FROM AMBITION TO REALITY 3

Steps to accelerate net zero delivery

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FOREWORD

SUE BROWN
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Countless analyses over the past years have made clear the urgency with which the world must decarbonize its industrial systems. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) tells us that the impacts of climate change are occurring more quickly than previously modeled. Analyses by the International Energy Agency (IEA) and Energy Transitions Commission tell us that annual investment in low carbon infrastructure needs to increase by around 3.5 times 2022 levels out to 2050. And studies such as Net-Zero America and Net Zero Australia provide us with a picture of the challenges that will be encountered at a landscape and social level over a relatively short period of time.

It is clear that delivering decarbonized infrastructure at the speed and scale required to achieve mid-century net zero requires more than strong intentions, government policies, and leading thinking alone. It requires action, and a radical but considered paradigm shift in the way energy infrastructure is delivered.

Informed by the early results from the inaugural Princeton Net Zero Stakeholder Survey, this paper focuses on the "how", "when" and "who" of pragmatic steps to change the way we deliver clean energy infrastructure. We show that the From Ambition to Reality (FATR) five shifts can help move the needle to overcome barriers to decarbonization. It will require industry participants to change their approaches; to collaborate more than we have ever done. And we need to act now. With less than seven years to 2030, a critical milestone towards mid-century net zero, the planet cannot afford to rely on traditional approaches.

We're proud to collaborate with the Andlinger Center for Energy and the Environment at Princeton University on the FATR series.

We challenge industry participants to work with us to build the new leading practice to accelerate net zero delivery and help deliver the low carbon industrial infrastructure required.

ANDREA GOLDSMITH
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I am delighted to introduce the latest update of From Ambition to Reality, the third in this series on rethinking infrastructure delivery practice in the effort to tackle climate change. The series is part of a research collaboration between Princeton's Andlinger Center for Energy and the Environment, and Worley, a leading global provider of professional project and asset services in the energy, chemicals and resources sectors.

Our collaboration with Worley represents exactly the kind of partnership between universities and companies that is needed to solve the most important challenges that are facing today's energy economy.

Worley joined Princeton University's E-ffiliates program in 2021, inspired by our influential Net-Zero America study, which provided one of the most comprehensive, detailed roadmaps for rebuilding U.S. energy and industrial infrastructure to release no net greenhouse gas emissions by 2050. Princeton, in collaboration with researchers in Australia, have since completed the Net Zero Australia study, and more recently commenced similar collaborative studies in India, China, and elsewhere.

The Princeton E-ffiliates program, administered by the Andlinger Center, provides an excellent platform for this kind of engagement. This expanding program offers corporations a unique opportunity to engage and collaborate in high-impact research and to find specific innovative solutions in energy and the environment.

With Worley, we are bridging the Andlinger Center's world-leading clean energy research and systems analysis with the real world of project delivery, in pursuit of a more sustainable net zero world.

In this latest publication, *From Ambition to Reality – Steps to accelerate net zero delivery*, the team explores a specific clean energy case study in depth from the European Union, the EU 2030 Hydrogen Strategy. Their analysis of this one exemplar demonstrates the enormity of the net zero challenge but shows how, with the adoption of the 5 key shifts in practice that were developed in the first publication, such an ambition could become a reality. They translate that analysis to initiatives that industry and other net zero stakeholders must get behind, not only for hydrogen but other clean energy value chains.

I hope you enjoy reading this latest installment in the journey from ambition to net zero reality.

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Dr Paul Ebert is Group Director of Sustainability and Energy Transition Leadership at Worley. His responsibilities include representation at and involvement in various international forums, assisting with Group responses to contemporary sustainability challenges, and peer-to-peer engagement with customers. He is recognized as one of Worley's senior broad subject matter experts in the energy transition.

Based in London, Paul is a mechanical engineer with a PhD in wind turbine aerodynamics. His 30-year career has focused on innovative asset development in the clean energy industries, starting as a wind farm project manager in the electrical utility area in Australia before broadening internationally to other technologies such as high-penetration renewable systems, energy storage, the emergence of low-emissions hydrogen and the integration of clean pathways into the heavy industrials.

Paul is a contributor to various organizations, including the World Economic Forum, the Energy Transitions Commission, the Engineering Leadership Group and the Climate Leaders Coalition. He is a former chair of the Advisory Panel to the Australian Renewable Energy Agency and has sat on advisory bodies including for the Australian National University, the University of Newcastle and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). He is currently on the Advisory Panel for Net Zero Australia.

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Dr Clare Anderson is the Group Director, Sustainability Performance for Worley and is passionate about the decarbonization of the energy, chemical and resources industries. She stewards Worley to meet the commitments made in our Climate Change Position Statement, embedding sustainability in the way we operate our business and deliver services to our customers.

Clare has a PhD in Chemical Engineering, relating to the adaptation of low carbon technologies. She is an experienced leader of large technical teams and has delivered major energy infrastructure projects in Europe, South Africa, and Australia. Her experience spans all phases of project development from concept development through to detailed design, construction, and operation.

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Based in the Highlands of Scotland, Kerry-Ann is recognized globally as a subject matter expert on hydrogen and has a 25-year track record of innovation, lateral thinking, and challenging the status quo to deliver results. In 2022, she was presented one of the inaugural Women in Hydrogen 50 awards in the category of projects and partnerships.

Kerry-Ann is the elected chair of the British Standards Institute GSE/5 hydrogen strategy committee, a non-executive director of the hydrogen production company Plus Zero, and regularly features in articles and podcasts on the hydrogen sector.

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His 11-year academic career follows three decades of international industry experience, firstly as a company founder, and then in senior executive and non-executive director roles. These included CEO of ZeroGen (an early pioneer in CCS), Deputy Chair of Gladstone Ports Corp and non-executive director of two listed engineering firms.

Chris spearheads the interdisciplinary Rapid Switch Initiative at the Andlinger Center and is an affiliated faculty member at Princeton's High Meadows Environmental Institute. His research combines engineering, business and social sciences to help mobilize decarbonization efforts across different regions and sectors. He co-led Princeton's influential Net-Zero America (2021) study and Net Zero Australia in collaboration with university partners in Australia. Chris is now turning his attention to the world's largest future emitters, co-leading collaborative efforts across India and China with plans to expand to Indonesia, Pakistan, Brazil, Nigeria and more.

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CONTENTS

CHAPTER

1 It’s time for radical steps

TURNING NET ZERO AMBITION INTO REALITY

We challenge all who are associated with delivering net zero.

The challenge is to consider and take the steps needed to transform infrastructure delivery practices to a new paradigm – a paradigm capable of accelerating the scale and speed of delivery that mid-century decarbonization demands.

That scale and speed is unprecedented. Never has the global community faced a more demanding infrastructure challenge. Taking a traditional approach will be simply too slow. Radical change is needed to build the assets of decarbonization in time. It means setting aside skepticism, and focusing on the pathway to get there pragmatically, and responsibly.

In a major update to our From Ambition to Reality (FATR) thinking, this paper builds on the work of our first two papers by focusing on a key question posed by many readers: "*That's great advice, but what steps can we take right now?*"

Using a new level of analysis, we explore these steps, initially using an example low-emissions value chain – renewable hydrogen in the European Union (EU). We examine the EU policy ambition in terms of the infrastructure required, exposing limitations in the way capital is deployed that put this ambition at risk. With input from a broad range of experts, steps to overcome these limitations are identified. These steps are then globalized into our framework to demonstrate how they can drive the scale and speed in net zero infrastructure to where it needs to be.

Our aim with this paper is to move thinking and action to a more tangible and practical level, with specific recommendations on steps and roles for relevant infrastructure delivery participants.

And we reiterate our challenge to those involved – to take these steps with us to build the infrastructure delivery practices needed and help turn the net zero ambition into reality.

THE COMPELLING CASE FOR CHANGE

Our first two FATR papers[1] proposed a new delivery paradigm consisting of five shifts (FATR shifts). The FATR shifts are shown in Figure 1 with corresponding "indicators of change", which are measures to indicate shift adoption. We believe these shifts are needed to build a durable response to the net zero infrastructure challenge. While they have resonated with many, they can make some people embedded in current delivery norms uncomfortable.

The FATR shifts are a radical departure from current practice. Actions such as sharing intellectual property with competitors, ordering equipment items ahead of the project curve, challenging the bespoke path to build standardized designs, embracing communities as equity partners – all with greater transparency through a digital platform – are not widespread practice.

Our second FATR paper demonstrated that many nations face a similar infrastructure challenge by comparing the smaller energy economy of Australia to the energy giant of the United States (US). For an economy handling just 3% of world primary energy, Australia's challenge is, in some areas, of a similar order to the US. For example, under certain assumptions, the carbon sequestration volume per year (or projections for low emissions hydrogen production) are similar for both Australia and the US.
At a global scale, the challenge is even more daunting, and the need for a radical change in approach is even more compelling.

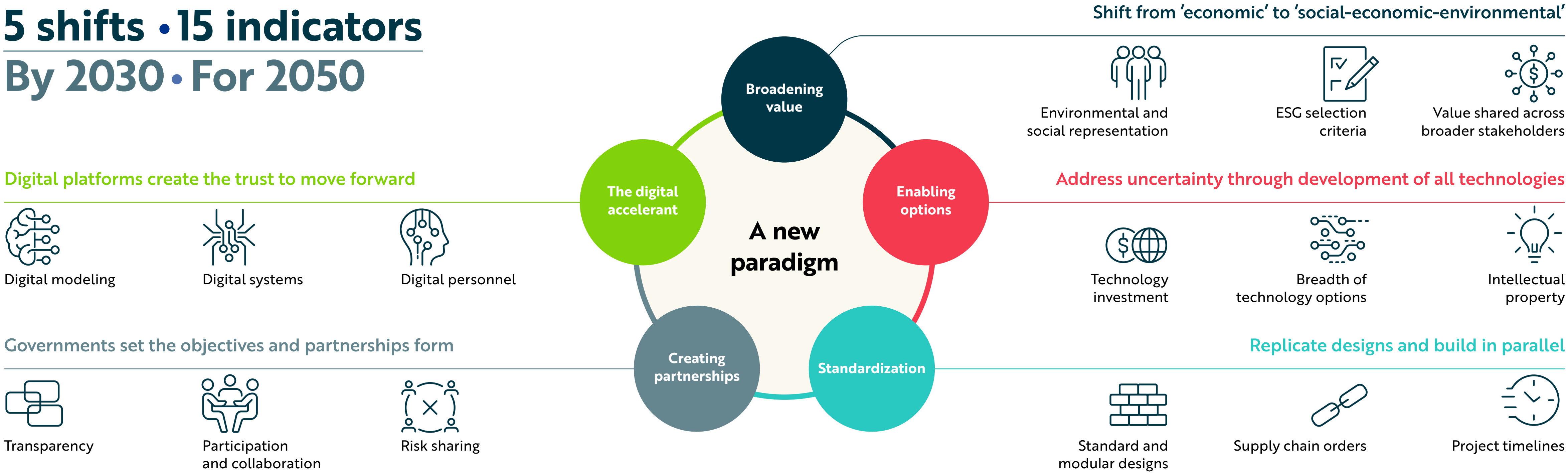


FIGURE 1 The FATR shifts of our net zero delivery paradigm and the three indicators of change for each shift

THE FRAMEWORK TO 2030

The second paper introduced the indicators of change for the FATR shifts as part of a broader framework, termed the **FATR Framework**. A desk top industry "pulse check" of these indicators showed a large gap between where infrastructure delivery practices were in 2022, and where we need to be by 2030 (Figure 2). We view the end of this decade as a critical target date to have the shifts in common practice to achieve a mid-century net zero ambition.

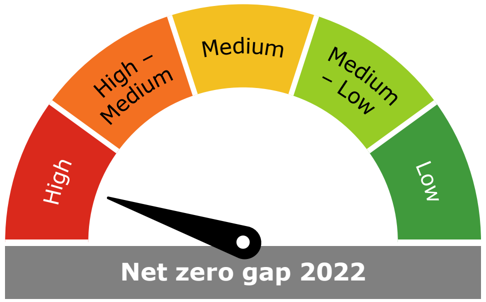


FIGURE 2 The net zero gap in 2022

We committed to exploring these indicators of change as a basis to assess implementation progress, course correct, and inform updates to the framework. A key resource will be Princeton University's (Princeton's) Net Zero Stakeholder Survey, which is to be run annually to 2030. The survey elicits views from diverse international stakeholders engaged in the development of energy and industrial infrastructure (a consolidated list of those stakeholders, which we term infrastructure "participants", is shown in Figure 3).

Asset owners and project developers	Those that develop, own and operate net zero infrastructure
Banks and investors	Those that provide funding to support the development and construction of net zero infrastructure
EPC services and contractors	Those that provide consulting, design, environmental assessment, project management and construction services to net zero infrastructure developments
Supply chain providers	Those involved in the production of upstream materials including mining, processing, refining and primary material manufacture
Equipment manufacturers	Those that manufacture and supply technologies used in net zero infrastructure
Policymakers and regulators	Federal and state government departments that set policies relevant to net zero infrastructure, and both their approval agencies and relevant market governance bodies
Communities, social and environmental GOs	Those associated with or influential in advocating for/against net zero infrastructure – e.g. landowners, community groups, Non-Government Organizations (NGOs), First Nations groups
Educators, universities and researchers	Large universities, community colleges, professional development and vocational training institutions, and those associated with net zero infrastructure related research
Labor organizations	Those representing workforces in net zero infrastructure related fields, including unions and interest groups

FIGURE 3 Who we designate as net zero "industry participants".
This aligns with the stakeholder groups used in the Princeton Net Zero Stakeholder Survey.

In this FATR paper, we consider the preliminary 2023 survey results and for the first time give an indication of a quantitative baseline, shown in Figure 4. While certain shifts are being implemented, this baseline shows there is still a long way to close the gap by 2030.

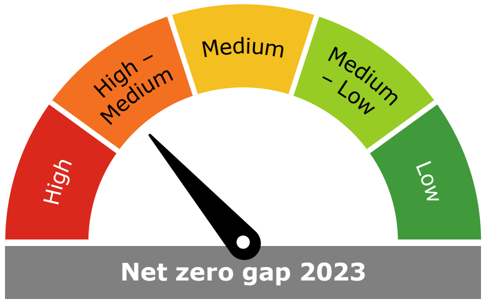


FIGURE 4 The net zero gap in 2023

FROM WHAT TO HOW

The FATR series is a collaboration between Worley and the Andlinger Center for Energy and the Environment at Princeton.

Our organizations are committed to driving sustainability outcomes, and this collaboration combines the analytical excellence of an academic leader, Princeton, with the pragmatic and practical experience of one of the world's leading providers of professional project and asset services in the energy, chemicals and resources sectors, Worley.

Through the FATR series, we are aiming to move the narrative around net zero from **what** we need to do to **how** to do it: How do we meet this enormous challenge, which is a labyrinth of complexity that ultimately rests on the delivery of technology and assets?

The FATR papers have concentrated on net zero supply-side infrastructure only. We are aware of the bigger issues in the decarbonization challenge outside of this scope, and in this paper, we begin to expand our focus outside that boundary, as our work exposes adjacent interdependencies. Key examples include stretched supply chains and constraints on skilled human resources, and the enormous quantity of transition materials required.

The broader issues of energy poverty, energy security, legal constructs, ecological protection, the nuances of global trade and political realities, are all relevant, and many are barriers to the achievement of net zero that together make the task appear almost impossible. However, recognizing that these macro issues are largely beyond our ability to influence, we are focusing our efforts on what it will take to deliver the physical tools of decarbonization: the infrastructure assets.

Climate change demands that we move to the delivery of these assets, and quickly. Ever more urgent action is needed to translate ambitions to rapid infrastructure development, and to achieve this, we call on all those involved in infrastructure delivery to make the paradigm shift.

This paper provides guidance on the steps to achieve that.

CHAPTER

2 A spotlight on hydrogen in the EU

HYDROGEN AS PART OF THE NEW ENERGY ECOSYSTEM

The potential of hydrogen as a vector for large-scale decarbonization has emerged in the last decade. Hydrogen now appears in almost all net zero scenarios. In the EU alone, hydrogen is included in more than 15 key pieces of policy and legislation, and the EU's clear ambition is for hydrogen to be produced and used in significant quantities by 2030.

Hydrogen's value as one of the pillars of decarbonization stems from its ability to mimic the characteristics of liquid and gaseous fossil fuels and because it can be produced using a diversity of low-emissions pathways. Hydrogen also offers a means to delink energy production from the time of end use, providing one solution to the output variability of certain renewables. Hydrogen therefore has the potential to be an enabler of deep decarbonization while also improving energy resilience and energy security across industry sectors.

Hydrogen is also an important chemical feedstock, which is how most of the 95 MTPA[2,3] of hydrogen produced globally is currently being used (in industries such as refining, and ammonia and fertilizer production, for example). However, around 99% of the hydrogen produced today is produced from fossil fuels without carbon abatement, resulting in significant carbon dioxide (CO_2 emissions.

The hydrogen of the future must be produced with low emissions and will be deployed in a much broader range of uses. The International Energy Agency's (IEA's) Net Zero Scenario[4] suggests that around 450 MTPA may be needed globally by mid-century to reach net zero, particularly across hard-to-abate sectors such as steel making, heavy transport, and synthetic fuel production. Low-emissions hydrogen has the potential to become a globally traded, economically impactful commodity industry, but there are challenges.

The physical qualities of hydrogen demand technical solutions that are engineered differently than traditional energy carriers. End-to-end thermodynamic efficiencies can be low with significant cost and broader strategic implications. Hydrogen is also an indirect greenhouse gas (with a global warming potential on the order of 6–10 times that of an equivalent quantity of CO_2 over a 100-year period)[5], which means that fugitive emissions of hydrogen need to be closely monitored and minimized. As a product, hydrogen also cuts across existing and traditionally siloed value chains, coupling diverse industries together, some for the first time and with quite different operating cultures.

The emerging low-emissions hydrogen ecosystem is immature. For example, nomenclature is variable and inconsistently applied, and clear commercial paths for capital allocation at scale remain unclear.

Despite this, a growing body of evidence for the importance of low-emissions hydrogen in decarbonization (e.g., studies like Net-Zero America[6] and Net Zero Australia[7], which were used in our first FATR papers) makes it important to consider hydrogen infrastructure requirements.

There is still significant debate around definitional nuances and the merits of various low-emissions hydrogen value chain pathways (see Pullout 1). In the context of the EU policy ambition for low-emissions hydrogen, we limit our focus in this paper to renewable hydrogen, defined as hydrogen produced by electrolysis powered by renewable electricity.

The clarity and relative maturity of the EU renewable hydrogen ambition make it a good case study to explore, so we begin by considering the background to that policy.

PULLOUT 1

Perspectives on hydrogen

Globally, the low-emissions hydrogen industry represents a diversity of ambition and policy drivers which have emerged relatively quickly. As a nascent industry, consensus on even basic terms is yet to emerge. This is highlighted in terms of the language of hydrogen and how to label it according to energy source and manufacturing technology.

Currently, there is a mix of terms, some voluntary and some mandatory, some legally defined, but differently so in various regions, some with only general consensus.

This lack of interoperability is a key concern for project developers looking at international trade and is an area of high priority for standardization.

MANDATORY

Low-carbon hydrogen

Used by policy makers in the UK and China to determine project funding. Varying methodologies for calculations with differing resulting emissions.

2.40 kgCO$_2$e/kgH$_2$

14.51 kgCO$_2$e/kgH$_2$

Clean hydrogen

Used by policy makers in the US and China to determine project funding. Different calculation methodologies.

0.45–4.00 kgCO$_2$e/kgH$_2$

4.90 kgCO$_2$e/kgH$_2$

Renewable hydrogen

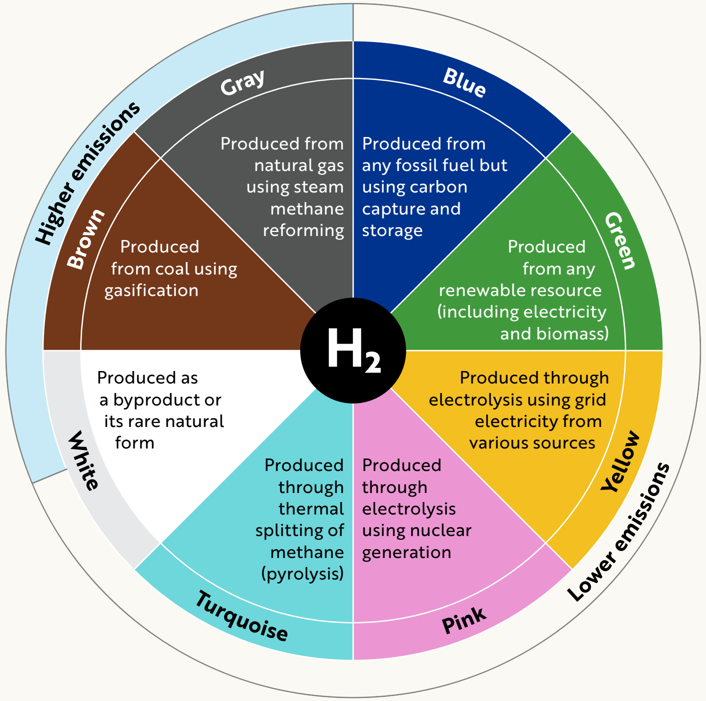
Used by EU policy makers to determine funding, taxes, import duties, etc.

Nomenclature used in this report

SAMPLE VOLUNTARY STANDARDS

1. Colors

Often used as a shorthand but with inconsistent definitions.



2. Green and Blue Hydrogen Standard

Voluntary industry standard developed by CertifHy using internal methodology. **4.37** kgCO$_2$e/kgH$_2$

3. Green Hydrogen Standard

Voluntary industry standard developed by GH$_2$ using the IPHE methodology. **1.0** kgCO$_2$e/kgH$_2$

THE EU'S GREEN HYDROGEN AMBITION

The EU is a political and economic collaboration of 27 member countries that has shown global leadership in sustainability. It was the first governing body to adopt a legally binding target of net zero by 2050 and the first to develop a comprehensive taxonomy of sustainable economic activities.

As part of its REPowerEU Plan (2022)[8], the EU has adopted a non-legally binding objective of 10 MTPA of domestic renewable hydrogen production by 2030. According to IEA figures, current production of renewable hydrogen in the EU is less than 20 KTPA[9], so this is a large increase required over the next seven years, even for an industry that is evolving rapidly. REPowerEU also includes an objective to import 10 MTPA of similarly produced hydrogen in the same timeframe, meaning that the total policy ambition for EU renewable hydrogen supply is 20 MTPA by 2030.

REPowerEU specifies that all of this hydrogen must be produced using electrolysis powered by renewable electricity. To prevent new hydrogen-related electricity loads from cannibalizing the existing renewable electricity supply, the Renewable Energy Directive (RED II) Delegated Acts require hydrogen projects to procure new renewable energy that is generated within the same market bid zones, while also demonstrating that electrolyzer usage balances with renewable generation over a prescribed period.

Hydrogen producers can choose to source electricity that is either supplied directly via private transmission infrastructure or through a grid connection.

To facilitate this ambition, the EU is developing a supporting regulatory and policy environment, which includes developing and rolling out its primary fiscal intervention mechanism, the European Hydrogen Bank (EHB). The EHB is expected to be operational by the end of 2023. With two streams, one for domestic production and one for imports, the EHB will provide a subsidy for renewable hydrogen, with the per-kg value of the subsidy to be determined through an auction system.

While there is complexity in the policy and regulatory mechanisms involved that is outside the scope of this paper, a clear and defined policy ambition exists in the EU to produce 10 MTPA of domestic renewable hydrogen. We now consider the infrastructure needed to achieve this ambition.

WHAT THE NUMBERS ARE TELLING US

The IEA Net Zero Scenario projects global production of low-emissions hydrogen rising to around 450 MTPA by 2050, with renewable hydrogen eventually accounting for around 75% of this total and requiring 15,000 terawatt-hours per year (TWh/y) of electricity to produce. This is around half of total global electricity demand in 2022, so the new infrastructure requirements to meet this additional electricity demand are significant.

The EU ambition of 10 MTPA by 2030 is orders of magnitude smaller than the IEA scenario for global hydrogen production in 2050, so the new infrastructure burden to reach the EU goal may be considered more achievable. Using the EU rules of engagement, we translated the 2030 EU ambition in technology deployment terms.

Figure 5 outlines one possible technology portfolio that could meet the 10 MTPA objective. This paper, it should be noted, does not set out to identify the best technology mix nor does it consider the feasibility of alternate pathways. The numbers shown in Figure 5, which are extraordinary, are intended to demonstrate the challenging scale and complexity of the deployment task.

Item	Macro quantities	Assumptions
Electrolyzers	39,000 MW PEM 36,000 MW Alkaline	Assuming a 50 / 50% split between PEM and Alkaline electrolyzers
H_2 storage	1.6 million tons aboveground storage 5 million tons strategic reserve 5 million tons line packing	1. A requirement for 4 weeks aboveground storage to mitigate for short-term market fluctuations 2. Development of a strategic hydrogen reserve in line with Council Directive 68/414/EEC re oil reserves 3. The proposed hydrogen backbone allows for levels of line packing
Onshore wind	36,631 MW / 91 TWh	Assuming 20% of production comes from onshore wind within the EU, using an average capacity factor of 0.284
Offshore wind	109,893 MW / 404 TWh	Assuming 60% of production comes from offshore wind within the EU, using an average capacity factor of 0.42
Solar	36,631 MW / 55 TWh	Assuming 20% of production comes from solar within the EU, using an average capacity factor of 0.17
Grid	109 GWs of new capacity requiring connection to the transmission grid	Assuming 60% of requirement is connected to the grid, and 40% is direct wire and not grid connected
H_2 pipelines	28,000 km	Using the numbers of the proposed Hydrogen Backbone
Water	107,166 million liters per annum of demineralized water 535,830 million liters per annum of seawater	Assuming the use of reverse osmosis with a maximum 20% acceptable brine content

FIGURE 5 Basic quantities to meet the H_2 demand sought, domestic. Acronyms are defined on page 54.

Using the example technology path in Figure 5, 10 MTPA of renewable hydrogen production in the EU would require:

- an order-of-magnitude increase in global electrolyzer manufacturing capacity from that currently
- a four-fold increase in annual capacity additions for offshore wind in the EU every year through to 2030, based on the maximum historical yearly deployment rate achieved over the last decade (2019)[10]
- a 35% increase in desalination capacity additions in seven years, compared to what was achieved in the EU in the decade to 202011
- potentially the connection of over 100 gigawatts (GW) of new renewable generation to the electrical grid (note, however, that we could not form a view on the degree of grid augmentation required, as it appears that this analysis has not yet been undertaken).

All this infrastructure would need to be developed, permitted, financed, and built in fewer than seven years. When considered alongside the other pillars of EU decarbonization that will need to be implemented concurrently, such as decarbonization of the power industry, and the anticipated global demand for renewable energy, technology and resources, the dimensions of the infrastructure delivery challenge become more apparent.

In summary, while the EU's renewable hydrogen ambition is just one part of a much larger infrastructure plan, its requirements are indeed daunting. Experience tells us that this ambition will not be satisfied entirely by small, bespoke projects. Rather, an undertaking of such scale, speed and complexity can be achieved only with the emergence of an era of hydrogen mega-projects.

The next chapter describes such a project and considers whether traditional approaches to project development and delivery can, through the decision sequencing of the capital discipline process, produce infrastructure results at the scale and speed that the EU's 2030 hydrogen ambition demands.

"While the EU's renewable hydrogen ambition is just one part of a much larger infrastructure plan, its requirements are indeed daunting."

CHAPTER

3 The role of capital discipline

WHAT WE MEAN BY CAPITAL DISCIPLINE

The delivery of virtually all large energy and industrial projects in most parts of the world is characterized by staged, disciplined decision-making that weighs risks and uncertainties of many kinds, from technological to social, political, and regulatory, and bottlenecks in materials and labor. Failure to mitigate such risks and uncertainties exposes developers and investors to three key issues:

- increased capital requirements due to cost overruns and/or delays in engineering, procurement, construction, and startup
- lower operating profits due to revenue shortfalls or operating cost overruns
- lack of achievement or withdrawal of social license, which impacts costs and profits.

Risks are exacerbated for long-lived investments, such as large industrial assets, including decarbonization facilities, which can have lifetimes of more than 50 years. Successful deployment relies on **capital discipline** – a sequence of derisking activities and decisions that consumes considerable resources and requires significant lead times. Figure 6 shows our view of the capital discipline process, based on the work of Greig et al (2023)[12], and defines the basic nomenclature used in the remainder of the paper.

Project inception → **Project end**

Project stage	**Project development**				**Project delivery**	**Project operations and decommissioning**	
Project phase	**Scoping (FEL0)** ID	**Pre-feasibility (FEL1)** ID	**Feasibility (FEL2)** ID	**Definition and approval (FEL3)** FID	**Construction and commissioning** COD	**Operations** ID	**Decommissioning**
Typical phase scope	Identify business opportunity and technology, project fit into existing portfolio and strategic aims.	Identify and examine project alternate configurations, consider project risks, undertake basic business case including revenue (off-take) options.	Apply for permits, undertake community engagement and environmental studies, approach and confirm land tenure, increase project definition + cost + schedule estimate, consider and engage finance and equipment procurement path, confirm business case feasibility.	Complete Front-End Engineering and Design (FEED), project estimate and execution plan, confirm finance and off-take provision, complete all statutory approvals, confirm key suppliers, make final investment decision.	Execute key contracts, complete detailed engineering, mobilize construction team, undertake construction, begin commissioning and ramp up to full operations.		
Phase timing	3 – 6 months	3 – 18 months	6 months – 3 years	2 months – 2 years	4 months – 5 years	5 – 50+ years	6 months – 25+ years
Project funding	**Development capital** Developer equity				**Project finance** Equity and construction finance	**Asset finance** Equity/institutional equity and debt	

Phase (Front-End Loading #)
ID Interim decision gate
FID Final investment decision
COD Commercial operations date

FIGURE 6 Indicative and stylized representation of capital discipline protocols, which in industry use various alternative nomenclature, based on the work of Greig et al (2023).[12] In this paper, we focus on project development and delivery. Areas in gray are out-of-scope.

Those responsible for investment decisions will generally have their own versions of Figure 6 and, in fact, there is neither a prescribed standard for such protocols nor a legal requirement that they be used. Nonetheless, company boards, governments, and those tasked with governance are increasingly likely to come under pressure from shareholders and constituents to apply robust capital discipline protocols to all forms of investment, including greenfield project development, acquisitions, and investing, with punitive penalties possible if these protocols are not applied.

In this process, developers begin by investing in a sequence of activities, progressively increasing the capital they put at risk to fund project conception, initial scoping, pre-feasibility studies, feasibility studies, social and environmental reviews, permitting, and financing. This sequence is often referred to as front-end-loading (FEL) studies.

When confidence that the project will deliver acceptable returns has been established, the developer may progress to securing all final permits, convincing various stakeholders to authorize the project, and approaching new providers of capital, typically including both equity co-participants and debt providers, to commit much larger sums of capital to build and commission the project. That commitment signals the final investment decision (FID). At each interim decision (ID) gate up to FID, developers/investors may continue, pause, or abandon the project if key derisking criteria are not satisfied.

After FID, projects advance to finalization of design details, procurement, construction, and startup, culminating in a working asset at the commercial operation date (COD). This is the point where a decarbonization asset starts operating and having a climate mitigation impact.

Small, uncomplicated projects might take as little as a year to complete, but large-scale, complex energy and industrial assets often take many years – in some cases, a decade or more. Once the project is fully operational and has satisfied all contracted performance requirements, financial returns should finally flow to investors, two to ten years or more after the project was first conceived.

The practice of capital discipline is crucial to maximizing the value delivered by projects, and to avoid project failures, which can bring disastrous financial, environmental, reputational, and other consequences, including to a broader set of stakeholders such as affected communities and Indigenous peoples. It is dangerous to compromise on capital discipline; yet capital discipline also imposes speed-limiting effects on the net zero transition.

To explore this tension, we consider the application of capital discipline to the types of projects needed to meet the EU's renewable hydrogen ambition. In other words, the delivery of mega-projects.

> **"It is dangerous to compromise on capital discipline; yet capital discipline also imposes speed-limiting effects on the net zero transition."**

THE NEED FOR MEGA-PROJECTS

Europe's largest renewable hydrogen project to reach FID to date is the 200 MW Holland Hydrogen 1 project, designed to deliver around 22 KTPA of renewable hydrogen to the refining industry in Rotterdam with an expected COD in 2025. Such projects represent an important evolution of the renewable hydrogen industry and are necessary to gather critical data and stress-test the ability to scale the supply chain for renewable hydrogen and its market boundaries.

To reach 10 MTPA by 2030, around 500 Holland Hydrogen 1-sized projects would need to be completed – a daunting challenge in the time available, given current limitations in human resources and technical expertise to manage so many projects concurrently. This suggests it will be necessary to significantly scale up individual projects.

Several project proposals with GW-scale electrolyzers are already being advanced in Europe, and these projects are closer to the size required. To further explore the potential for renewable hydrogen mega-projects, we developed a conceptual "base" project in terms of basic components and specifications, shown in Figure 7a.

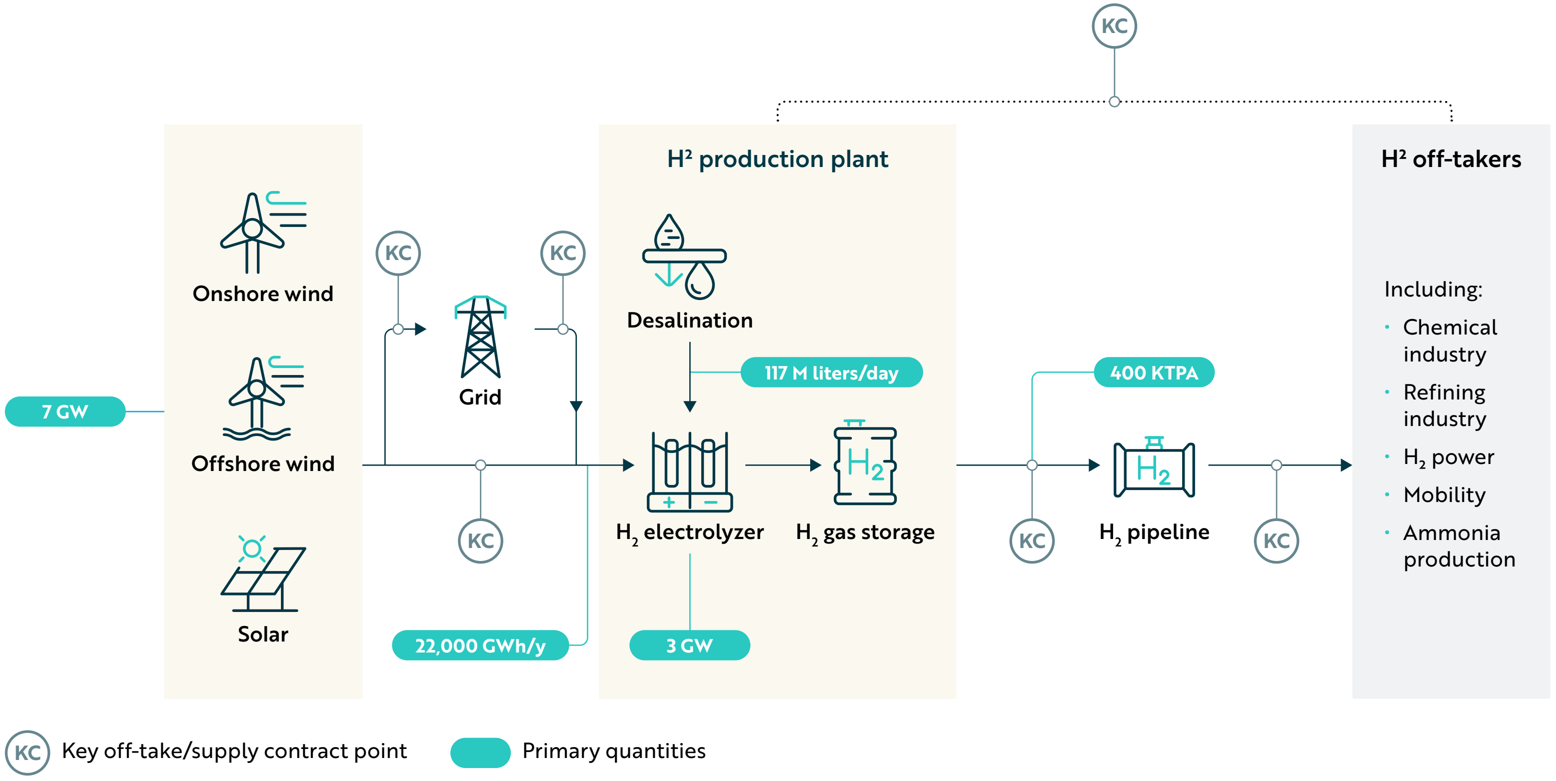


FIGURE 7A The scale needed to meet the ambition – our Base Hydrogen Project – showing key contract points and quantities. 25 of these projects would need to be built and operating by 2030 to meet the EU ambition. Off-takers are shown grayed as they are out-of-scope in our analysis.

This **Base Hydrogen Project** (with a 3 GW electrolyzer and 400 KTPA production capacity) represents an asset at a scale that is commensurate with the policy ambition. Approximately 25 projects of this size would need to reach COD by 2030 to realize the EU policy ambition of 10 MTPA of renewable hydrogen production. The prospect of developing 25 projects of this scale in parallel is challenging to anyone familiar with industrial project development.

The scale drives the need for direct connection of generation assets to the hydrogen production plant, but because electricity may still be procured via energy markets, two energy pathways are shown in Figure 7a. The assumption is that projects will need to be located close to renewable generation, which may limit siting opportunities.

Our Base Hydrogen Project assumes that the water being supplied is desalinated and that compressed gaseous hydrogen will be delivered to off-takers via pipelines (off-takers' end-use facilities are outside the scope of this paper). Some energy storage or balancing may be needed on the electricity supply side, but for simplicity this also remains out of scope.

Figure 7a shows the key contracts (KCs) needed to complete the Base Hydrogen Project. We have assumed a project structure in which the developer is involved in all value chain elements is unlikely at such a large scale. A more integrated project structure is possible through joint ventures between parties or the development actions of very large companies, but for illustrative purposes our example can be condensed to three KC components, shown in the simplified project in Figure 7b.

This simplified version allows us to cut through the complexity involved and examine a critical element of this infrastructure puzzle: the timescale to take mega-projects from concept to fully operational.

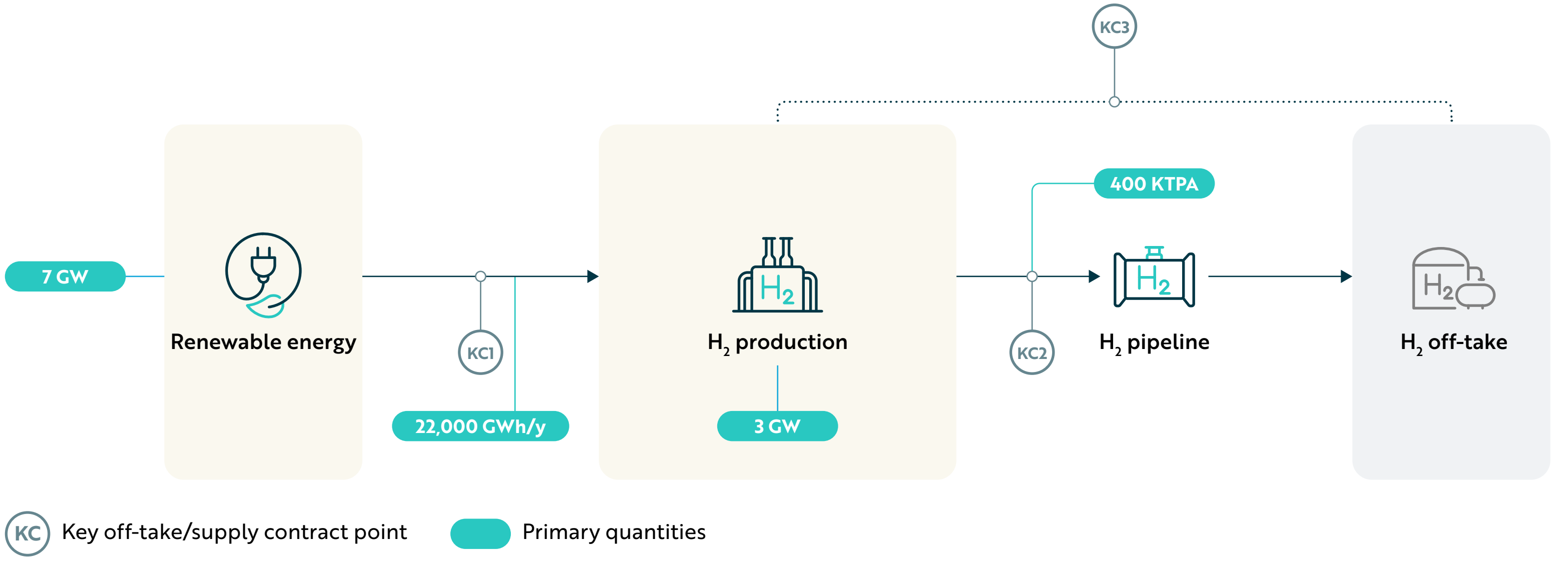


FIGURE 7B Our Base Hydrogen Project in its simplest terms, showing core key contracts and quantities. Off-take is shown grayed as this is out-of-scope in our analysis.

THE BIG DISCONNECT

We estimate it would take a **minimum** of eight years to reach COD for the asset represented in Figure 7b if traditional capital discipline approaches are followed. At the time of writing no one has developed, designed, constructed, and commissioned a renewable hydrogen production plant of this size before, anywhere in the world, so we expect in practice it could take significantly longer.

To meet a 2030 target date, all 25 base projects would need to have advanced through the stage of feasibility studies (FEL2) by the end of 2023. Based on our knowledge of the current market, this will not happen. Further, every subsequent step of the process would have to be executed flawlessly, which rarely occurs in practice.

We therefore contend that the level of ambition implied by the EU's renewable hydrogen target is likely to remain beyond reach without a fundamental overhaul of traditional project delivery practices.

To inform this view, we mapped the separate development phases (described in Figure 6) for the three core Base Project KC components to produce the basic schedules shown in Figure 8.

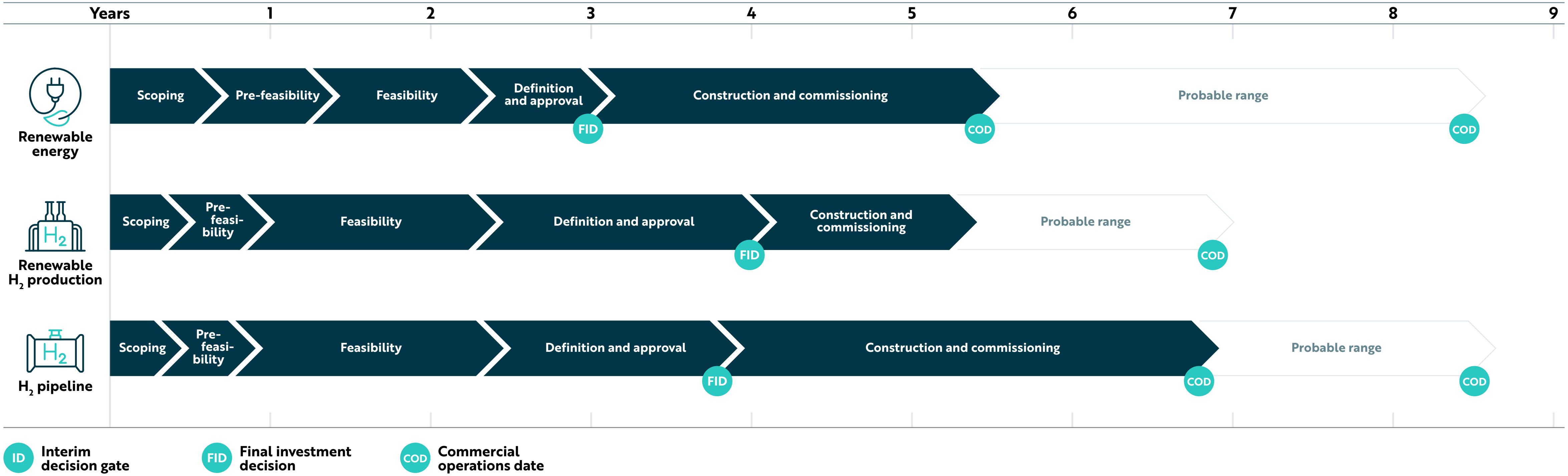


FIGURE 8 Ambitious view of current development and delivery times for core components of our Base Hydrogen Project, under a traditional Capital Discipline approach and all projects developed in isolation. The dark filled phases depicts the best possible timeline, with the probable range also shown.

Several assumptions were applied:

- that a sense of urgency exists – the EU's response to date around energy security concerns demonstrates that European solutions can progress quickly by world standards
- that Base Project KC elements progress separately, led by different entities, and follow EU rules
- project CODs are closer to 2030, meaning by EU renewable hydrogen rules, renewable electricity supply must come from new generation assets
- the electricity grid does not need significant augmentation (this is potentially a gross simplification, though it ultimately does not impact our conclusions), but significant hydrogen pipeline laterals are needed
- the project is not among the first to progress, requiring all greenfield infrastructure - which means any early mover advantages such as existing infrastructure and hydrogen off-takers, or access to surplus clean energy supply either in the market or developing now, are not available
- while this project may not be the first of its kind, 25 assets need to be advanced essentially in parallel, so learnings from other mega-projects will be limited
- for simplicity, offshore wind dictates the renewable energy supply development timeline. Recognizing that certain regions will favor different renewable technologies and timelines will vary greatly depending on local issues, this is a simplification.

"The level of ambition implied by the EU's renewable hydrogen target is likely to remain beyond reach without a fundamental overhaul of traditional project delivery practices."

Figure 8 indicates an expected range for each individual component of the overall Base Hydrogen Project schedule, reflecting uncertainties in such things as equipment supply. Considered separately, the hydrogen production side **could** be delivering product in as early as 5.5 years. However, the interdependencies between components that necessitate taking specific actions to mitigate investment risk heavily restrict the speed of deployment.

This is shown in the hypothetical combined schedule in Figure 9, which highlights decision dependencies across the core supply-side infrastructure. Here, simultaneous decisions need to occur to justify subjecting valuable development capital to continuing risk. This alignment means the total project is dependent on the longest schedule phase of each component – which in turn means that 5.5 year timeframe becomes around 8.0 years. When additional factors are considered, such as the potential extension of permitting times, challenges to pipeline routes, constrained equipment supply, and any number of other issues, project durations beyond 10 years are more probable.

Such a pathway, constrained by traditional delivery practices, will put EU policy targets for renewable hydrogen beyond reach.

The example described here is highly stylized and nominal, but illustrates a dependency problem that Uden, et al.[13] have termed the "chicken-or-egg problem" in which "uncertainty surrounding access to enabling infrastructure, end-use markets, and/or performance of counterparties" results in stalled or slow projects. The same paper uses carbon capture and storage as its example, but notes that other clean technologies, such as wind and solar projects that need grid connection, face the same problem.

Uden, et al. (2022) also point to another issue, which they term "path-dependence", where policy decisions taken in the present impact the ability to advance other options in the future. In the case of the EU, the constraints of the current policy (requiring renewable generation within a certain market zone, or defining renewable hydrogen in narrow terms, for instance) may prevent the development of alternative low-emissions hydrogen production pathways that could make the ambition more achievable. Here, conditionality can become the enemy of decarbonization success.

These problems apply to many elements of achieving net zero by mid-century and must be overcome, or the industries involved will not be able to effectively deploy the vast amounts of capital needed, at the speed required.

So, if the hydrogen industry cannot reach the EU's policy ambition using traditional methods, what will it take?

This question and our response are at the heart of the next chapter, which investigates the role of the five FATR shifts in driving projects – and a whole industry – to move faster.

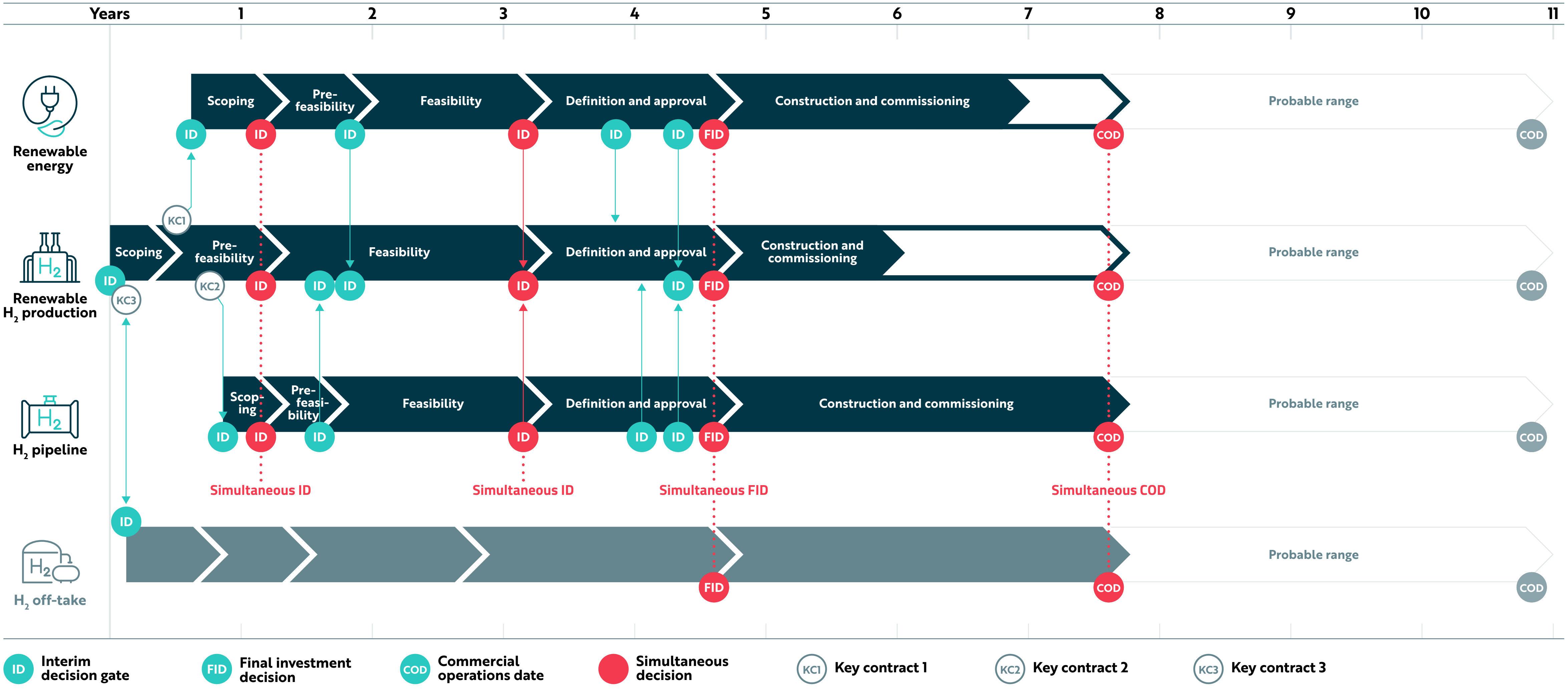


FIGURE 9 Combined basic schedule after adjusting for decision gate dependencies and alignment steps needed to mitigate development capital risk, Base Hydrogen Project. Notional investment decisions based on typical relationship contracts are shown, including preliminary, indicative and firm contract offers.

CHAPTER

4 Radical change to accelerate an industry

RADICAL BUT RESPONSIBLE

The infrastructure challenge of achieving net zero by mid-century requires a new paradigm, which is radical but responsible. Capital discipline timelines must be compressed while retaining the essential principles of value assurance to prevent project failures and a deceleration of climate change mitigation efforts.

The five FATR shifts (Figure 10), developed in the first papers in the FATR series, can accelerate project delivery while maintaining the risk management value of capital discipline. They represent a fundamental change from the way infrastructure is currently delivered:

- **Broadening value** is about considering more than financial value in a project, including benefits to communities and the environment
- **Enabling options** keeps all technology solutions on the table, allowing approaches to pivot as roadblocks appear
- **Standardization** of componentry, replicating between projects and providing certainty to the supply chains, allows manufacturing ahead of the project curve and projects to run more in parallel than sequentially
- **Creating partnerships** is collaboration between participants at a new level, sharing learnings and intellectual property
- **The digital accelerant** uses platforms to enhance all these shifts, sharing information, building trust amongst stakeholders, and driving faster, more efficient project processes.

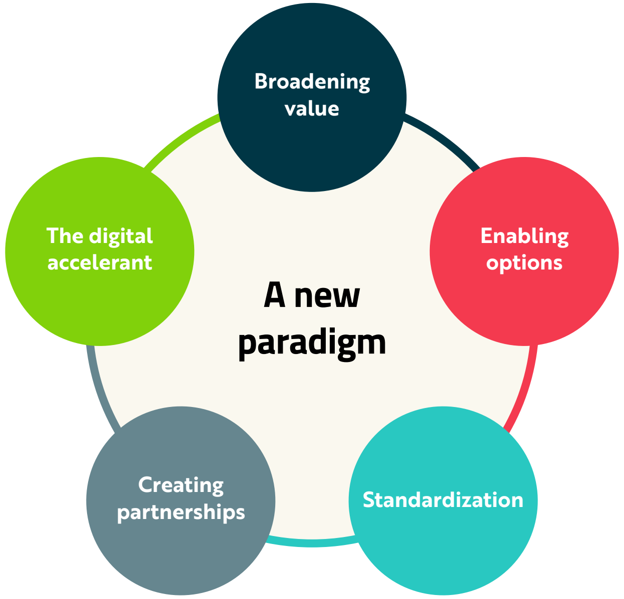


FIGURE 10 The FATR shifts

Feedback on the FATR shifts indicates that these concepts resonate with infrastructure participants, but can make some uncomfortable, principally because the shifts challenge related norms and practices. As an example, numerous developers of hydrogen projects were approached to provide case studies to help illuminate project progression for this paper. All politely declined.

Readers may also question the resulting outcomes of some of the shifts. For example, there are advantages in adopting the bespoke over standardization where that enables innovation; commercial tension between parties can drive better capital efficiency and provide competitive advantage to increase shareholder value; and digitization can bring cyber security risks.

> "The infrastructure challenge of achieving net zero by mid-century requires a new paradigm, which is radical but responsible."

Nonetheless, we maintain that the FATR shifts will be crucial to meet the scale and speed challenges of mid-century net zero infrastructure delivery.

To demonstrate their application, we considered what it will take to drive the hydrogen industry as a vector for large-scale decarbonization, tackle the barriers holding that industry back and see how initiatives in line with the FATR shifts could accelerate infrastructure delivery.

BARRIERS CONFRONTING THE LOW-EMISSIONS HYDROGEN INDUSTRY

Barriers to the rapid expansion of a broader clean hydrogen industry were explored with sector stakeholder groups across Europe, the UK, and the US, as part of a project undertaken by the Andlinger Center for Energy and the Environment[14], and with industry experts who are actively engaged on related projects in Europe through workshops facilitated by Worley and Princeton.

The identified barriers can be summarized into three categories: **certainty** (for investors and participants across the net zero value chain), **acceptance** (by society), and **productivity** (across the project delivery value chain) as shown in Figure 11.

A lack of investment **certainty** could result in failure to mobilize the large sums of capital needed to fund required expansions across the value chain and, in our specific EU example, could mean falling short of the policy objective. Investment uncertainty can arise due to a lack of confidence in, for example, the timing of demand, the timing of enabling infrastructure, and the trajectories of future cost reductions. As described in Chapter 3, this lack of certainty would result in a slower industry response and longer schedules.

A deficit in stakeholder **acceptance** can compromise the durability of policy support, impact the ability to obtain regulatory approvals or access to land, trigger legal challenges, and hold back investors who perceive reputational risks. Such a deficit can arise from a number of potential issues: stakeholders who perceive poor engagement and project benefit sharing; stakeholders losing confidence in the performance, safety or environmental consequences of the technology; or perceptions of adverse impacts on social wellbeing or local quality of life by host communities. The speed and scale of infrastructure delivery suffers when social acceptance is compromised and vice versa: speed and scale can be enhanced when acceptance moves beyond a base level of tolerance to enduring, proactive support.

Productivity in our context refers to performance (safety, quality, speed, and cost) across the delivery value chain, which influences timescales for translating project concepts to investment decisions and, ultimately, to assets that reach COD. Productivity is compromised by poor planning, lack of clarity or miscommunication about project expectations and performance standards, inconsistent terminology, design errors, specification inaccuracies, unreliable or underdeveloped supply chains (including for human resources), ineffective learning, and failure to share and translate learnings for future projects. Each of these factors serves to slow infrastructure delivery.

Certainty
OVERCOMING THE RISK OF INVESTMENT

- Future demand visibility
- Future hydrogen price trajectory
- Future hydrogen costs of technology
- Customers' willingness to pay
- Renewable (and transmission) capacity availability
- Ability to satisfy regulators/customers of renewable origin
- Ability to obtain reliable technology supply
- Access to land and water resources

Acceptance
BUILDING AN ACCEPTABLE SOCIAL, COMMERCIAL AND POLITICAL CONTRACT

- Impact on energy bills
- Public skepticism of sector's green credentials
- Public skepticism of hydrogen safety
- Communities unconvinced of positive to negative trade-offs in project development
- Lack of trust in oil and gas sector's climate goals
- Lack of transparency in criteria for allocating public funding

Productivity
GETTING THE PACE OF DEPLOYMENT TO WHAT IS NEEDED

- Capacity in equipment supply chains
- Workforce readiness
- Depth of capacity in EPC organizations
- Complexity and time of permitting and approval process
- Capacity in regulatory and permitting agencies
- Bespoke project designs slow down learning
- Developer insistence on firewalls between project teams

FIGURE 11 High-level summary of stakeholder perceptions of risk and uncertainties that might constrain the achievement of 2030 clean hydrogen ambitions.

APPLYING THE FATR SHIFTS – OUR EU RENEWABLE H_2 PLAN

We explored the role of the FATR shifts in overcoming the risks and threats described in Figure 11 by mapping each to a shift (or shifts) that could help overcome them. The results are shown in Figure 12.

Two key findings are evident from this analysis:

- there is an opportunity to use the shifts to address the issues of certainty, acceptance and productivity that currently challenge the renewable hydrogen sector. The shifts provide a framework to progress more than just individual projects and have relevancy beyond supply-side assets – including the potential to influence upstream and downstream supply chains, hydrogen demand, workforce skills, policy, and pricing
- many of the risks and threats identified in Figure 11 could be mitigated by a combination of the shifts. For example, increased transparency (#4 Creating partnerships and #5 The digital accelerant) and sharing of project designs (#3 Standardization, #4 Creating partnerships, and #5 The digital accelerant) could help address public concerns around hydrogen safety and the green credentials of projects, as well as challenges related to the complexity and timing of permitting, depth of capacity in supply chains, and slow learning rates.

	Barriers addressed			Relevant FATR shifts				
Barriers to net zero infrastructure delivery	Certainty	Acceptance	Productivity	Broadening value	Enabling options	Standardization	Creating partnerships	The digital accelerant
Willingness to pay	✓			●				
Public skepticism of hydrogen safety		✓		●	●			
Public skepticism of sector's green credentials		✓		●				
Complexity and time of permitting and approvals process			✓	●	●	●	●	●
Communities' resistance to projects "not in my backyard"		✓		●				
Lack of trust in oil and gas sector's climate goals		✓		●				
Lack of transparency in allocating public funding		✓		●				●
Renewable (and transmission) capacity availability	✓				●		●	
Depth of capacity in EPC organizations			✓		●	●		
Capacity in equipment supply chains			✓		●	●		
Workforce readiness			✓		●		●	
Capacity in regulatory and permitting agencies			✓		●	●		●
Bespoke project designs slow down learning			✓			●		●
Developer insistence on firewalls between project teams			✓			●	●	
Ability to satisfy regulators of renewable origin	✓							●
Ability to certify renewable origin for customers	✓							●
Future demand visibility	✓							
Future hydrogen price trajectory	✓						●	
Future hydrogen costs of technology	✓						●	

● Broadening value ● Enabling options ● Standardization ● Creating partnerships ● The digital accelerant

FIGURE 12 Mapping of the outcomes sought in Figure 11 across Certainty, Acceptance and Productivity, to the five key shifts.

We then considered the issues in Figure 12 within the current enabling policy context of the EU and formulated a series of initiatives in response. Figure 13 summarizes our **EU Renewable H_2 Plan**, designed to support the EU's renewable hydrogen ambition, and allow capital discipline to drive faster deployment and scale-up of supply-side assets.

The plan describes each initiative in terms of relevant FATR shifts, barriers addressed, ease of implementation and potential to impact broad industry ambition. Figure 13 is presented at a high level while Addendum 1 provides more detail on the rationale for our ratings as well as a view on the impacts on our Base Hydrogen Project in terms of schedule, net present value (NPV) and emissions.

The FATR shift, "Creating partnerships" is at the core of all but one of the initiatives, an unsurprising result that we also see in practice as illustrated in the natural gas example shown in Pullout 2.

Our EU Renewable H_2 Plan reflects our view of key elements needed to deliver projects to achieve the EU's renewable hydrogen ambition, by facilitating the certainty, acceptance and productivity needed while maintaining capital discipline.

H_2 Initiative	1	2	3	4	5
Initiative goal	**H_2 leading practice guidelines**	**Consistency on H_2 messaging**	**H_2 skills development**	**Share H_2 info & build trust**	**Adopt the new paradigm**
What we mean	EU-wide leading practice guidelines for development, design, delivery and operations of large H_2 value chain assets	Agreement on terminology, value proposition and messaging on issues such as safety, costs and fugitives	A coordinated, value chain-wide approach to building the required workforce skills	Facilitate safe sharing of information and build trust in project paths and outcomes across stakeholders	Radically change delivery practices to facilitate the required scale and speed of infrastructure delivery to meet the H_2 ambition
Relevant shifts	Broadening value, Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, Creating partnerships	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant
Barrier addressed	Acceptance	Acceptance	Certainty	Acceptance	Productivity
Industry impact	Lower	Lower	Medium	Medium	Higher

H_2 Initiative	6	7	8	9	10
Initiative goal	**H_2 industry standardization**	**Commoditized H_2 market**	**Cross-sectoral siting coordination**	**Supply & demand underwriting**	**Govt led enabling infrastructure**
What we mean	Explore and drive the productivity gain of standardisation across the H_2 industry, including across engineering standards, and potentially mandated by policy	Create a commodity trading platform which allows for creation of derivatives, pricing and H_2 Exchange-Traded Funds	Link qualified value chain parties and shared infrastructure together at pre-vetted sites with expedited permitting via a coordinating entity	Government provides a competitive market mechanism to remove risk associated with supply chain expansion and H_2 off-take	Master plan, control and build the electrical grid, pipeline and digital shared and regulated infrastructure required ahead of curve
Relevant shifts	Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, The digital accelerant	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant	Standardization, Creating partnerships, The digital accelerant	Broadening value, Standardization, Creating partnerships, The digital accelerant
Barrier addressed	Productivity	Certainty	Certainty	Certainty	Productivity
Industry impact	Medium	Medium	Medium	Higher	Higher

Easier to implement → **Harder to implement**

Broadening value · Enabling options · Standardization · Creating partnerships · The digital accelerant

FIGURE 13 Our EU Renewable H_2 Plan to assist the industry meet the EU ambition. See Addendum 1 for more details and impacts of each initiative on our Base Hydrogen Project.

WILL THIS PLAN BE ENOUGH TO MEET THE EU 2030 HYDROGEN AMBITION?

What impact might the initiatives in our plan collectively have on the Base Hydrogen Project defined in Chapter 3? The results, which clearly show the requirement of underwritten markets and/or infrastructure, neither of which is the norm, are illustrated in Figure 14.

The plan facilitates a set of new circumstances, including:

- the greenfield enabling infrastructure has already advanced through master planning, freeing the project from this dependency
- trust has been developed with affected communities through adoption of best practice guidelines and the sharing of information and values
- collaboration among industry participants has driven standardization and an exchange of learnings between mega-projects
- the risks of deploying billions of dollars in an emerging market has been alleviated through transparent trading platforms and government underwriting
- the industry has partnered with critical supply chain entities and underwritten suppliers' future orders and inventories.

In Figure 14, the 8 to 10-year Base Hydrogen Project timeline has been reduced to 5 to 6 years, illustrating the potential for significant schedule compression compared to the base case depicted in Figure 9 due, essentially, to the dependencies between components relaxing.

In this paper, we have focused on supply-side infrastructure but acknowledge other dependencies including development of immense quantities of raw materials, manufacture of new technology at scale, a seismic shift in workforce skills and commercialization of hydrogen end-use infrastructure.

Progress on many of these issues is being directionally supported by EU legislation, and yet, as we conclude in Chapter 3, policy conditionality itself could limit the rate at which a low-emissions hydrogen economy might grow.

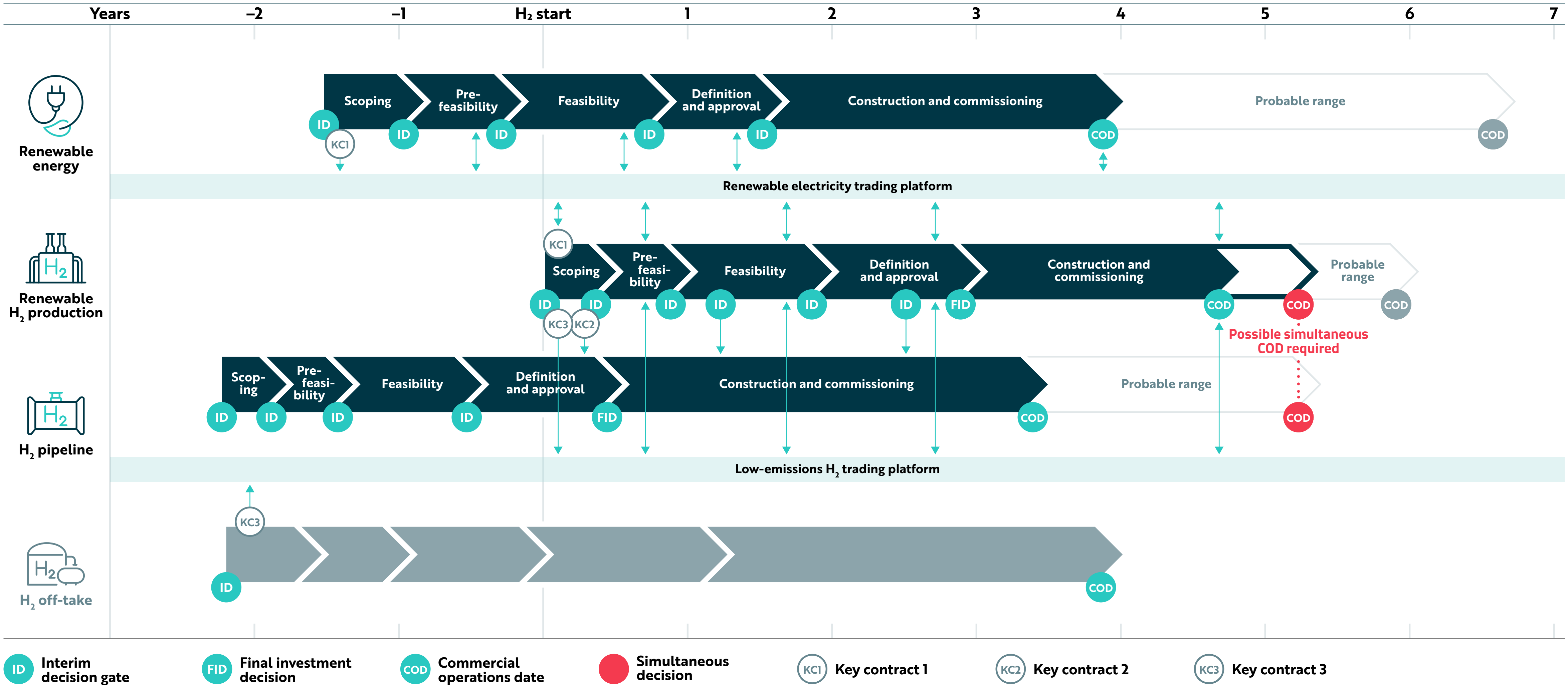


FIGURE 14 Stylized schedule of our Base Hydrogen Project following application of the EU Renewable H_2 Plan. Here the largest physical risk is the H_2 pipeline not being available, while the underwritten trading platforms provide increased options for electricity and off-take. Notional investment decisions based on typical relationship contracts are shown, including preliminary, indicative and firm contract offers.

DRIVING THE HYDROGEN INDUSTRY TO WHERE IT NEEDS TO BE

Irrespective of policy direction, time is critical. It will take time to develop a new hydrogen ecosystem, to drive all the components of the value chain to the maturity needed and for capital discipline to assure value and deliver the infrastructure needed, efficiently, effectively, and safely. Finally, it takes time to implement the shifts and influence the project delivery path.

All this takes time that we don't have.

The FATR shifts can accelerate project delivery while maintaining the risk management value of capital discipline, but these shifts need to be widely and effectively adopted by 2030 to catalyze the rapid expansion needed through the 2030s and 2040s.

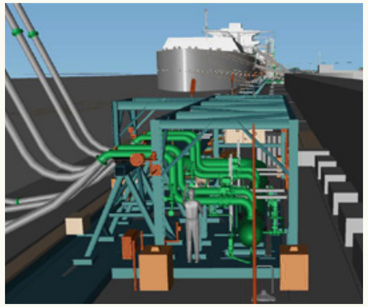
We called for adoption of the FATR shifts by 2030 in our second FATR paper and our view of the importance of meeting that date has not changed. While a radical paradigm change may make industry participants uncomfortable, it is essential to achieve the scale and speed of deployment needed.

> "The FATR shifts can accelerate project delivery while maintaining the risk management value of capital discipline, but these shifts need to be widely and effectively adopted by 2030 to catalyze the rapid expansion needed through the 2030s and 2040s."

PULLOUT 2

Lessons from natural gas

The gas shocks of the Russia/Ukraine conflict have driven some extraordinarily fast project responses to build alternative energy supplies, and just one example is a recent Floating Storage and Regasification Unit (FSRU) installed in northern Germany. This project successfully designed, procured, and constructed the new facility to deliver gas into the grid system within 8.5 months. Typically, such a project would take around 2.5 to 3 years, or around 5 years for an onshore equivalent.



Engineering of new skids by Worley

Technically, the project scope included significant modifications to the existing port infrastructure, the connection to services and the domestic natural gas grid via a new pipeline, and modifications to the FSRU vessel.

To support these energy projects, special LNG legislation was fast-tracked, with the German Government simplifying (but not relaxing) the permitting processes. Risk was handled differently, including allowing sole sourcing of suppliers, the purchasing ahead of engineering designs and the running of traditional FEL stages in parallel through special flexible and collaborative contracts.

The project team stated that the most important aspect of this success was an aligned common objective, requiring cooperation between industry, local authorities, and government, with the latter providing a degree of underwriting to allow capital discipline of exposed parties to be maintained.

This is an extreme schedule-driven example in response to a real energy security crisis and considering that the project was completed without interrupting operations at the existing oil and LPG terminal, is an extraordinary achievement. Implicit throughout this are the FATR key shifts, particularly in new levels of cooperation and partnership, broadening value, and doing things in parallel.

We contend that the same is possible in climate response – and at much larger scale – to which we suggest the same level of crisis is rapidly approaching.

CHAPTER

5 Building momentum with the FATR Framework

THE CASE FOR ADOPTION

Only seven years remain until 2030. Greenhouse gas emissions must be reduced by nearly half (compared to 2010 levels) if we are to avoid global average temperature rising by more than 1.5ºC.

Our examination of the EU 2030 renewable hydrogen target in previous chapters demonstrates that even in a highly committed region like Europe, where contemporary policy is strongly aligned with the decarbonization agenda, and an energy security crisis is driving extraordinary project responses, the path to net zero remains a hard road.

The FATR shifts can accelerate project delivery, maintain capital discipline, and move industries forward to meet the decarbonization challenge. But a level of pragmatism is needed to allow time for this new paradigm to mature and be broadly adopted, given practical realities on the ground.

Transitioning to net zero is deeply complex and involves a broader ecosystem than we have examined in this paper. Policy ambition is important, but it need not, and should not, compromise the disciplined allocation of private sector capital. Undisciplined spending risks outcomes where projects underperform and momentum stalls – or worse, project failures cause a loss of confidence among investors, communities, and businesses, and the result is a disorderly and ultimately failed climate response.

Pragmatism need not imply a slow and inflexible approach. It means taking on the challenge, cognizant of the constraints, risks, and difficulties that apply and dealing with these issues in a practical and logical manner. It may mean upending conventional wisdom and practicing and adopting new approaches that appear radical. It will almost certainly require individuals and organizations to step outside their comfort zones, be flexible, and embrace adaptive management.

Ultimately, meeting the challenge is about turning ambition (**what** needs to happen) to reality (**how** to make it happen). We believe the FATR shifts offer a key to success if they are applied widely among net zero infrastructure participants by 2030. The immediate and pressing task for industry is to make the shifts a practical, commercially acceptable, and effective reality.

"Only seven years remain until 2030. Greenhouse gas emissions must be reduced by nearly half (compared to 2010 levels) if we are to avoid global average temperature rising by more than 1.5ºC."

BRIDGING THE GAP

In our 2022 FATR paper, we concluded, based on an industry desktop 'pulse check', that there was a large gap between the behavior of infrastructure participants and the actions required to implement the FATR shifts by the 2030 goal. That paper also introduced 15 **indicators of change** – three for each shift – that serve as key measures for comparing and testing whether delivery practices are changing. We provided a view on how these indicators would need to change in time to lower the gap by 2030, summarized in the **FATR Framework** (see Addendum 2), and committed to updating them regularly.

Helping to inform those updates is the Princeton Net Zero Stakeholder Survey, conducted for the first time in 2023 and initially targeting 10 broad stakeholder groups. This anonymized global survey, run independently by Princeton, is intended to be undertaken each year to 2030 to provide a quantitative baseline and directional data on current and future delivery practices around net zero infrastructure.

The 2023 survey garnered global stakeholder group coverage, including hundreds of senior sector leaders and project managers/directors with subject matter expertise, along with a variety of other stakeholders.

Princeton plans to publish results and analysis from the 2023 inaugural survey separately, but early results offer a view of participants' current positions.

The results show some indication that the FATR shifts are being adopted. Enabling options appears to be receiving greater and more uniform attention amongst infrastructure participants. Broadening value may be more challenging, with respondents most uncertain about progress, indicating it to be both the most and least likely to shift over the next 12 months.

Our conclusions on the size of the gap from the 2023 Survey results are summarized in Figure 15. While the figure appears to show movement over the last year, these results must be interpreted cautiously given the qualitative nature of the 2022 process. As such, the 2023 results will be the baseline and will be officially confirmed when the survey results are finalized.

With a long way still to go to lower the gap to 2030, the task becomes about building momentum from this baseline.

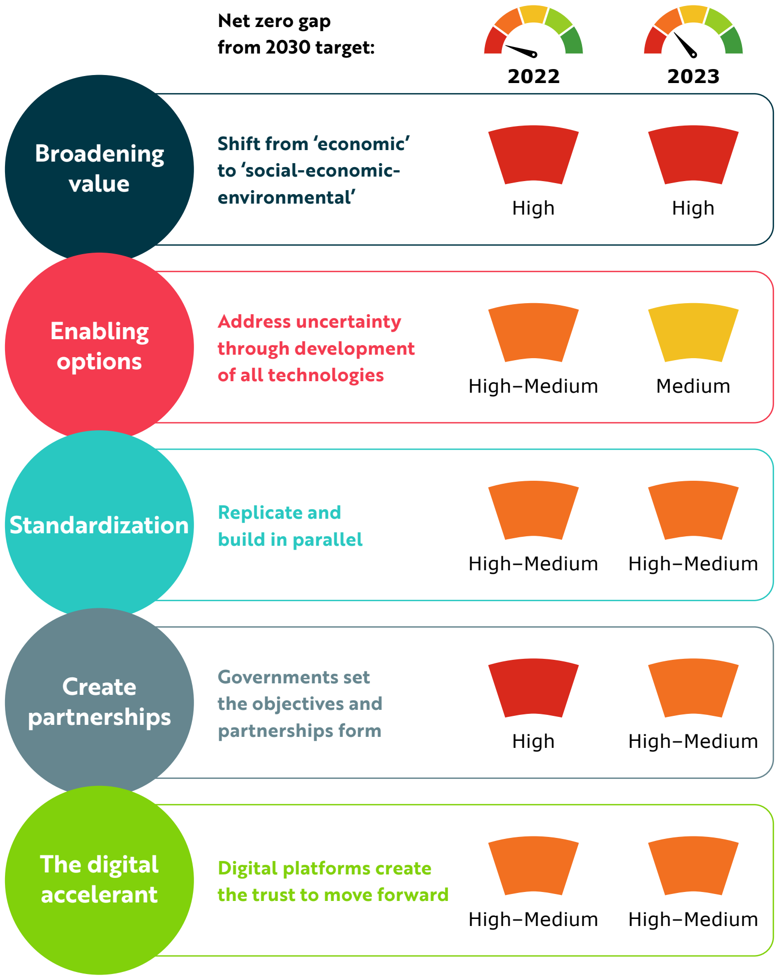


FIGURE 15 Our new 2023 quantitative baseline based on early results from Princeton's 2023 Net Zero Stakeholder Survey, shown against the qualitative view of 2022. Color indicates gap from the 2030 target, while the indicators at top provide an overall summary across all shifts.

FROM REGIONAL INITIATIVES TO GLOBAL STEPS

If you compare the 10 MTPA EU domestic hydrogen ambition by 2030 with the IEA Net Zero Emissions scenario global estimate of 450 MTPA by 2050, the scale of the broader, global clean hydrogen task is plain.

In the same IEA scenario, the clean hydrogen value chain (in all its forms) represents only around 10% of world energy production in 2050. The technological demands and geographic reach of the infrastructure needed to decarbonize **all** the world's energy supply side are vast and complex.

We recognize that to drive momentum for change called for in the FATR Framework, more granular detail is required. To provide this, we considered the steps that can be taken now at a global level to accelerate net zero delivery.

Most of the barriers across the three critical areas of certainty, acceptance, and productivity described in Chapter 4 are, broadly speaking, common to other technologies and many geographies. The 10 initiatives included in our EU Renewable H_2 Plan of Chapter 4 (Figure 13) have the potential, with small changes, to accelerate the capital discipline process across a much broader set of net zero infrastructure investments.

From those 10 initiatives, we considered the five most broadly applicable across all technologies and likely achievable in the immediate future to develop our **2024 FATR Plan**, the details of which are provided in Figure 16, with initiatives ranked by expected level of implementation difficulty.

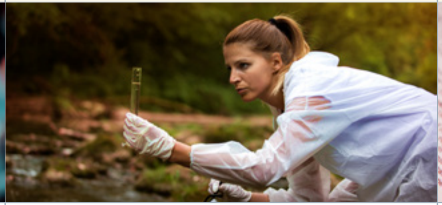
With a focus on pragmatic steps, this plan outlines initiatives that can help overcome some of the barriers and build momentum around all net zero infrastructure delivery over the next 12 months.

The 2024 FATR Plan steps are:

- **FATR Initiative 1** – Facilitate transparency and information sharing
- **FATR Initiative 2** – Build leading practice guidelines
- **FATR Initiative 3** – Establish consistent terminology and narratives
- **FATR Initiative 4** – Expedite the workforce needed
- **FATR Initiative 5** – Convene coalitions for standardization.

These are steps that infrastructure participants can consider taking right now; in Chapter 6, we suggest who should play a role in each.

Later FATR papers will introduce more initiatives, but the ambition in these five, and the extensive practitioner collaboration they require, should not be underestimated. Paradigm change does not come easy.

FATR Initiative	**1**	**2**	**3**	**4**	**5**
Initiative goal	**Facilitate transparency and information sharing**	**Build leading practice guidelines**	**Establish consistent terminology and narratives**	**Expedite the workforce needed**	**Convene coalitions for standardization**
					
What this means	Create safe places and tools to collect and share project knowledge and experience without repercussions or unacceptable risk, helping to overcome reluctance to share. Start by creating a space to share agreed information scope, and leverage this goodwill into a platform for information sharing to create a sustained and increased sharing culture with sectoral-wide benefits.	Build guidelines on what an acceptable net zero infrastructure development involves, across technology suites, setting the benchmark to aspire to. This must include emerging practices on how communities and interest groups, such as Indigenous Peoples, are consulted, concepts of value sharing and how to factor non-financial metrics into the capital decision process.	Work across practitioners to develop standard nomenclature and terminology. Some technologies are misunderstood, including Carbon Capture and Storage, the role of low-emissions feedstocks and areas such as Power-to-X. More work is needed to help stakeholders understand the scale of infrastructure needed, and that ultimately trade-offs in terms of where that is located.	Identify the skills sets for delivery under the new paradigm. Work with educational institutions to prepare for the workforce of the future, not as individual companies, but as industries. Share resources between companies, building up the portfolio of informed and skilled practitioners that are needed.	Convene stakeholder forums to encourage and accelerate standardization in the deployment of net zero assets. Include representation from suppliers, investors, and financiers. These groups are not to determine what a standard solution will look like, rather to encourage a philosophy towards standardisation.
Specific 12-month goals	• Identify and attract membership • Convene events specifically for safely engaging and sharing information • Develop a digital platform with clear rules for sharing and use	• Establish regional working groups • Working groups to produce relevant reports specific to regions • Socialize and drive towards standard practice	• Identify respected stakeholder group to champion narratives • Draft an energy transition dictionary of terms as a first step • Champion with players	• Estimate the future workforce needed • Consider disruptive frontiers of AI and digital automation • Outline an engagement plan across the relevant identified landscape	• Attract and convene standardization forums • Identify a set of energy transition sector-wide standardization opportunities relevant to all decarbonization pillars
Relevant shifts	Broadening value, Enabling options, Creating partnerships, The digital accelerant	Enabling options, Standardization, Creating partnerships	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, Creating partnerships, The digital accelerant	Enabling options, Standardization, Creating partnerships, The digital accelerant
Barrier addressed	**Acceptance and Productivity**	**Acceptance**	**Acceptance**	**Certainty**	**Productivity**

Easier to implement ⟷ **Harder to implement**

● Broadening value ● Enabling options ● Standardization ● Creating partnerships ● The digital accelerant

FIGURE 16 Our 2024 FATR Plan, the global next steps needed to build momentum towards 2030.

AN UPDATED FATR FRAMEWORK FOR IMMEDIATE ACTION

The 2024 FATR Plan updates the FATR Framework as shown in Figure 17. The updated framework provides overarching direction to 2030 and recommends immediate next steps. Our intention through the FATR series is to continue to update this framework, using direct experience with net zero infrastructure and informed by the collective experiences of our organizations and collaborators, together with insights from the Princeton Net Zero Stakeholder Survey.

In future FATR papers we intend to report on progress on these steps and consider dependencies outside the supply-side infrastructure that has been our focus until now. There are broader issues at play that need attention, and this attention is something we intend to provide.

		2022	2023	2026	2030
Broadening value	Environmental and social representation ESG selection criteria Value shared across broader stakeholders	High	High	• Contributing to broader ESG goals • Scorecards with ESG goals • Value added to communities, not subtracted	• Accountable for project success • ESG equality weighted with financial objectives • Community equity
Enabling options	Technology investment Breadth of technology options Intellectual property	High–Medium	Medium	• Capital moving to early-stage technology development and first movers • Increased number of diverse technologies in early development • Shared amongst collaborative partners	• First-of-a-kind technologies deployed at record rates required for net zero transitions • Order of magnitude greater technologies at all technology commercial readiness levels • Shared publicly and between countries
Standardization	Standard and modular designs Supply chain orders Project timelines	High–Medium	High–Medium	• Modularization becoming more widely used • Investments made to ready supply chains • Projects meeting schedules and some setting new benchmarks	• Standards and standardized designs are widespread even in complex industries • Governments underwriting supply chains for pre-manufacture, lead times <6 months for complex equipment • Continuous improvements on schedule benchmarks
Create partnerships	Transparency Participation and collaboration Risk sharing	High	High–Medium	• Development of online performance data access platforms • New partnership models forming • New risk/reward models emerging	• Public access to the performance data • Shared ownership and open collaboration • Risk/reward evenly and appropriately distributed
The digital accelerant	Digital modeling Digital systems Digital personnel	High–Medium	High–Medium	• Digital project progression cradle-to-grave has been achieved • Standard digital systems emerging • Digital strategies being implemented on projects	• Assets delivered and data openly available across trusted digital platforms • Assets connected through common systems • Digital considered a core integrated discipline

Steps for 2024

FATR Initiative 1
Facilitate transparency and information sharing

FATR Initiative 2
Build leading practice guidelines

FATR Initiative 3
Establish consistent terminology and narratives

FATR Initiative 4
Expedite the workforce needed

FATR Initiative 5
Convene coalitions for standardization

FIGURE 17 The updated FATR Framework indicating the recommended initiative steps for 2024. Indicators show gap from the 2030 target using the color definition in Figures 2 and 3.

CHAPTER

6 Time to step up

INFRASTRUCTURE PARTICIPANTS MUST DRIVE THE CHANGE

Net zero by mid-century will not be achieved through market forces and cutthroat competition alone. Those behaviors might continue, but it was deep collaboration and risk and reward sharing among many that dramatically accelerated space travel and the development of COVID-19 vaccines.

In Chapter 4, our EU Renewable H_2 Plan outlines initiatives to help overcome barriers to realizing the potential of renewable hydrogen as a tool for decarbonization in Europe within the capital discipline frameworks demanded by private finance. A similar plan can and should be developed for every clean energy value chain and so, in Chapter 5, we applied the same process to the broader net zero infrastructure ecosystem. The resulting 2024 FATR Plan provides a more general, global path to include within the updated FATR Framework.

These plans, and the initiatives within each, require the involvement and collaboration of all industry participants to succeed. Figures 18 and 19 show our view on who should lead, support and be consulted through the lens of the infrastructure participants identified in Chapter 1 (Figure 3).

Figure 18 shows our view of roles in relation to our EU Renewable H_2 Plan, including an indication of the target year of implementation for each initiative out to 2030.

EU Renewable H_2 Plan

	1 H_2 leading practice guidelines	2 Consistency on H_2 messaging	3 H_2 skills development	4 Share H_2 info & build trust	5 Adopt the new paradigm	6 H_2 industry standardization	7 Commoditized H_2 market	8 Cross-sectoral siting coordination	9 Supply & demand underwriting	10 Govt led enabling infrastructure
Asset owners and project developers	Lead(s)	Lead(s)	Key support	Lead(s)	Key support	Lead(s)	Consulted	Consulted	Consulted	Key support
Banks and investors	Key support	Key support	Consulted	Consulted	Consulted	Key support	Key support	Consulted	Consulted	Consulted
EPC services and contractors	Key support	Lead(s)	Lead(s)	Lead(s)	Lead(s)	Lead(s)	Consulted	Consulted	Consulted	Consulted
Supply chain providers	Consulted	Consulted	Key support	Consulted	Lead(s)	Consulted	Consulted	Consulted	Consulted	Consulted
Equipment manufacturers	Consulted	Key support	Key support	Consulted	Lead(s)	Key support	Consulted	Consulted	Consulted	Consulted
Policymakers and regulators	Lead(s)	Consulted	Lead(s)	Lead(s)	Lead(s)	Key support	Lead(s)	Lead(s)	Lead(s)	Lead(s)
Communities, social and environmental NGOs	Consulted	Consulted	Consulted	Key support	Consulted	Consulted	Consulted	Key support	Consulted	Consulted
Educators, universities and researchers	Consulted	Consulted	Lead(s)	Key support	Key support	Consulted	Consulted	Consulted	Consulted	Consulted
Labor organizations	Consulted	Consulted	Key support	Consulted	Key support	Consulted	Consulted	Consulted	Consulted	Consulted
Target implementation year	2024	2024	2028	2024	2030	2030	2027	2027	2027	2029

Infrastructure participant role: Lead(s) · Key support · Consulted

FIGURE 18 Our mapping of infrastructure participants against initiatives for the EU Renewable H_2 Plan, in terms of who is best to lead, support, and needs to be consulted, and target implementation year.

Figure 19 shows the same for our 2024 FATR Plan noting that our framework calls for all of these to be completed in 2024. This is ambitious, but necessary.

In subsequent FATR papers these plans will continue to evolve, along with updates to the FATR Framework to help continue to guide the path to 2030.

These figures also raise the necessity of involvement by a variety of stakeholders and across a range of fronts. And this is where we issue a challenge.

	2024 FATR Plan				
	1 Facilitate transparency and information sharing	2 Build leading practice guidelines	3 Establish consistent terminology and narratives	4 Expedite the workforce needed	5 Convene coalitions for standardization
Asset owners and project developers	Lead(s)	Lead(s)	Lead(s)	Key support	Lead(s)
Banks and investors	Key support	Consulted	Key support	Consulted	Consulted
EPC services and contractors	Key support	Lead(s)	Lead(s)	Lead(s)	Lead(s)
Supply chain providers	Consulted	Consulted	Consulted	Key support	Consulted
Equipment manufacturers	Consulted	Consulted	Key support	Key support	Lead(s)
Policymakers and regulators	Lead(s)	Key support	Consulted	Lead(s)	Key support
Communities, social and environmental NGOs	Consulted	Key support	Consulted	Consulted	Consulted
Educators, universities and researchers	Key support	Consulted	Key support	Lead(s)	Key support
Labor organizations	Consulted	Key support	Consulted	Key support	Consulted
Target implementation year	All FATR initiatives in 2024				

Infrastructure participant role: Lead(s) | Key support | Consulted

FIGURE 19 Our mapping of infrastructure participants against initiatives for the 2024 FATR Plan, in terms of who is best to lead, support, needs to be consulted, and target implementation year.

BIGGER AND BOLDER

Many of these initiatives, particularly those with longer durations, require bigger and bolder action and while all participants have a role, governments are central to their implementation.

We call on policymakers and regulators to consider the elements of public policy that can speed up the deployment of capital to build net zero infrastructure at the scale and speed required. Specifically, we call on governments to:

- initiate the master planning and development of enabling infrastructure ahead of ambition timelines to avoid lags in investment decision sequencing
- incentivize the sharing of infrastructure between project proponents, potentially as a condition of eligibility for government incentives
- form constructs that can reward innovation and provide certainty on the revenue and supply sides
- facilitate the required social dialogue for agreeing on the siting and identification of infrastructure precincts and easements at a scale commensurate with the net zero challenge.

We also call on governments to consider how policy conditionality can negatively impact net zero outcomes – the "path dependency" discussed in Chapter 2.

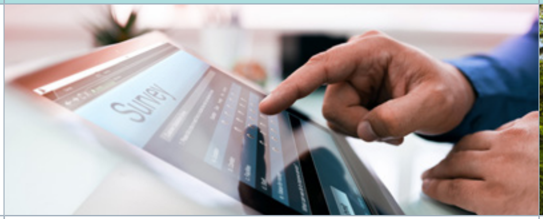
COMMITTING TO CHANGE

Worley and Princeton commit to championing changes that will build the enduring practices and confidence needed to drive infrastructure investment at the scale and speed net zero demands.

Based on the FATR 2024 Plan, collectively we're committing to eight initiatives that begin to build momentum of fundamental change for the industry. They are:

- continuation of the Princeton Net Zero Stakeholder Survey
- the From Ambition to Reality Summit
- expansion of Industry Leadership Forums
- commitment to Mission Innovation
- workforce skills analysis
- EU Renewable H_2 Standardization Working Group
- a guide to sharing project value and building trust
- Net-Zero X Initiative.

Details are outlined in Figure 20. We encourage other infrastructure participants to be part of these steps and/or to consider their own commitments to change.

Initiative step	Princeton Net Zero Stakeholder Survey	From Ambition to Reality Summit	Industry Leadership Forums	Commitment to Mission Innovation
				
What	Infrastructure participants survey across three regions examining current and projected net zero infrastructure delivery practices.	A summit to debate, challenge and consider net zero delivery practices. Focused on tangible, practical asset outcomes, delivering step changes in delivery.	A Chatham House Rule, industry-led conference, held independently in Europe, Australia and the US, focused on sharing industry learnings across diverse topics including sustainability and energy transition.	Coordination role for the Net-Zero Industries Mission (NZIM) on behalf of 23 countries and the EU, to accelerate global decarbonization of the high intensity and hard-to-abate industry sectors.
Key aims	To measure and understand practices and their changes. Enable researchers to consider initiatives to align practices with net zero challenges. Provide input for FATR Framework updates.	To build momentum across influential infrastructure players; to ensure research is industry aligned, and has a demonstrable net zero impact.	To improve industry collaboration across key sector issues.	NZIM aims to accelerate global uptake of decarbonization technology, through building industry confidence in solution viability via knowledge sharing of operational scale demonstrations and supporting research.
Timing	Annually, starting in 2023 with baseline results and temporal trends from 2024.	First summit in September 2023 at Princeton. Targeted to run every year to 2030.	In-person events to be held in the three locations for the first time in 2024.	Resource provided to 2025. MI is intended to operate through to 2030.
Relevant 2024 FATR Plan Initiative	1 2 3 4 5	1 3 5	1	1 3
Relevant Renewable H_2 Plan Initiative	5	–	4	2 4
Relevant shifts	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant	Creating partnerships	Broadening value, Enabling options, Creating partnerships
Commitment lead	**Worley and Andlinger Center for Energy and the Environment**	**Worley and Andlinger Center for Energy and the Environment**	**Worley**	**Worley**

● Broadening value ● Enabling options ● Standardization ● Creating partnerships ● The digital accelerant

Figure 20 continues on the next page.

FIGURE 20 Our eight initiative steps for completion in 2024 in line with the FATR Framework.

Initiative step	Workforce skills analysis	EU Renewable H_2 Standardization Working Group	Guide to sharing project value and building trust	Net-Zero X Initiative
				
What	Undertake and release results of a study into skills needed to meet projected net zero scenarios.	Formation of the EU's first Renewable H_2 Standardization Working Group, and identification of initial opportunities and targets.	Publication of a new guide on sharing project value and building trust with communities. To be socialized with relevant stakeholders, to build broader momentum.	A deep understanding of what it would take to achieve net zero emissions globally.
Key aims	To consolidate current knowledge, and provide a firmer foundation to progress skill development thinking. To socialize findings with relevant stakeholders.	To encourage and accelerate the move towards a standard approach to hydrogen production assets and start leveraging the benefits of standardization.	To share learnings from the field, assist developers to build a social contract, and start establishing broader best practice guidelines.	To expand Princeton's influential, high-resolution Net Zero country studies to the world's largest future emitters via collaborations with locally led research teams.
Timing	Targeting publication of the report by end of 2024.	Identification of initial working group by March 2024. Publication and socialization of targets by end 2024.	Publication by August 2024, socialization with stakeholders in September 2024.	Make modeling frameworks fully accessible and open-source by June 2024. Complete India and China Net-Zero studies by December 2026. Progress scoping for Indonesia, Mexico, Brazil, Pakistan and Nigeria by December 2025.
Relevant 2024 FATR Plan Initiative	4	5	2 3	1 4
Relevant Renewable H_2 Plan Initiative	3	6	1 2	2 3 4 5 10
Relevant shifts	Broadening value, Enabling options, Creating partnerships	Enabling options, Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, Creating partnerships	Enabling options, Creating partnerships
Commitment lead	**Worley and Andlinger Center for Energy and the Environment**	**Worley**	**Worley**	**Andlinger Center for Energy and the Environment**

● Broadening value ● Enabling options ● Standardization ● Creating partnerships ● The digital accelerant

FIGURE 20 Our eight initiative steps for completion in 2024 in line with the FATR Framework (continued).

ACCELERATING INFRASTRUCTURE DELIVERY TO 2030

The global carbon budget is reducing rapidly. And the speed and scale of the net zero infrastructure delivery challenge requires a bold, whole-of-industry approach.

We call on our fellow infrastructure participants – our peers, our customers, our suppliers, along with governments, institutions, financiers, technology providers, influencers, and others – to put aside conventional practices and commit to radical, necessary change.

Mid-century net zero is achievable. We can establish industries and broad communities of practice before 2030 and accelerate the radical change needed to apply the trillions of dollars of investment wisely to deliver the infrastructure we need.

This is about radical but responsible change. We are talking about doing things differently, but within the frameworks of capital discipline.

It was the Princeton Scientist Albert Einstein who said:

"*We cannot solve our problems with the same thinking we used when we created them.*"

Only through radical approaches will we have a chance to meet this once-in-a-generation challenge and convert net zero ambition to reality.

What steps are you prepared to take?

Addenda 1 & 2, references, acronyms

ADDENDUM 1 DETAIL ON OUR RATINGS CONSIDERATIONS IN FIGURE 13 AND HOW EACH IMPACTS OUR BASE HYDROGEN PROJECT

Initiative goal	**H_2 leading practice guidelines**	**Consistency on H_2 messaging**	**H_2 skills development**	**Share H_2 info & build trust**
Relevant shifts	Broadening value, Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant	Broadening value, Enabling options, Creating partnerships	Broadening value, Enabling options, Standardization, Creating partnerships, The digital accelerant
Industry impact	**Lower** Guidelines set minimum expectations for projects and acceptable development practice standards increasing stakeholder acceptance and lowering risk. While not essential, they can accelerate schedules and increase the number of projects reaching FID significantly.	**Lower** Stakeholders can easily get confused when practitioners use different terminology and messaging. This can lower stakeholder trust, particularly around overall value proposition. Messaging consensus, while not essential, will lead to greater trust and more projects to FID.	**Medium** Skills will be vital across all elements of the H_2 industry. There is some potential to transfer from other industries, but new skill sets are also required. Ultimately a decelerating impact on project rollout will occur if the ability to source skilled labor continues.	**Medium** Practitioners not sharing real-world project learnings and practices may be perceived as protecting commercial interests, but overall prevents the industry from generating best practice. While not essential, can drive effective and faster overall industry development.
Ease of implementation	Many precedents exist in other industries. The difficulty will be reaching a consensus among development stakeholders, some whom may resist setting higher project standards.	Some precedents for such across other industries. Key difficulty likely around consensus and then alignment across broad players, who may already prefer their own messaging.	Moves already underway on training and skills development, although patchy and not at the scale needed yet. Training is a well-worn path, many precedents and existing constructs.	While several industries openly share information, this practice is not common in energy infrastructure. Players may share at some level, but avoid deep sharing needed.
Base Hydrogen Project impact	Schedule (green) NPV (yellow) Emissions (yellow) Guidelines will improve the quality of the mega-project in the eye of approval and social contract stakeholders, accelerating the schedule. While they may decrease NPV by driving higher standards, schedule decrease should overcome this. Little impact on emissions reduction results, although greater visibility on emissions performance expected.	Schedule (green) NPV (green) Emissions (yellow) Project stakeholder engagement will be more effective, potentially avoiding stakeholder delays, driving faster approvals, increasing effective engagement with the finance community and accelerating schedule. Overall, improving project NPV. Likely little impact in overall emissions reduction results.	Schedule (green) NPV (green) Emissions (green) Access to skills at the right time will positively impact every project metric. Schedule will improve as skill delays drop and project safety rates improve as access to the right skills for the right job improves. Projects will be designed, costed and rolled out faster, driving better outcomes.	Schedule (green) NPV (green) Emissions (green) Applying learnings from others allows increased safety, avoids schedule erosion and cost escalation, improving time to deploy and project commercials. Improvement practices can be shared leading to better operating assets, and better emissions benefits. Sharing intellectual property can accelerate these benefits significantly.

Easier to implement ← → **Harder to implement**

Relevant shifts key

- Broadening value (dark blue)
- Enabling options (red)
- Standardization (teal)
- Creating partnerships (grey)
- The digital accelerant (green)

Industry impact key

Lower / Medium / Higher

Industry impact is relative to initiative goal average.

Base Hydrogen Project impact key

- Red: Negatively influences the metric
- Yellow: Neutral to the metric
- Green: Positively influences the metric

Schedule means the time needed to get the project to COD.

NPV means the Net Present Value of the project, a measure of its commercial merit.

Emissions means the overall greenhouse gas (GHG) emissions reduction impact of building and operating the project.

Continues on the next page.

Initiative goal	Adopt the new paradigm	H_2 industry standardization	Commoditized H_2 market	Cross-sectoral siting coordination
Relevant shifts				
Industry impact	**Higher** Understanding the infrastructure scale and speed needed for net zero, the changes in delivery practice to achieve this, and then implementing those practices is an essential practitioner step. This would have a massive positive impact on driving the industry forward.	**Medium** Will assist supply chains to grow faster, decreasing cost through improved learning curves. Regulators/statutory bodies will be more comfortable, leading to faster approvals. Certifications will be easier and equipment cheaper. Industry speed and commercials will improve.	**Medium** The ability to monetize hydrogen across a regulated market would provide certainty into the revenue streams of projects, help drive innovation in associated financial products, and add return certainty to investors. It would also provide clear guidance on pricing for off-takers.	**Medium** Builds broad connections between parties through the process of prequalification which aligns processes, contracting forms and project siting. Much faster project progression, particularly in relation to social contract, land and enabling infrastructure connection.
Ease of implementation	Many practitioners are challenged by or may not even believe that change is necessary. Some may refuse to align, although early indications are that many are interested.	Standardization is common, but often resisted in large capital projects where bespoke delivery is normal. Significant equipment supplier resistance possible, protecting interests.	Strong financial markets already associated with energy and other commodities, so precedents. Legal construct could take time to develop and implement.	Requires very strong government action to drive site identification and the construct behind prequalification. May be resisted by certain communities, leading to political fallout.
Base Hydrogen Project impact	Schedule NPV Emissions A project driven within an industry ecosystem that has changed its delivery paradigm will be faster and likely significantly cheaper than one driven using traditional delivery practice. There are positives and negatives for emissions, which may cancel out.	Schedule NPV Emissions Standardizing will help guarantee timely technology supply, lower the cost of that supply, reduce schedule, improve performance and NPV. Engineering front-end loading will be lower, and the approvals process faster given other standardized exemplars. Slight emissions penalty risk, as equipment is not designed specifically for project site.	Schedule NPV Emissions Adds accessible revenue opportunities through new value creation processes and products, improving NPV. Certainty will help with faster decisions and schedule. Not expected to impact emissions reduction quantum significantly, although may favor projects that have higher emissions reduction per dollar of capital deployed.	Schedule NPV Emissions Schedule is improved by removing counterparty identification risk, although decision dependencies may still remain. Potentially lowers capital cost – this with schedule improves NPV. Better infrastructure alignment, and more chances for infrastructure sharing, which should drive better emissions outcomes across the full value chain.

Easier to implement … **Harder to implement**

Relevant shifts key

- Broadening value
- Enabling options
- Standardization
- Creating partnerships
- The digital accelerant

Industry impact key

Lower / Medium / Higher

Industry impact is relative to initiative goal average.

Base Hydrogen Project impact key

- Negatively influences the metric
- Neutral to the metric
- Positively influences the metric

Schedule means the time needed to get the project to COD.

NPV means the Net Present Value of the project, a measure of its commercial merit.

Emissions means the overall greenhouse gas (GHG) emissions reduction impact of building and operating the project.

Continues on the next page.

Initiative goal	Supply & demand underwriting	Government led enabling infrastructure
Relevant shifts	Standardization, Creating partnerships, The digital accelerant	Broadening value, Standardization, Creating partnerships, The digital accelerant
Industry impact	**Higher** Fundamentally alters the risk profile for investors, massively improving the ability to move capital faster. Very high benefit to speed and scale, particularly with the ability to drive other shift requirements such as standardization and broadening value.	**Higher** A fundamental aspect of building a Europe-wide hydrogen ecosystem and industry. Will drive the evolution of efficient supply-to-demand matching, the strategic placement of supply chains, the stimulation of projects and skills, and fair transition considerations.
Ease of implementation	Needs careful policy design to avoid unintended consequences, and to keep both competition and innovation alive for the benefit of stakeholders. Likely slow, legalistic process.	Creates a natural monopoly that needs careful design. Assets may be deeply socially unpopular, and requires significant government action, all with political fallout.
Base Hydrogen Project impact	Schedule: positive; NPV: positive; Emissions: positive Allows large gains in schedule as it decouples investment decisions from procurement and off-take risk, removing dependency lag. Lower investment risk improves cost of capital and NPV. If underwriting quantum is linked to emissions outcome, can drive a better emissions reduction response.	Schedule: positive; NPV: positive; Emissions: positive Having access to well-designed and positioned infrastructure ahead of project decision sequencing will fundamentally improve the project schedule. A regulated return basis for the infrastructure should improve the project NPV, limit government equity, and drive better emissions outcome across the value chain.

Easier to implement → **Harder to implement**

Relevant shifts key

- Broadening value
- Enabling options
- Standardization
- Creating partnerships
- The digital accelerant

Industry impact key

Lower / Medium / Higher

Industry impact is relative to initiative goal average.

Base Hydrogen Project impact key

- Negatively influences the metric
- Neutral to the metric
- Positively influences the metric

Schedule means the time needed to get the project to COD.

NPV means the Net Present Value of the project, a measure of its commercial merit.

Emissions means the overall greenhouse gas (GHG) emissions reduction impact of building and operating the project.

ADDENDUM 2 WHERE OUR FATR FRAMEWORK WAS IN 2022

The 2022 FATR Framework shows the path to implementation of the 5 shifts by 2030. The graphic shows the "indicators of change" for each shift, which are measures indicating implementation movement, and what we would expect to see for each moving forward to 2030.

Shift	Indicators of change	2022 gap	2022	2026	2030
Broadening value	**Environmental and social representation** **ESG selection criteria** **Value shared across broader stakeholders**	High	• Regulatory focus • Financial objectives only • Return on investment	• Contributing to broader ESG goals • Scorecards with ESG goals • Value added to communities, not subtracted	• Accountable for project success • ESG equality weighted with financial objectives • Community equity
Enabling options	**Technology investment** **Breadth of technology options** **Intellectual property**	High–Medium	• Financed by governments and large organizations • Limited to those known to work and low risk • Not shared and litigious	• Capital moving to early-stage technology development and first movers • Increased number of diverse technologies in early development • Shared amongst collaborative partners	• First-of-a-kind technologies deployed at record rates required for net zero transitions • Order of magnitude greater technologies at all technology commercial readiness levels • Shared publicly and between countries
Standardization	**Standard and modular designs** **Supply chain orders** **Project timelines**	High–Medium	• Bespoke designs for complex industries • Bespoke ordering, lead times of >12 months for complex equipment • Shared amongst collaborative partners	• Modularization becoming more widely used • Investments made to ready supply chains • Projects meeting schedules and some setting new benchmarks	• Standards and standardized designs are widespread even in complex industries • Governments underwriting supply chains for pre-manufacture, lead times <6 months for complex equipment • Continuous improvements on schedule benchmarks
Create partnerships	**Transparency** **Participation and collaboration** **Risk sharing**	High	• Need-to-know basis • Project players act independently • Pushed into contracts	• Development of online performance data access platforms • New partnership models forming • New risk/reward models emerging	• Public access to the performance data • Shared ownership and open collaboration • Risk/reward evenly and appropriately distributed
The digital accelerant	**Digital modeling** **Digital systems** **Digital personnel**	High–Medium	• Digital enablers emerging across value chain • Bespoke digital systems • Digital personnel separate to core project teams	• Digital project progression cradle-to-grave has been achieved • Standard digital systems emerging • Digital strategies being implemented on projects	• Assets delivered and data openly available across trusted digital platforms • Assets connected through common systems • Digital considered a core integrated discipline

Colors above indicate gap from 2030 target: High | High–Medium | Medium | Medium–Low | Low

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FATR3 UNITS, ACRONYMS AND NOMENCLATURE

ATSE	Australian Academy of Technological Sciences & Engineering
CCS	Carbon Capture and Storage
CEO	Chief Executive Officer
COD	Commercial Operation Date
CO_2	Carbon dioxide
COVID-19	Coronavirus Disease 2019
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EHB	European Hydrogen Bank
EPC	Engineering, Procurement, Construction
EU	European Union
FATR	From Ambition to Reality
FEED	Front-End Engineering and Design
FEL	Front-End Loading
FID	Final Investment Decision
FSRU	Floating Storage and Regasification Unit
GHG	Greenhouse Gas
GW	Gigawatt
GWh/yr	Gigawatt hours per year
GWP	Global Warming Potential
H_2	Hydrogen
H_2O	Water

ID	Interim Decision
IEA	International Energy Agency
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
KC	Key Contracts
$kgCO_2e/kgH_2$	Kilograms carbon dioxide equivalent per kilogram hydrogen
km	Kilometers
KTPA	Kilo Tons per annum
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MI	Mission Innovation
MTPA	Million Tons per annum
MW	Megawatt
NGO	Non-government Organization
NH_3	Ammonia
NPV	Net Present Value
PEM	Proton Exchange Membrane
PhD	Doctor of Philosophy
RED	Renewable Energy Directive
TWh/y	Terawatt hours per year
UK	United Kingdom
US	United States of America

Thank you for taking a step towards accelerating net zero delivery.

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