WORLD ENERGY COUNCIL

WORKING PAPER

HYDROGEN ON THE HORIZON: READY, ALMOST SET, GO?

WORKING PAPER | NATIONAL HYDROGEN STRATEGIES

World Energy Council, in collaboration with EPRI and PwC

ABOUT

WORLD ENERGY COUNCIL

The World Energy Council has been at the heart of global, regional and national energy debates for nearly a century, developing new thinking and driving effective action around the world to achieve the benefits of sustainable energy for all.

Comprised of over 3,000 member organisations in nearly 90 countries, drawn from governments, private and state corporations, academia and new and wider system shapers stakeholders, the Council is the world's first and only truly global member-based energy network.

The Council works dynamically across the whole energy sector as a global energy transitions platform, pulling together intelligent leadership to catalyse and inform the world's energy policy dialogue, create impact and drive practical action.

The Council does not advocate for any country, company, technology or source of energy. The World Energy Council remains thoroughly committed to the challenge of being both impartial and impactful.

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WORKING PAPER

This Working Paper on hydrogen is part of a series of publications by the World Energy Council focused on Innovation. It was developed in collaboration with the Electric Power Research Institute (EPRI) and PwC.

EPRI and Gas Technology Institute (GTI) have created the Low-Carbon Resources Initiative (LCRI) to address the challenges and gaps in achieving deep carbon reductions across the energy economy. LCRI is focused on the value chain of alternative energy carriers and low-carbon fuels—such as hydrogen, ammonia, biofuels (including renewable natural gas, and synthetic fuels—and research, development, and demonstration to enable their production, storage, delivery, and use across the energy economy. These energy carriers/fuels are needed to enable affordable pathways to economy-wide decarbonization by mid-century. This five-year, global collaborative will identify and accelerate fundamental development of promising technologies; demonstrate and assess the performance of key technologies and processes, identifying pathways to possible improvements; and inform key stakeholders and the public about technology options and potential pathways to a low-carbon future.

PwC is a network of firms in 155 countries with over 284,000 people committed to delivering quality in assurance, advisory and tax services, including more than 20,000 professionals engaged in the energy, utilities and resources sectors. With its global strategy, The New Equation, PwC is responding to the challenges shaping the world today, with a focus on building trust and delivering sustained outcomes that create value for organisations, their stakeholders and broader society. Climate change is one of the world's most pressing problems, and PwC has committed to reach net zero greenhouse gas emissions by 2030 and is working with organisations to accelerate their own climate-based transformation. PwC and the World Energy Council have a common goal of promoting energy transition and sustainability by engaging with policymakers and leading industry players. Our shared view is that energy transition and sustainability are achieved through the interaction of robust policy frameworks and a strong, competitive energy industry.
Learn more about PwC

In a fast-paced era of disruptive changes, this working paper aims at facilitating strategic sharing of knowledge between the Council's members and the other energy stakeholders and policy shapers and contribute to a global dialogue on hydrogen's role in energy transitions.

This working paper builds upon earlier work by the Council and involved extensive research on national strategy developments and interviews with 38 experts from 23 countries, reflecting 61 % of the global Total Primary Energy Supply – TPES (2018 data, OECD) and 70% of global GDP (2019 data, WB).

INTRODUCTION

The World Energy Council, in collaboration with EPRI and PwC, aims to provide a better understanding of hydrogen development worldwide for the energy community, building on the expertise and experience of its global network. In this context, we published a new Innovation Insights Briefing on Hydrogen in July 2021, seeking to start a multi-stakeholder, multi-level community dialogue on hydrogen's role in energy transitions.

Our work has identified the following 4 areas for further discussion:

1. **Significant divergences are emerging across countries and regions,** as national hydrogen strategies reveal varying attitudes towards hydrogen's role in energy transitions. This signals a need to embrace diversity – eliminating a one size fits all mindset – and enable differing technologies and use cases to be explored.

2. **Confusion over 'colours' is stifling innovation,** with over-simplification and colour prejudice risking the premature exclusion of some technological routes that could potentially be more cost- and carbon-effective. There is a need for further dialogue which looks beyond colour to also explore carbon equivalence.

3. **Demand-centric hydrogen perspectives are needed to advance the Humanising Energy agenda.** The current hydrogen conversation focuses heavily on supply, ignoring the role of hydrogen users. Discussions must explore what's needed to trigger demand, with a specific focus on the development of hydrogen infrastructure and a global supply chain.

4. **The hydrogen economy could stimulate job creation and economic growth,** potentially helping to fulfil 'build forward together' ambitions post-COVID-19. Several national hydrogen strategies highlight jobs as an important driver of hydrogen development, with opportunities to reskill the existing workforce and upskill a new workforce.

To help inform the dialogue on these 4 topics, we are releasing 3-part series working papers for the hydrogen road builders, providing additional insights on:

- National Hydrogen Strategies;
- Inputs From Senior Leaders On Hydrogen Developments;
- Hydrogen Demand And Cost Dynamics.

This Working Paper focuses on exploring the national hydrogen strategies being increasingly published globally to support hydrogen development. It builds onto the Council's German Member Committee's report looking at national hydrogen strategies that was published in September 2020, and further explores the different hydrogen stories emerging between countries and regions.

1. GLOBAL STATE OF PLAY OF NATIONAL HYDROGEN STRATEGIES

The development of a “hydrogen economy” is still at its early stages with few countries having published strategies, though there is broadening global interest and support. To date,[1] 12 countries and the European Union (EU) have published their national hydrogen strategies, with 9 published within the last year alone. A further 19 countries are currently drafting their strategies with many aiming to publish in 2021, demonstrating a clear acceleration of government interest backed by, potentially, COP26 acting as a catalyst.

A few countries have been particularly influential with their hydrogen strategies. Japan’s early commitment catalysed interest in the Asian-Pacific region, with South Korea and Australia publishing their own strategies shortly afterwards. Germany was an early mover in Europe and helped push the EU hydrogen strategy during its EU presidency. In Latin America, Chile has moved quickly with many neighbouring countries also now in the process of developing their strategies.

Table 1. Overview of the countries activities towards developing a hydrogen strategy[2]

	Policy discussions, official statements, initial demonstration projects			Strategy in preparation	Strategy available
Africa	Cape Verde Burkina Faso	Mali Nigeria	South Africa Tunisia	Egypt Morocco	
Asia	Bangladesh	Hong Kong, China	India	China New Zealand* Singapore Uzbekistan	Australia (2019) Japan (2017) South Korea (2019)
Europe	Bulgaria Croatia Czech Republic Denmark Estonia Finland* Georgia	Greece Iceland Latvia Lithuania Luxembourg Malta	Romania Serbia Slovenia Switzerland Turkey Ukraine	Austria Belgium Italy Poland Russian Federation* Sweden Slovakia United Kingdom	European Union (2020) France (2020) Germany (2020) Netherlands (2020) Norway (2020) Portugal (2020) Spain (2020) Hungary (2021)
Latin America & the Caribbean	Argentina Bolivia Costa Rica	Panama Paraguay	Peru Trinidad and Tobago	Brazil Colombia Uruguay	Chile (2020)
Middle East and Gulf States	Israel	United Arab Emirates		Oman Saudi Arabia	
North America	Mexico	United States of America			Canada (2020)

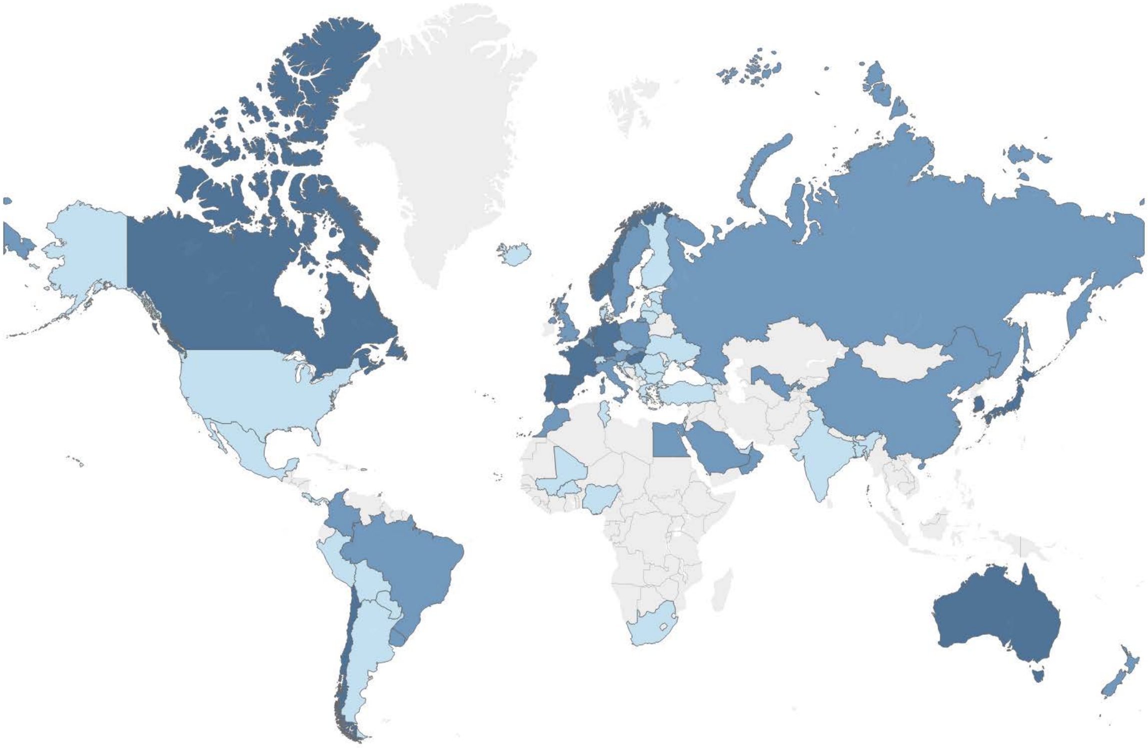
** - Roadmap available*

Source: World Energy Council

Individual country contexts are also critical in determining how countries might use hydrogen in their energy transitions, with potential hydrogen development following a plurality of differing paths and sectoral priorities (see Section 3), building upon differing supply sources, and using various policy tools to encourage uptake (see Section 4).

[1] *National Hydrogen Strategies published until 07/06/2021.*
[2] *Methodology: This assessment considers a national hydrogen strategy as an official document dedicated to hydrogen development within the country with high level support from the State. Published white papers and roadmaps are not considered national strategies if a strategy is in preparation.*

Figure 1. Overview map of the countries activities towards developing a hydrogen strategy



State of play

- Published national strategy
- National strategy in preparation
- Policy discussions/Initial demonstration projects

Source: World Energy Council

WORKING PAPER | NATIONAL HYDROGEN STRATEGIES

2. SUMMARY OVERVIEW OF THE NATIONAL HYDROGEN STRATEGIES[3]

The **table 2** below aims to summarise the differing objectives and sectoral priorities of the published national hydrogen strategies.

	ASIA			EUROPE								LAC	NORTH AMERICA
CATEGORY	Australia	Japan	South Korea	EU	France	Germany	Hungary	Netherlands	Norway	Portugal	Spain	Chile	Canada
Strategy contains timeline for market development with targets	Detailed	Detailed	Detailed	Detailed	Mentioned	Detailed	Mentioned	Mentioned	Not seen	Mentioned	Detailed	Detailed	Detailed
Strategy contains hydrogen cost targets	Mentioned	Detailed	Detailed	Not seen	Not seen	Not seen	Not seen	Not seen	Not seen	Not seen	Not seen	Mentioned	Mentioned
Strategy includes measures to support H2 development													
Direct investments	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Not seen	Mentioned	Detailed	Detailed	Mentioned	Mentioned	Mentioned
Other economic and financial mechanisms	Detailed	Mentioned	Detailed	Detailed	Detailed	Detailed	Mentioned	Detailed	Detailed	Detailed	Mentioned	Mentioned	Mentioned
Legislative and regulatory measures	Detailed	Mentioned	Detailed	Detailed	Mentioned	Detailed	Mentioned	Detailed	Mentioned	Detailed	Detailed	Detailed	Mentioned
Standardisation strategy and priorities	Detailed	Detailed	Detailed	Mentioned	Mentioned	Detailed	Mentioned	Mentioned	Detailed	Detailed	Detailed	Mentioned	Detailed
Research & development initiatives	Detailed	Detailed	Detailed	Mentioned	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Detailed	Mentioned	Detailed
International strategy	Detailed	Detailed	Mentioned	Mentioned	Mentioned	Detailed	Detailed	Detailed	Mentioned	Detailed	Detailed	Mentioned	Mentioned
Strategy addresses social issues for H2 development	Detailed	Detailed	Detailed	Not seen	Detailed	Mentioned	Not seen	Mentioned	Mentioned	Detailed	Detailed	Detailed	Detailed
Strategy includes review and update	Mentioned	Not seen	Not seen	Not seen	Not seen	Detailed	Not seen	Not seen	Mentioned	Mentioned	Detailed	Mentioned	Not seen
Strategy's H2 target source by 2030	Clean	Fossil-based with CCS	From natural gas	Low carbon	Low-carbon & fossil based	Carbon-free	Low carbon & carbon free	Blue & Green	Clean	Green	Renewable	Green	Low carbon intensity
Strategy's H2 target source by 2050	Clean	CO_2-free	Eco-friendly CO_2-free	Clean / Renewable	Low-carbon	Renewable	Low carbon & carbon free	Green	Clean	Green	Renewable	Green	Low carbon intensity
Import / Self-reliance / Export	Export; Self-reliance	Import	Import; Export (tech)	Depends on Member States	Export	Import; Export (tech)	Self-reliance	Import to export H2 (EU hub)	Self-reliance	Self-reliance; Export	Self-reliance; Export	Self-reliance; Export	Self-reliance; Export
MAIN GOALS / DRIVERS													
Decarbonisation	Lower	Immediate	Lower	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Diversify energy supply	Lower	Immediate	Long term	Lower	Lower	Immediate	Immediate	Immediate	Lower	Immediate	Immediate	Lower	Immediate
Foster economic growth	Immediate	Immediate	Immediate	Lower	Immediate	Immediate	Lower	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Integration of renewables	Lower	Lower	Long term	Immediate	Lower	Immediate	Lower	Immediate	Lower	Immediate	Immediate	Immediate	Immediate
SECTORAL PRIORITIES													
Heating	Immediate	Immediate	Lower	Lower	Lower	Lower	Immediate	Immediate	Lower	Immediate	Lower	Immediate	Immediate
Industry													
Iron and Steel	Long term	Lower	Lower	Long term	Immediate	Immediate	Long term	Immediate	Lower	Immediate	Lower	Not seen	Immediate
Chemical feedstock	Immediate	Lower	Not seen	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Refining	Not seen	Lower	Not seen	Immediate	Immediate	Immediate	Immediate	Immediate	Lower	Immediate	Immediate	Immediate	Immediate
Others (cement, etc.)	Not seen	Not seen	Not seen	Not seen	Immediate	Lower	Long term	Lower	Not seen	Immediate	Lower	Not seen	Immediate
Power													
Power generation	Lower	Immediate	Immediate	Lower	Not seen	Not seen	Lower	Lower	Not seen	Lower	Lower	Not seen	Lower
Back-up services	Lower	Lower	Lower	Lower	Not seen	Not seen	Long term	Lower	Not seen	Lower	Lower	Not seen	Lower
Transport													
Passenger vehicles	Lower	Immediate	Immediate	Lower	Lower	Lower	Long term	Immediate	Lower	Lower	Lower	Long term	Immediate
Medium and heavy duty	Immediate	Long term	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Lower	Immediate	Lower	Immediate	Immediate
Buses	Immediate	Long term	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Lower	Immediate	Lower	Immediate	Immediate
Rail	Lower	Lower	Lower	Immediate	Immediate	Immediate	Lower	Immediate	Not seen	Immediate	Lower	Not seen	Long term
Maritime	Long term	Lower	Lower	Long term	Lower	Long term	Lower	Lower	Immediate	Long term	Lower	Long term	Long term
Aviation	Lower	Lower	Not seen	Long term	Immediate	Long term	Not seen	Lower	Lower	Long term	Lower	Long term	Long term

Source: World Energy Council

Strategies content: Detailed · Mentioned · Not seen

Goals and sector priorities: Immediate priority · Long term priority · Lower priority · Not seen

[3] *Methodology: National strategies published until 30th May 2021.*

3. PRIORITY SECTORS

Differing country contexts mean that the sectoral priorities vary significantly across countries with no global priority sector yet emerging. In addition to the varying national contexts, many of the production technologies and proposed hydrogen applications are still not commercially proven, despite there being more consensus in some areas relative to others.

Globally, decarbonisation ambitions are the key driver for increasing interest in hydrogen. The hard to abate sectors provide the focal points for hydrogen uptake with many countries exploring how hydrogen can help to decarbonise these sectors. Focal areas range from heavy duty and long-distance transport applications (buses, trucks, etc.) to carbon-intensive industrial sectors that already require and consume fossil fuel derived hydrogen (refineries, fertilisers, steel). Other end-use applications are also gaining traction, despite requiring additional innovation and supporting measures to encourage uptake. For instance, hydrogen in space heating is being explored by some countries, with research looking into repurposing the existing infrastructure (e.g., converting natural gas to dedicated hydrogen pipelines, repurposed boilers, etc.). Opportunities in aviation are emerging but in a slower timeframe due to aircrafts' complex system interactions and safety considerations. The Hydrogen Council anticipates that low-carbon hydrogen may be cost competitive in 22 end applications by 2030.[4] Further innovation in hydrogen-related technologies, as well as in their alternatives, are expected to emerge over the coming years, which may have an effect on the competitiveness of hydrogen in numerous applications. At the same time, infrastructure for hydrogen production, transport and storage poses significant challenges to its uptake in end-use sectors. The cost of infrastructure depending on location of supply and demand, technologies used, and public and private support in the early stage can pose risks to further developments. Additionally, risks related to the development of large-scale renewable energy projects, from land availability to public acceptance, add up to the challenges associated with further hydrogen uptake.

In the short term, countries are emphasising differing ambitions for hydrogen.

> ***"Hydrogen today is not a bubble, but the sentiment of many people is several steps ahead of the actual reality. The adoption will likely be slower as stipulated by the enthusiasts."*** *PHILIPP HASLER, EMERALD VENTURES, SWITZERLAND*

JAPAN AND SOUTH KOREA: DEVELOPING HYDROGEN ECONOMIES

Japan and South Korea have advanced economies and limited natural energy resources, and accordingly have been major importers of energy. They share several sectoral priorities, notably targeting the power sector with Japan already having targets for electricity production from hydrogen. The focus is on decentralised small-scale power generation using hydrogen through fuel cells for home use ("Ene-farm") being deployed in Japan to generate electrical power and heat water. In South Korea, the government is exploring central power generation along with fuel cell use by decentralised systems in homes and buildings and has set ambitious targets. Both countries are also looking at the transport sector with an emphasis on fuel cell vehicles (FCVs) to be deployed in the domestic markets with targets for light vehicle use. South Korea in particular aims to be a global leader of hydrogen powered vehicles and is focused on potential export markets.

AUSTRALIA: EXPORT FOCUS

In contrast, Australia is a major energy exporter, and the Australian strategy places stronger focus on hydrogen production and export while also considering its own use in transport, focusing on heavy-duty and long-distance transport, and the large-scale production of clean ammonia.

EUROPE: DECARBONISING INDUSTRIAL AND TRANSPORT SECTORS

Europe is a major energy user aiming for an increased renewable energy share across most of its member countries, with limited renewable capacities. The primary goal for using clean hydrogen in Europe is to decarbonise industry although transport is also being targeted. In Germany, the emphasis is on chemical, petrochemicals and steelmaking industries together with a focus on heavy-duty vehicles such as military vehicles, haulage and buses. France is focusing on replacing carbon-based hydrogen in existing industrial sectors (e.g., refining, chemistry, agribusiness) while also looking to pilot projects in the maritime and aviation sectors and seeking to be a key producer of electrolysers. In the Netherlands, the government is considering the development of a hydrogen infrastructure to connect the different users. Norway is cautious about significant clean hydrogen production due to the notable infrastructure costs but is exploring potential solutions, such as producing hydrogen close to customers and transporting the CO_2 back to Norway for storage. Elsewhere, Spain and

[4] *(Hydrogen Council, 2021).*

Portugal are focusing on the production and domestic consumption of renewable hydrogen, with longer term export aims. While the local production of clean hydrogen is being explored, significant imports are expected from countries where clean hydrogen can be produced more economically at scale, notably in the Middle East, North Africa, Latin America.

CHILE AND CANADA: PRODUCING, CONSUMING AND EXPORTING CLEAN HYDROGEN

In the Americas, Chile and Canada both aim to develop local supply and demand, before considering export in the mid-term. Chile has excellent renewable energy conditions, therefore its immediate aim is to replace imported ammonia with locally produced green ammonia and grey hydrogen with green hydrogen in oil refineries while also expecting green hydrogen to become attractive for heavy and long-distance transport. On the other hand, Canada, a major hydrocarbon exporter, sees short term opportunities in transport where mature end-use applications are already available and technology readiness is high with fuel cells expected to be deployed in road haulage, rail, and shipping. Canada also envisages decarbonising heating through natural gas blending with hydrogen.

4. POLICY TOOLS

With the role of hydrogen in the energy system still to be resolved, the governments are currently focused on understanding where hydrogen might be useful in their energy transitions. This means exploring all opportunities in the value chain while also recognising the need to address the "chicken and egg" problem requiring both supply and demand within the energy system. To enable hydrogen within their energy systems, countries are considering a wide variety of policy instruments and tools with some particularly innovative measures. The relative success of the different approaches will help to identify best practice for policy and regulation for enabling hydrogen within the energy system in differing contexts.

N.B.: This comparison of the policy instruments only includes countries with published national hydrogen strategies by May 2021 (see Section 1) but other countries are already exploring similar policies as they develop their formal strategies and are likely to echo the ideas presented below.

4.1 VISION SETTING

Publishing a national strategy or roadmap can be an important step for setting out a vision for stakeholders. While the current hydrogen strategies differ greatly in content and format, they all provide a vision for hydrogen across sectors, usually with a timeline for market development, and identifying priorities with specific targets. In doing so, the strategies provide visibility to market players on the policies, regulations and incentives to achieve the ambition. Key policy instruments are highlighted below.

Some strategies also include information about the review process, therefore acknowledging the ongoing evaluation and potential to adapt. For example, Australia will conduct a hydrogen infrastructure assessment by 2022 and then at least every 5 years to drive public action.

4.2 ENABLING SWITCHING TO HYDROGEN

4.2.1 DIRECT FINANCIAL SUPPORT

Hydrogen technologies are in early stages of commercialisation, with many strategies targeting direct public and private investments to support pilot projects to achieve economies of scale. The investment required is significant with Goldman Sachs (an investment bank) estimating the hydrogen market could be worth $11.7 trillion by 2050, split between Asia, the U.S, and Europe.[5] According to the Hydrogen Council, a $50 billion gap and 65 GW of electrolyser capacity needs to be bridged by 2030 to reach a breakeven between grey and renewable hydrogen. The EU strategy estimates cumulative investments in renewable hydrogen in Europe could be up to €180-470 billion by 2050, and in the range of €3-18 billion for low-carbon fossil-based hydrogen.

[5] *(Goldstein, 2020).*

Several governments have pledged direct public funding to 2030 to develop their national hydrogen industries or economy. Japan has committed some $1.5 billion to support zero-emission hydrogen production locally and overseas and to develop distribution infrastructure. France plans to invest €7 billion by 2030 targeting industrial decarbonisation, heavy duty transport, and R&D, while Germany has adopted a "package for the future" with €7 billion to speed up the market rollout of hydrogen technologies nationally, complemented by €2 billion to foster international partnerships. Funds are also coming from existing budgets to support energy transitions or innovation. For instance, the EU is using its Important Projects of Common European Interest (IPCEIs) support mechanism for R&D projects involving more than one Member State. Some national strategies are also including hydrogen within their post-COVID recovery plans to secure extra funds.

Mobilising private funding is also critical and can be combined with public funds. For instance, the Dutch government aims to invest up to €338 million in green hydrogen projects in addition to planned investments of €9 billion of which most are private, in northern Netherlands to develop an integrated hydrogen ecosystem. The EU has created the European Clean Hydrogen Alliance to help buildup a clear and robust pipeline of viable investment projects, which aims to coordinate investments and policies along thehydrogen value chain and promote cooperation across private and public stakeholders. However, most national strategiesare unclear about mobilising private investments.

4.2.2 FINANCIAL INCENTIVES

Cost is a key obstacle in the uptake of hydrogen within the energy system, particularly in countries only considering hydrogen from renewable energy sources. As a nascent energy vector, the development of a hydrogen market requires significant financial incentives to bridge the economic gap with existing alternatives. Financial measures such as tax policy and subsidies can be key tools for governments to help enable the development of hydrogen value chains.

Tax policy is an effective instrument to incentivise switching from fossil fuels to new energy carriers. Where emissions trading schemes are in place, a higher carbon price could be a particularly effective incentive to enable hydrogen. A carbon tax is another option being considered, for example Norway plans a CO_2 tax increased annually by 5% until 2025. Other options look at lowering taxes for hydrogen fuels with reduced road toll fees, ferry charges or parking fees for hydrogen fuelled vehicles/vessels, or by exempting producers of green hydrogen from electricity levies to encourage their uptake. The EU strategy suggests developing a Carbon Contracts for Difference (CCfD) programme to support the production of low carbon, circular steel, and basic chemicals, in which long-term contracts with a public counterpart would remunerate investors by paying the difference between the CO_2 strike price and the actual CO_2 price in the Emissions Trading System (EU-ETS) to bridge the cost gap compared to conventional hydrogen production.

> ***"Implementing carbon border tariffs would motivate foreign producers and EU importers to reduce their carbon emissions, while ensuring a level playing field in a WTO-compatible way."*** ROBIN MILLS, QAMAR ENERGY, UAE

Subsidies can also help encourage hydrogen demand by targeting priority sectors identified, for example via subsidies for hydrogen fuelled vehicles or refunds for employees commuting via hydrogen powered vehicles. In Portugal, hydrogen production associated with existing solar and wind power plants is promoted through a "purchase" mechanism by which feed-in tariffs are replaced with incentives for hydrogen production.

Lessons learned: Spain's solar bubble

Spain has been one of the leaders in renewable industry development in Europe, but it has been a bumpy road. In 2007, the Spanish government announced a new "feed-in tariffs" policy to support solar energy allowing producers to develop solar systems, both PV and solar thermal, and sell back to the grid at above-market rates. It quickly became apparent that the fixed tariffs were overly generous, and the build-up of solar capacity soon exceeded several times the government's targets. The government responded by retrospectively adjusting the tariffs down, turning the solar boom into a bust and creating concern about regulatory instability. The experience of Spain, and of other pioneer countries that suffered similar renewable policy challenges, has helped policymakers develop more market responsive mechanisms which can underpin a more stable market for investors in renewables.

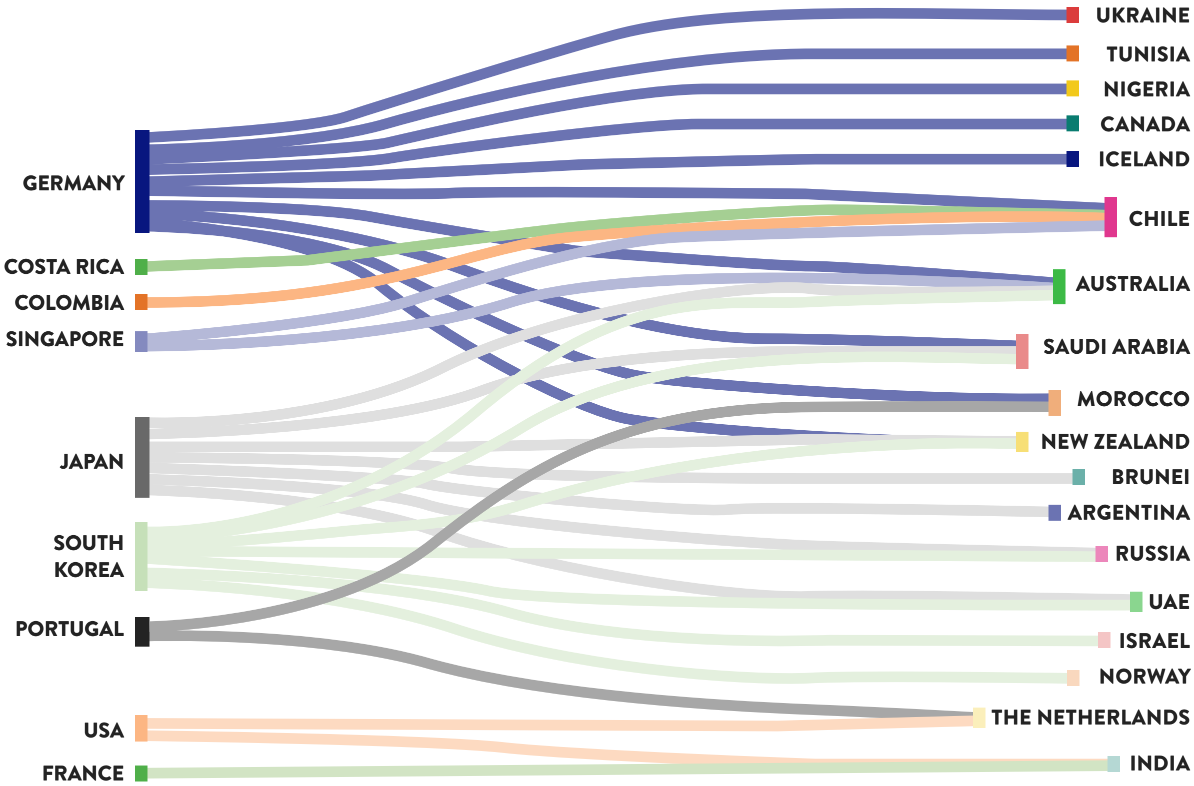
4.3 FACILITATING INTERNATIONAL HYDROGEN MARKETS

Developing hydrogen as an energy vector will also require building an international hydrogen market to enable the cost-effective production and trade of hydrogen. To help achieve this, various countries are developing bilateral agreements to coordinate R&D programmes, explore harmonising standards (see Section 4.4.2), and encourage the emerging global hydrogen trade. Japan's Hydrogen Energy Ministerial Meeting is a key example and has resulted in the Tokyo Statement from October 2018, involving 21 nations, multinational regions and international organisations that detailed various initiatives to promote the popularisation and expansion of hydrogen energy with a yearly assessment of progress.

Currently most international, regional, and bilateral cooperation and partnerships focus on common projects to develop value chains and joint R&D initiatives. For instance, the Mission Innovation initiative with 24 countries and the European Commission aims to increase government investment in clean energy R&D involving the private sector and encouraging international collaboration for hydrogen innovations. Japan, the USA and the EU have the International Partnership for a Hydrogen Economy (IPHE) as a coordinated research programme for the hydrogen value-chain. The Africa-Europe Green Energy Initiative aims to raise awareness of hydrogen opportunities and promote the development of joint innovation projects (including EU funding via the Neighbourhood Investment Platform).

At this stage, most partnerships are bilateral (see Figure 2) with Memorandums of Understanding (MoU), developing collaboration on management, technology development, financing of research projects and the potential for import-export value chains (e.g., Portugal and the Netherlands, Germany and Saudi Arabia, Chile and Singapore). Japan and Germany are expected to be significant net-hydrogen importing countries and have been particularly active seeking to develop bilateral partnerships and secure sufficient supply. Germany, for example, is creating a compilation of atlasesfor potential green hydrogen generation and its downstream products to help identify future destination countries and opportunities for export installations.

Figure 2. Bilateral Partnerships [6]



Source: World Energy Council, modified from German Member Committee map, 2021 [7]

[6] *Methodology: The bilateral partnerships are exclusively government-to-government agreements that can encompass trade relations around hydrogen (import/export of hydrogen fuel and/or technologies), demonstrations projects, and Memorandums of Understandings. Based on information available on 27th May 2021.*
[7] *Global Overview on Activities Towards H2 Strategies - H2 partnerships globally.*

Lessons learned: Solar energy industry

The solar energy boom did not develop in one country alone and instead resulted from competition between several countries developing their own industries. Although the technology began in 1954 in the USA with a focus on the space industry, technology developments led to significant price falls and were boosted by a German law in 2000 encouraging renewable energy and incentivising solar panel production. The EU's 2007 climate and energy package introduced binding legislation with 2020 targets and prompted a boom for the solar panel industry in the EU market.

Chinese mass production of solar cells at scale slashed prices and led to China dominating the solar panel market. This transitioned them from being a non-existent market player to capturing almost 70 % of today's global production within 20 years. While global competition has led to reduced prices, trade relationships have been strained with various trade disputes with China. Some experts already envisage a similar situation with Chinese electrolyser production.

4.4 CREATING THE CONDITIONS FOR MARKET DEVELOPMENT

4.4.1 WHAT IS THE ROLE FOR LEGISLATION AND REGULATION TODAY?

Legislative and regulatory measures are yet to be fully developed and instead the focus so far is on rapidly enabling hydrogen projects by simplifying the existing frameworks as well as reducing potential barriers and administrative burdens. For instance, Portugal is promoting the simplification of licensing procedures – environmental, industrial, municipal – for some hydrogen production projects. In France, strategic sector contracts and commitments[8] between government and companies aim to help develop public-private partnerships (PPPs) (See Box: "Facilitating hydrogen uptake: public-private partnerships"), reduce administrative burden for hydrogen projects, and facilitate the launch of initiatives. Chile will review land use regulations and associated permitting processes to identify and reduce potential barriers for hydrogen, which include analysing, holding, and leasing public lands which display adequate conditions for competitive development of green hydrogen and its derivatives. Chile also plans to review and update power market regulation to effectively allow the participation of hydrogen technologies in the provision of various services (energy, capacity, ancillary services).

> ***"To make the successful switch to hydrogen, policy support, business cases, and regulatory measures are needed, especially in hard to decarbonise sectors (e.g., steelmaking)."*** *FRANK WOUTERS, EU-GCC CLEAN ENERGY NETWORK, UAE*

> ***"There is a need for policies that are performance based; policies that are driving decarbonisation, but that are technology agnostic, and are not excluding technologies like hydrogen."***
> *SABINA RUSSELL, ZEN CLEAN ENERGY SOLUTIONS, CANADA*

Some countries are developing overarching legislative measures. South Korea has passed an overarching "Hydrogen Law" laying the legal basis to support hydrogen with measures to develop education programmes, prepare hydrogen related statistics, establish safety standards, legislate for fuelling systems and installation. South Korea's "Hydrogen Green Mobility Regulation-free Special Zone Project" aims to demonstrate hydrogen-based mobility technologies. The EU plans a common low-carbon standard for hydrogen production installations based on their full lifecycle GHG performance that could be relative to the existing ETS benchmark for hydrogen production.

With many hydrogen applications in their early development, the current legislative and regulatory framework for hydrogen is following a gradual approach, navigating between the need to offer sufficient certainty to investors and project developers, and the need to provide flexibility for different stages of development. [9]

[8] *"Engagements pour la croissance verte" (ECVs) – Commitments for Green Growth, and "Contrats Stratégiques de Filière" (CSFs) – Strategic Sector Contracts.*
[9] *(Zinglersen, 2021).*

> ***"To develop hydrogen projects, we need a bankable structure, that includes a robust technical and performance design and bankable clients that can engage for a long duration, namely governments."***
>
> *CRISTINA MARTIN, HDF ENERGY, MEXICO*

Lessons learned: LNG contracts of the 1960s

In the early 1960s, air pollution in Japan helped encourage the use of imported LNG as a cleaner and more environmentally friendly fuel for power generation compared to coal or oil. However, Japanese power companies were only willing to switch to LNG with financial assistance from the government to cover the high capital costs.

Long-term contracts, with a duration of 15-30 years between exporters and importing utilities provided the basis for establishing the sector. The contracts needed to be long enough for investments to be recovered in exporting and importing countries, and to provide a guaranteed cash-flow to assist the financing of the investments. Lessons from helping to establish the LNG market could also help the development of hydrogen.

> ***"Avoid becoming locked in and then end up constraining the growth of the industry when at some point you want to be moving towards a more liquid and flexible model."***
>
> *ROBIN MILLS, QAMAR ENERGY, UAE*

In addition to legislative and regulatory measures, many softer and more flexible tools are helping market participants develop their hydrogen projects. For instance, Chile will establish a task force to accompany developers in permitting and piloting processes for green hydrogen projects and coordinate public services in key sectors to reduce uncertainty for private initiatives, generate learning, solve market coordination failures, and enable the safe introduction of new fuels and processes. Canada aims to promote open access to information to establish tiered, time-based requirements for renewable hydrogen content in government supported projects, and develop a suite of tools and resources, hosted through a central, government-run website, for early hydrogen markets to help end-users quantitatively evaluate hydrogen as an option for their operations.

Facilitating hydrogen uptake: hydrogen hubs

Hydrogen hubs, or clusters of large-scale demand, are local areas where various existing and potential hydrogen users from differing sectors are co-located. The co-location within hubs can make developing infrastructure (such as pipelines, storage and refuelling stations) more cost-effective by promoting economies of scale and synergies from sector coupling to help develop the value chain.

The strategies consider different approaches to identify, locate and fund potential clusters. Key issues affecting the choice of potential hub site choice include: access to demand; land availability; import or production potential via port, road and rail infrastructure; access to existing gas transmission network; favourable local economic, social and environmental factors (such as suitable skilled workforce) for community support. In several countries, industry is leading efforts to form clusters for cross-sector collaboration to develop the value chain and enable scaling up. Beyond industry, academic and research institutes are also seeking to co-locate in potential hub locations.

> ***"The work that's being done on hydrogen valleys or clusters will be a game changer. Once built, they will show the integrated and holistic aspects of hydrogen working together. An important transition will start to happen when there will be comprehensive deployment across major sectors, and the sector coupling and integrative aspect of hydrogen become visible."***
>
> *DARYL WILSON, HYDROGEN ASSOCIATION, CANADA*

Facilitating hydrogen uptake: public-private partnerships

Private-Public Partnerships (PPPs) can be an important lever for hydrogen development by coordinating public and private sector efforts. Hydrogen's momentum is more likely to be built through private sector engagement with government support via an enabling environment (e.g., carbon-pricing, favourable investment climate).

In 2008, the EU set up the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) as a public-private partnership to support research, technological development and demonstration activities in fuel cell and hydrogen energy technologies in Europe. In 2021, the EU is now setting up the Clean Hydrogen Partnership, to build on the work of the FCH JU to accelerate the development and deployment of a European value chain for clean hydrogen technologies, focusing on producing, distributing, and storing clean hydrogen and, on supplying hard-to-decarbonise sectors. Other examples include the government-led Special Purpose Company (SPC) that are being launched in several countries with support on financing and taxation to develop hydrogen-fuelled applications.

4.4.2 STANDARDISATION IS NEEDED BUT MAYBE NOT YET

Standards and certification mechanisms can help harmonise processes important for hydrogen development. The development of a common language for hydrogen and some rules shared at the international level could establish a level playing field by enabling effective cross-border trade and providing more certainty to investors. At this stage, however, standardisation priorities differ widely between countries making collaboration more difficult and delaying developing hydrogen demand and investment.

Hydrogen safety is frequently mentioned as a priority field for standardisation with standards for industry and transport sectors. While establishing international standards could take several years to establish, initiatives have begun. The American Institute of Chemical Engineers (AIChE) has a hydrogen safety group looking at standards. Outside of safety, France is working with financial institutions on co-financing models for ecosystem deployment projects that pool different uses (mobility, industry, etc.) at the local level. At the international level, the development of an agreed Guarantee of Origin scheme should be a priority to establish the hydrogen production source with one initiative from CertifHy,[10] a multi-stakeholder project whose aim between 2014 and 2016 was to develop a common European-wide definition of green hydrogen and to develop a hydrogen Guarantee of Origin scheme deployable across Europe, supported by a roadmap for implementation.

> ***"Standards are ahead of the commercialisation of the fuel cell equipment. There are already standards for fuel cell generators for vehicles and electrolysers etc. However, development of codes related to installation and operation of the equipment is lagging. There is a good international harmonised standardisation approach taking place with ISO and IEC. As for the codes, each country / jurisdiction is developing its own as equipment gets deployed."***
>
> *JEFF GRANT, ZEN CLEAN ENERGY SOLUTIONS, CANADA*

Currently there is little consideration on how to develop standards and certification mechanisms, that are usually originating from private initiatives and raising questions about harmonisation. Japan has been a notable exception, suggesting international rules for the ocean transportation of liquefied hydrogen to be developed via the International Maritime Organisation (IMO). Within its own federal system, Canada plans to establish a Codes and Standards working group with inter-provincial Authorities to share lessons learned and identify gaps in codes and standards.

4.4.3 HYDROGEN COLOUR DEBATE IS AN OBSTACLE TO UPTAKE

The existing strategies cite divergent forms of hydrogen based on colour or carbon intensity of production for 2030 and 2050 (see Table 3). The choice of hydrogen production methods depends largely on the resources available and existing energy systems within each country, as well as the policy objectives being pursued (i.e., decarbonisation, fostering economic growth, etc.). They also resort to diverse terminologies with differing assumptions and attitudes towards certain technologies. Most notably, hydrogen produced using nuclear energy has a variety of different colour categorisations.

[10] https://www.certifhy.eu/project-description/project-description.html

Table 3. Summary Of Colours / Carbon Intensity Of Hydrogen Per Country [11]

Country	By 2030	By 2050	Definition
Australia	Clean	Clean	Clean: SMR with CCS (90% capture rate) or electrolysis using renewable power
Canada	Low Carbon Intensity	Low Carbon Intensity	Refers to CertifHy Low Carbon Hydrogen definitions: CertifHy green hydrogen (from biomass sources or electrolysis using wind, solar, and hydroelectricity) and CertifHy low carbon hydrogen (fossil fuels SMR + 90% CCUS, pyrolysis, nuclear)
Chile	Green	Green	Using renewable power
EU	Low Carbon	Clean / Renewable	SMR + CCS* or using renewable power with the EU Taxonomy providing a benchmark of 3tCO2e/tH2
France	Low carbon and fossil based	Low carbon	Low carbon: Electrolytic H2 production can incl. both renewable and nuclear power
Germany	Carbon-free	Renewable	Carbon-free: SMR with CCS*, methane pyrolysis, etc. Renewable: using renewable power
Hungary	Low carbon & carbon free	Low carbon & carbon free	Carbon-free: green/renewable H2 produced by the decomposition of water by renewable electricity. Renewable electricity comes from PV panels and cheap electricity (e.g. surplus renewable electricity, nuclear power, imports from cross-border of carbon-free electricity) through the national grid. Low Carbon: Blue or Turquoise hydrogen.
Japan	Fossil-based with CCS	CO2-free	CO2-free: fossil-based + CCS (60% carbon rate today to virtually 100% in the future), supplemented by low-cost renewables
Netherlands	Blue & Green	Green	Green: primarily electrolysis using "sustainable" electricity, but also biogenic feedstocks produced sustainably Blue: produced from natural gas with CCS*
Norway	Clean	Clean	Clean: Steam reforming of NG/other fossil fuels + CCS (90-95% capture rate)
Portugal	Green	Green	Using renewable power
South Korea	From Natural Gas	Eco-friendly CO2-free	By-product and sourced from natural gas, supplemented with H2 from Power-to-Gas projects utilising surplus and dedicated renewable electricity
Spain	Renewable	Renewable	Water electrolysis using renewable electricity and also H2 obtained through the reforming of biogas or the biochemical conversion of biomass, provided that the established sustainability requirements are met

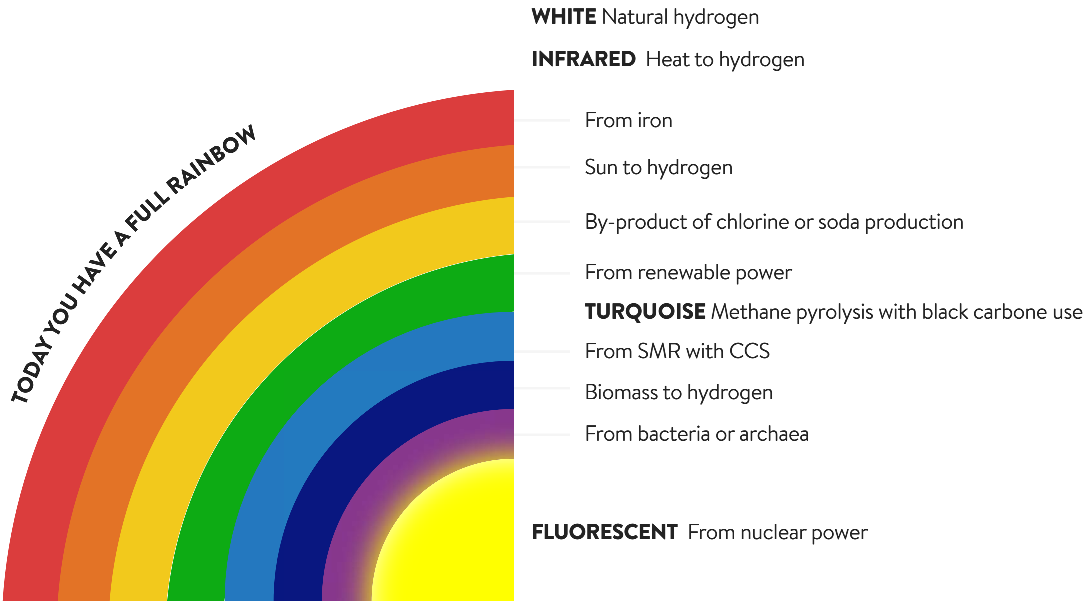
**: Carbon capture rate is not defined in the strategy.*

Source: World Energy Council

Recently, attempts at settling the "colour debate" have started to emerge with an aim to establish clear definitions of the carbon content, technology, and electricity source behind them (e.g., Figure 3 and Figure 4).

[11] *As defined in their national strategies.*

Figure 3. An Illustrative Hydrogen Colour Rainbow



Source: World Energy Council, illustrative diagram based on contribution from Studies Committee member, 2021

Figure 4. An Illustrative Hydrogen Colour Spectrum

	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind, Solar, Hydro, Geothermal, Tidal	Minimal
	Purple/Pink Hydrogen		Nuclear	
	Yellow Hydrogen		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS gasification + CCUS	Natural gas, coal	Low
	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
	Grey Hydrogen	Natural gas reforming		Medium
	Brown Hydrogen	Gasification	Brown coal (lignite)	High
	Black Hydrogen		Black coal	

**GCG footprint given as a general guide but it is accepted that each category can be higher in some cases.*

Source: Global Energy Infrastructure (GEI), 2021

Increasingly, the proliferation of differing hydrogen shades is overly complicating the discussion. At the same time, there is an increasing focus on carbon intensity or carbon equivalence, in addition to colour. Carbon intensity – expressed in tonnes CO2eq per ton of hydrogen produced – is a technology neutral criterion to assess the hydrogen emission footprint. It opens the debate about competition between various hydrogen production routes that meet the required carbon intensity at least costs. This will vary with context so in one case hydrogen produced using renewable electric could be most appropriate while in another context hydrogen produced with carbon capture could be more suitable and economic. A carbon intensity approach is already taking shape in the European Union, where the EU Taxonomy – a classification system, establishing environmentally sustainable economic activities – states that a carbon intensity benchmark of 3 tCO2eq/tH2 is required to have hydrogen production classified as an environmentally sustainable economic activity.

FROM COMPLEXITY → **TO ONE CLEAR INDICATOR BASED ON CARBON INTENSITY**
(hydrogen colours diagram) *(e.g. tCO2eq, kWhs, TWh... /tH2)*

ANNEX

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ACKNOWLEDGEMENTS

PROJECT MANAGEMENT

Dr. Angela Wilkinson (Secretary General & CEO), Neil Hughes (International Executive Director, EPRI), Jeroen van Hoof (Global Power & Utilities Leader, Partner, PwC Netherlands), Martin Young (Senior Director, Insights), Cliodhna O'Flaherty-Mouscadet (Senior Manager, Partners), Gina Domanig (Innovation Executive Co-chair), Richard Lancaster (Innovation Executive Co-chair), Sam Muraki (Vice Chair of Asia Pacific and South Asia), Jeffery Preece (Senior Program Manager, EPRI), Adj. Prof. Dr. Juergen Peterseim (Global H2 industry lead, PwC), Dr. Olesya Hatop (Global Clients & Markets Industry Executive, PwC)

PROJECT TEAM

Lucie Togni, Rami Fakhoury, Aaliya Deen, Joseph Stekli, Florian Schäfer, Nils Babenhauserheide, Moritz Zahn, Carlo Steinbach

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*awaiting membership approval

62–64 Cornhill
London EC3V 3NH
United Kingdom
T (+44) 20 7734 5996
F (+44) 20 7734 5926
E info@worldenergy.org

www.worldenergy.org | @WECouncil