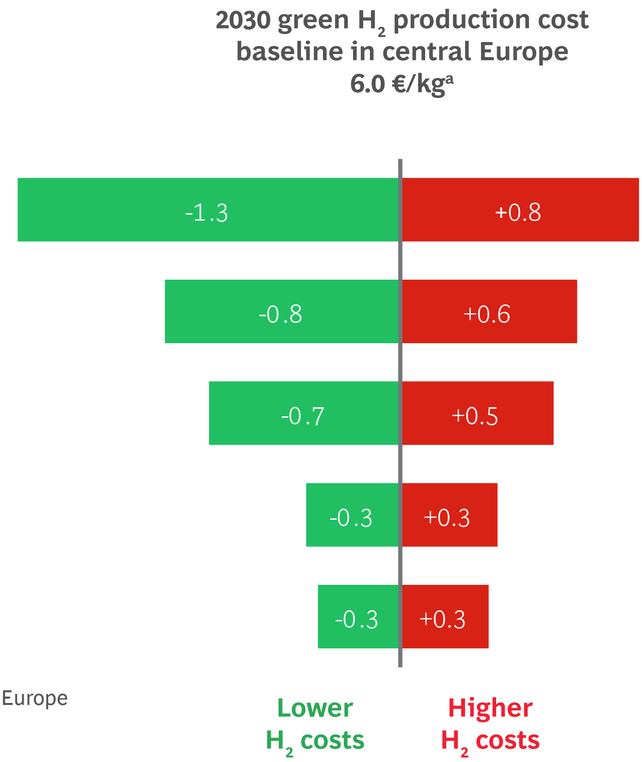
Structural supply chain constraints on the part of electrolyzer manufacturers as well as more-complex-than-expected system designs result in persistently high electrolyzer system costs. Updated assessments also suggest limited cost reduction potential for many components already being used today on an industrial scale, such as power electronics or gas conditioning. Decreasing electrolyzer system costs can be achieved by streamlined project development processes and capabilities, closer collaboration across the value chain, and scale in the project portfolio.

Optimizing **electrolyzer efficiency** can help push down the cost of hydrogen production. However, large improvements in these factors will entail a trade-off with electrolyzer CAPEX.

Low-cost green electricity at high electrolyzer utilization as major drivers for attractive hydrogen economics

Exhibit 3: Green hydrogen production cost sensitivities

	Baseline value	Sensitivity analysis
Delivered (green) electricity (€/MWh)	65	-25/+15
Electrolyzer utilization (%)	55%	+25/-10 pp
Electrolyzer system costs (€/kW)	1,700	-500/+400
Electrolyzer WACC (%)	8%	±2 pp
Electrolyzer efficiency (%)	62%	±3 pp



a. Real in 2023, representative of current asset project cost projections in central Europe

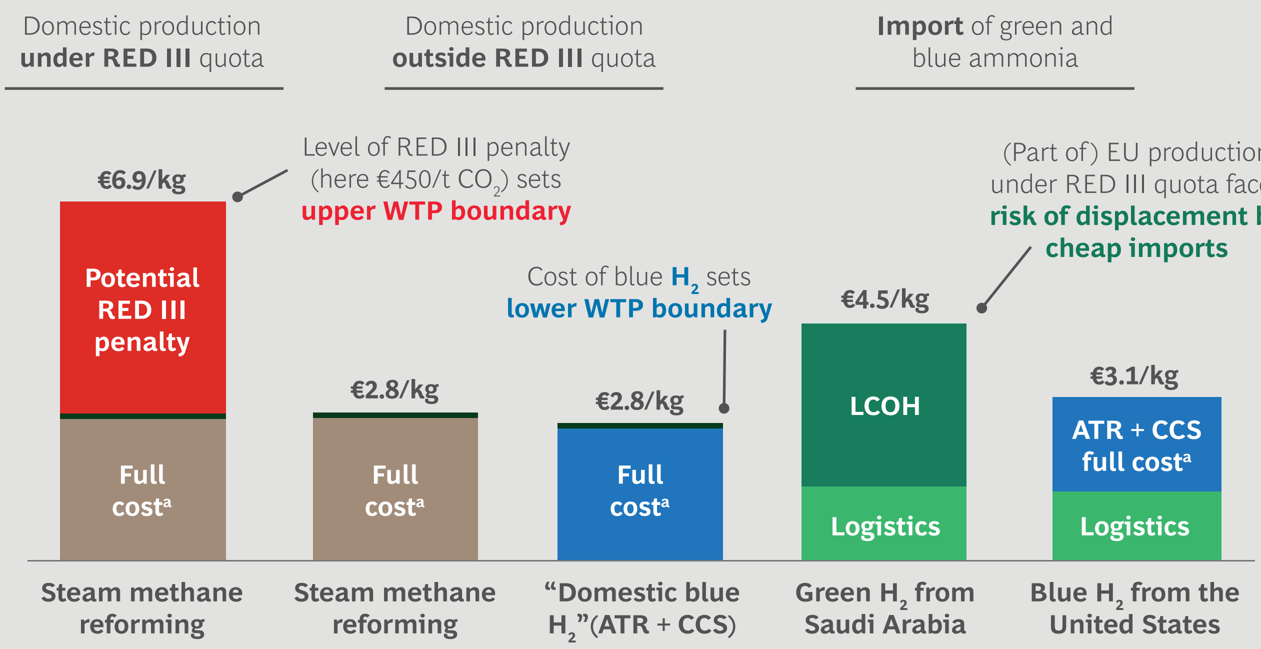
Note: Electrolyzer life span of 15 years and electrolyzer OPEX of €0.3/kg H_2

Source: BCG analysis

Major offtakers are themselves at risk. Cheaper green end-product imports pose a significant threat to offtakers in sectors like ammonia, methanol, and steel. The European ammonia industry already lost significant market share during last year's energy crisis. At domestic green hydrogen prices beyond €4–5/kg, European producers would hardly be able to compete with green ammonia imported from regions with better renewable power conditions. And this threat may only intensify over time. As the global hydrogen market matures and regions with better renewable conditions achieve steeper production cost declines, increasing European production volumes of products such as ammonia, methanol, or iron sponge will be at risk—potentially diminishing Europe's future hydrogen market potential.

Ammonia: Willingness to pay for green hydrogen determined by RED III and blue hydrogen costs

Exhibit 4: Dutch ammonia players' willingness to pay for green hydrogen in 2030



a. CAPEX, OPEX, natural gas, and CO_2 costs for steam methane reforming, ATR, and CCS, respectively

Source: BCG analysis

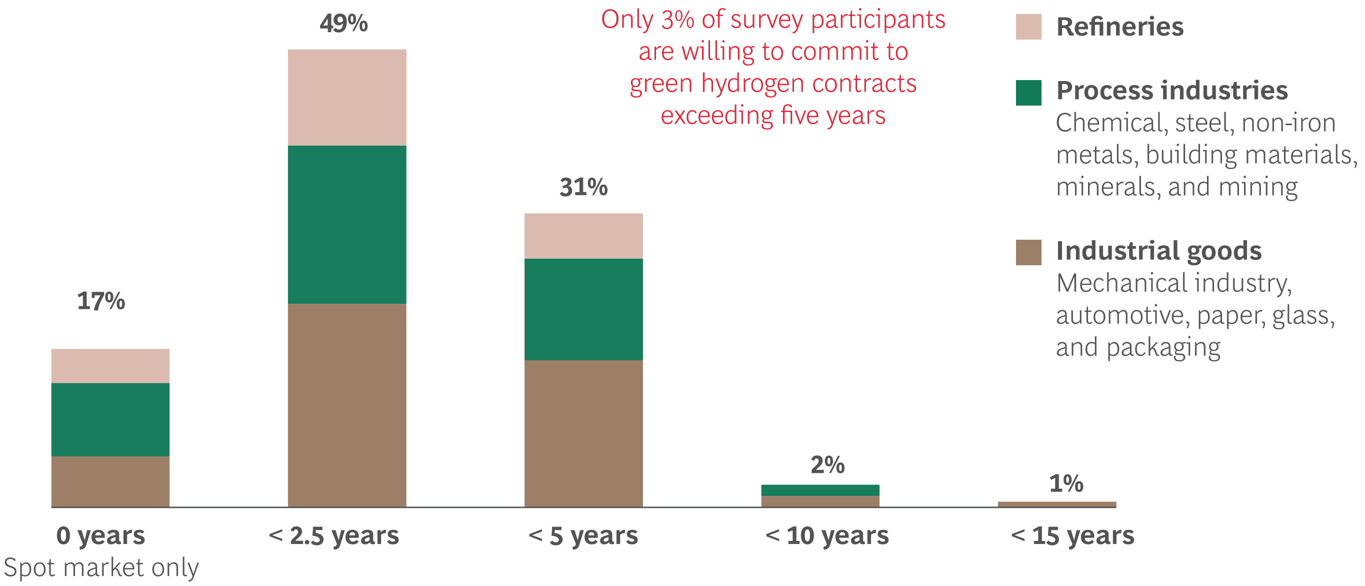
Offtakers are unable to commit to long-term contracts. With the common market expectation of decreasing production costs from new projects over time, offtakers of green hydrogen are very reluctant to commit to long-term contracts of more than a few years.

Yet without secure long-term offtake, early hydrogen project developers face the risk of stranded assets, undermining investment prospects. This deadlock perpetuates a chicken-and-egg problem, preventing the hydrogen market from gaining faster momentum.

Very few green hydrogen customers are able to commit to long-term offtake contracts

Exhibit 5: Industry customers' willingness to commit to hydrogen contracts (survey with 166 participants)

Survey question: "What commitment period for green hydrogen supply contracts would you be most willing to enter into?"



Source: Based on responses to a customer survey with n = 166 respondents in Germany and the Netherlands across relevant sectors; BCG analysis

Policymakers aren't done yet

Despite all progress: Under Europe's current regulatory environment, domestic green hydrogen will remain the fuel of the future. Ambitious national implementation of EU regulation is needed now to create incentives throughout the hydrogen value chain.

Regulations should help bring green hydrogen costs to offtakers at least below €5/kg, given that higher costs than that would severely threaten the international competitiveness of key offtake industries, particularly chemicals and steel—even compared to green imports. To achieve this, double-sided auctioning initiatives like the European Hydrogen Bank and H2Global could be expanded in their financial volume and extended in their scope to also support large-scale domestic projects.[3] To increase the competitiveness of domestic projects in these auctions, policymakers should continue granting CAPEX funding (e.g., IPCEI) for the coming years and consider allowing green hydrogen producers to source power from new renewable generation with state-backed price guarantees like carbon contracts for difference schemes.[4] Beyond 2030, other green hydrogen cost decreases toward €3/kg will require electrolyzers operating at maximum capacity at the lowest possible green power costs. Turning this European hydrogen dream into reality will require regulators to immediately accelerate the deployment of low-carbon power, grid, and storage infrastructure, and to stimulate demand-side flexibility.

Upcoming demand-side regulation needs to create sufficient willingness to pay. For existing gray hydrogen producers such as refineries and chemical companies, RED III is planning firm quotas for green hydrogen shares. To generate a willingness to pay beyond €5/kg, this would need to carry hefty noncompliance penalties of around €450/t CO_2. In parallel, Europe should establish frameworks that enable producers of green commodities to sell at a premium. For example, green steel or fertilizer quotas would allow key green hydrogen offtakers to pass additional costs on down the value chain.[5] Finally, any demand-side subsidy schemes should be tailored to specific industries. For example, if Germany's carbon contracts for difference tenders were industry-agnostic, a company aiming to shift from natural gas to hydrogen-based steel production would have to compete against a company electrifying its heat generation at a much lower cost. In practice, this would decelerate decarbonization efforts in all industries where decarbonization is comparatively expensive and drastically limit short-term hydrogen demand.

The development of hydrogen infrastructure must not be delayed. To create infrastructure clarity for producers and offtakers alike, policymakers need to impose ambitious planning through grid agencies, create favorable investment conditions through incentive regulation and public funds, and prioritize the rapid deployment of transport and storage infrastructure. Connecting EU industrial centers with the lowest-cost hydrogen production sites should be a priority for the decade ahead.

Exact design of only a few regulations will strongly impact the European green hydrogen market

Exhibit 6: Key regulations needed to enable the takeoff of the European green hydrogen market

	H_2 supply	Refineries	Chemicals	Steel	Power	Infrastructure
Goals	Bring H_2 costs to offtakers **below ~ €5/kg**	**Raise willingness to pay above €5/kg H_2** for relevant volumes to match expected supply				Create **clarity** within this year
Regulatory instruments	Expand funds for **H2Global/the Europ. Hydrogen Bank** (EU) and **SDE++** (NL) Extend **H_2Global/the European Hydrogen Bank** to large-scale domestic projects **Decrease LCOH:** Electrolyzer CAPEX funding, RES CfD for green H_2 production, accelerated deployment of RES, power grids, and demand-side flexibility	RED III noncompliance penalty **~ €450/t CO_2**		**Green steel quota**	Incentives for **new H_2 capacity**, e.g., targeted H_2 backup tenders Financing of the gap between **H_2 and natural gas**, e.g., CCfDs **Use of existing mechanisms** to speed implemention[c]	NL: already clear perspective given DE: finish H_2 concept within ’23 as planned Implement H_2 in **grid developm. plan** and **incentive regulation** Ensure **initial public funding and planning** and decisions similar to German LNG act
		Adjust e-mobility multiplier[a] to set conditions for **HBE/GHG quota of > €3/kg**	**Sector-specific demand-side subsidies[b]**			
			RED III applicability also on **imported end products**, e.g., fertilizer			
			Evaluation of (subsidized) local **“safety reserve” volume** production			
				Sufficient DRI CAPEX subsidies		

a. To prevent the market from being flooded with certificates when e-mobility scales up

b. E.g., through targeted climate protection agreements in Germany and continued rollout of tailor-made agreements in the Netherlands

c. Climate protection agreements and power plant tenders in DE, SDE++, and tailor-made agreements in NL

Source: BCG analysis

3. Such public tender schemes would also help alleviate the “contract duration dilemma.”
4. In many European power markets, wholesale prices will exceed the levelized cost of renewable power production during many hours in any given year throughout this decade. With unsubsidized renewables, this will result in low electrolyzer utilization and hence higher green hydrogen prices. Green hydrogen produced from renewable sites under a (nominally, but not factually subsidized) carbon contracts for difference scheme would decrease the cost of invested capital and result in cheaper green hydrogen production while still providing project developers with reasonable returns.
5. Such RFNBO quotas would need to be accompanied by strict product certification rules for both domestic and imported goods.

Hydrogen players should also embrace action

The absence of decisive regulation should not prevent hydrogen players from taking action. The emerging hydrogen market is a rare market opportunity. The question is not whether it will flourish, but rather exactly when in the coming years, where, and how. Proactivity will empower hydrogen players to seize immense potential and establish a leading position in this transformative market.

Market players should embrace risk-taking and get a robust pipeline of hydrogen projects FID-ready. This will require risking significant development expenditure—but for the likely reward of faster capability buildup, privileged access to the most promising offtakers, strategic partnerships with equipment manufacturers, and higher credibility with key regulatory bodies. In earlier emerging industries like offshore wind and electromobility, early movers have reaped lasting dividends. Hydrogen seems to be the same.

The cost of green hydrogen needs to fall faster. Players should push to streamline project development and scale up collaborations with electrolyzer OEMs and EPCs. They should also reemphasize technical and economic integration between electrolyzers and renewable generation assets, often requiring close collaboration across business units.

Producers should reassess their target customer base. The emerging regulatory environment is (re)shaping Europe's demand market. Future producers should revisit their go-to-market approach and make sure they understand how upcoming regulations will impact potential offtakers' hydrogen appetite, their willingness to pay, and their (partial) default or relocation risk.

The industry should conduct factual and well-informed advocacy. Scaling hydrogen in otherwise hard-to-abate applications is in society's interest. In recent years, much of advocacy has centered on formulating ambitious goals to create the needed transformative momentum. Now that regulation and public funding need to be focused on finally kick-starting the green hydrogen market, regulators are increasingly receptive to facts about the key obstacles ahead and to pragmatic solutions to remove them. Unrealistic claims about the cost of green hydrogen, its competitiveness, and time to scale will do the hydrogen industry, its customers, and society at large a disservice.

Europe’s (green) hydrogen market has made major progress in recent years, but without additional funding and a regulatory framework, hydrogen still risks remaining the fuel of the future. Ambitious national implementation of EU regulation is needed now.

Policymakers and market players alike need to increase momentum to make sure this transformative industry reaches its full potential.

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