Enabling Measures Roadmap for Green Hydrogen

IRENA International Renewable Energy Agency

WORLD ECONOMIC FORUM

Supported by ***Accenture***

Europe

Japan

Version: *November 2021*

Contents

***Version**: November 2021. Please note that this is a live document and will be updated as the initiative progresses.*

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Overview of the Initiative

The World Economic Forum and IRENA are pleased to present the Enabling Measures Roadmaps for Green Hydrogen (Europe and Japan)

The Roadmaps were developed through the World Economic Forum's Accelerating Clean Hydrogen Initiative and IRENA's Collaborative Framework on Green Hydrogen

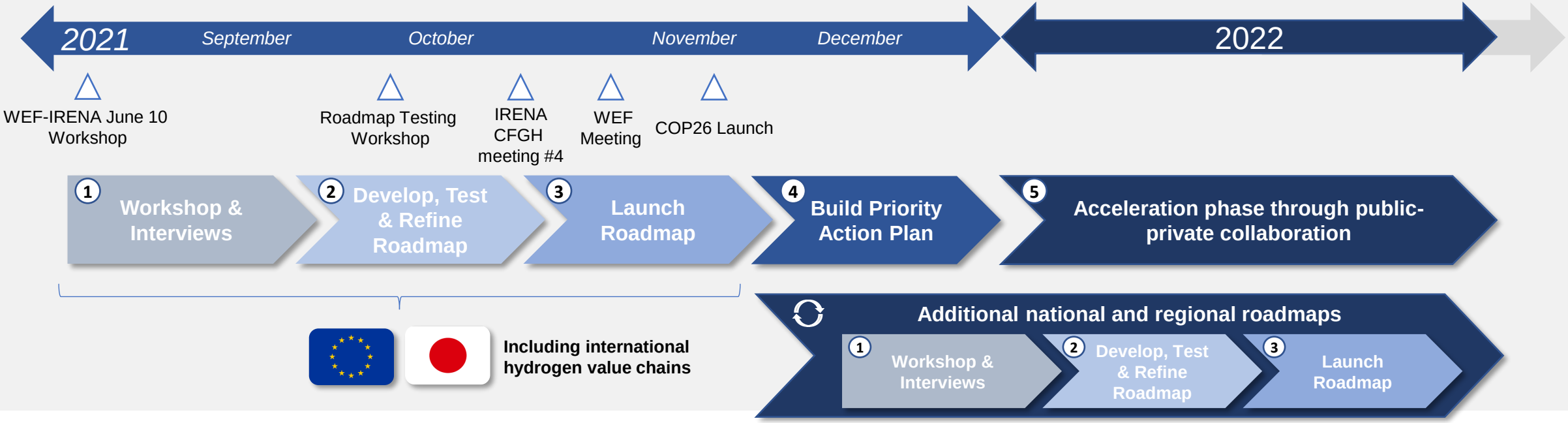
Activities under the joint initiative:

1. *Identify barriers to scale up markets and the corresponding critical enabling measures needed to support their removal (this document).*
2. *Identify priority enabling measures requiring accelerated action.*
3. *Convene dialogue and collaborative activity between policy makers, industry and other key stakeholders to accelerate priority enabling measures.*

Enabling Measures Roadmap: Plan Overview

Enabling Measures. For the purpose of the initiative, the term *enabling measures* should be defined as actions and activities that drive the accelerated growth of **a traded green hydrogen market**. It is envisaged that these *enabling measures* will support the development of the traded market primarily through policy, standards, regulation and also more intangible elements such as cooperation and public acceptance of green hydrogen.

Timeline



Enabling Measures Roadmap: Consultation Process

THE PURPOSE OF THE ROADMAP IS TO IDENTIFY THE KEY ACTIONS REQUIRED TO REACH A SCALED AND TRADED GREEN HYDROGEN MARKET

The Roadmap is a toolbox for policy makers, identifying the top ten enabling measures and critical timelines required to reach scale

The first Roadmaps focus on Europe and Japan *…with other countries and regions to follow*

Activity Timeline

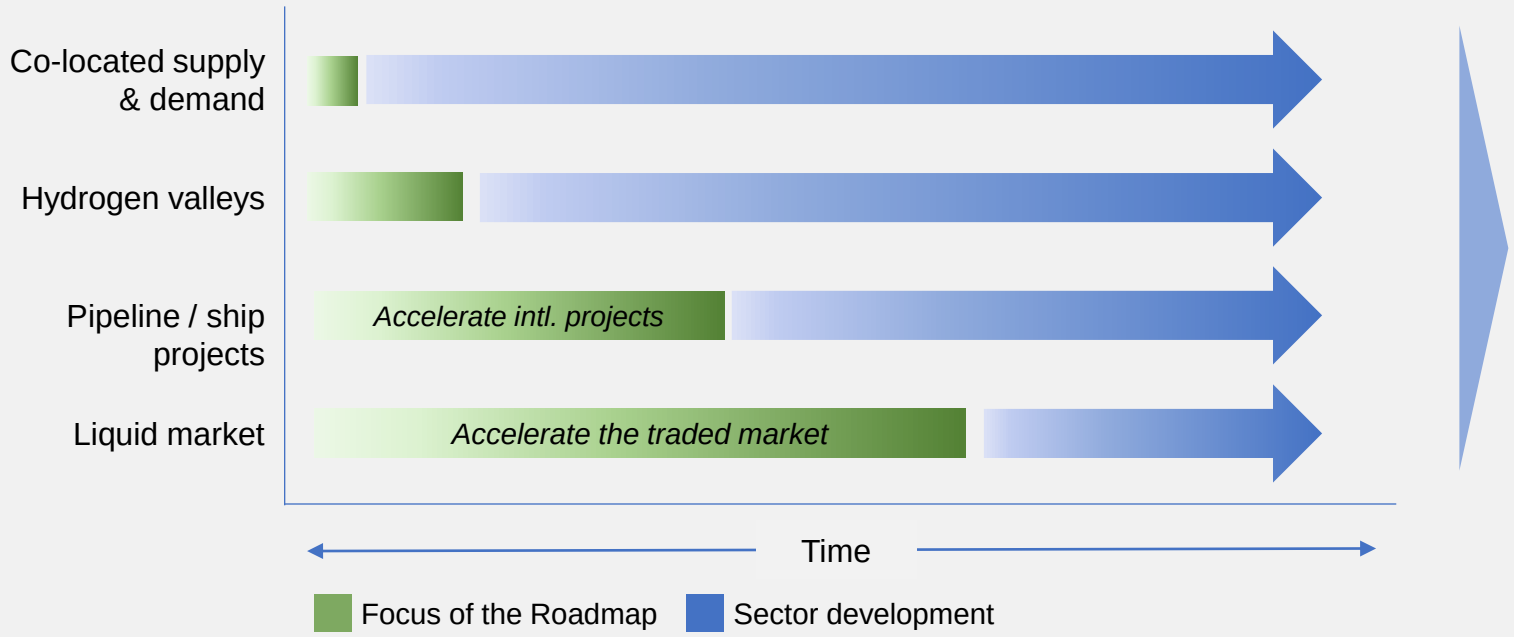
10th June 2021	July - September 2021	21st October 2021	Tuesday 26th October 2021	4th November 2021	Ongoing Programme
Joint IRENA-WEF Workshop *on Enabling Measures for Green Hydrogen*	**Consultations** with industry and international organisations on key enabling measures for green hydrogen	**IRENA 4th Collaborative Framework on Green Hydrogen Meeting** *to present first draft of the Roadmap and gather feedback*	**WEF Accelerating Clean Hydrogen Initiative Meeting** *to present first draft of the Roadmap and gather feedback*	*Enabling Measures Roadmap for Green Hydrogen* ***launch on Energy Day at COP26***	*Additional national and regional roadmaps & Acceleration programme (implementation)*

Enabling Measures Roadmap: Key Focus

Hypothesis:

The traded green hydrogen market will develop after lower risk business cases have been proven. In order to accelerate the green hydrogen market at a global scale, key enabling measures for **international / regionally traded markets** must be brought forward and accelerated in the short / mid term – within the next 5-10 years.

Timeline of Development



Enabling Measures Roadmap for Green Hydrogen

Top 10 objectives and supporting enabling measures

to accelerate the hydrogen market to get to scaled / traded markets

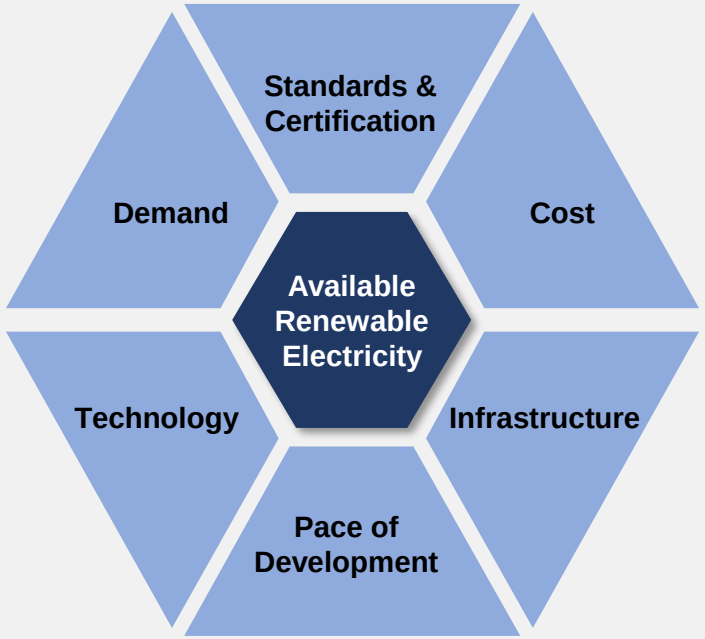
Contents

Building the Roadmap framework: Barriers to Scale

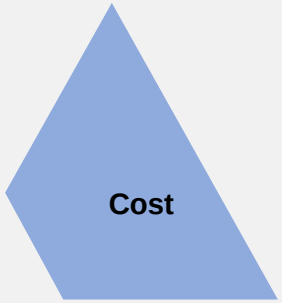
STEP 1 – Identify Barriers

STEP 2 – Breakdown Barriers to *Level 2*

CORE INTERRELATED BARRIERS



EXAMPLE LEVEL 1 BARRIER



LEVEL 2 BARRIERS

1. Lack of carbon cost internalisation
2. Lack of upstream support
3. Lack of downstream support
4. Unfit market design

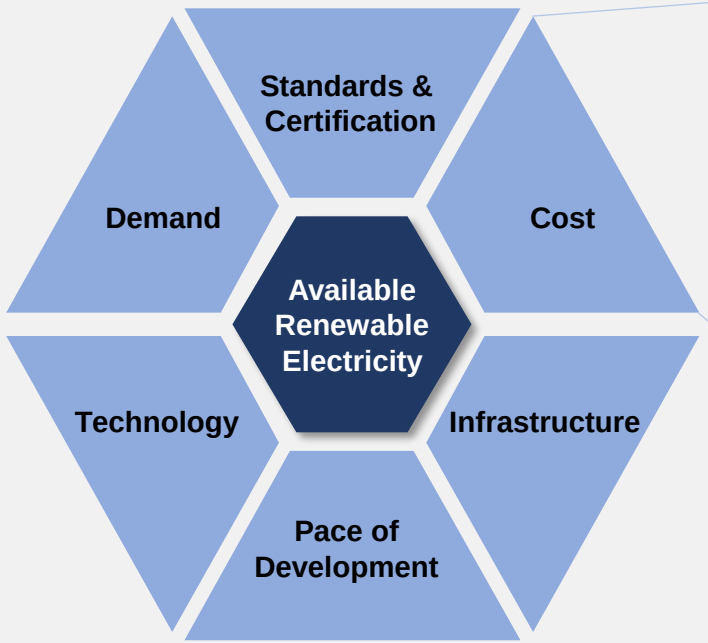
See appendix for Level 2 breakdown

Building the Roadmap framework: Enabling Measures

STEP 3 – Identify Objectives

STEP 4 – Identify Enabling Measures

BARRIERS



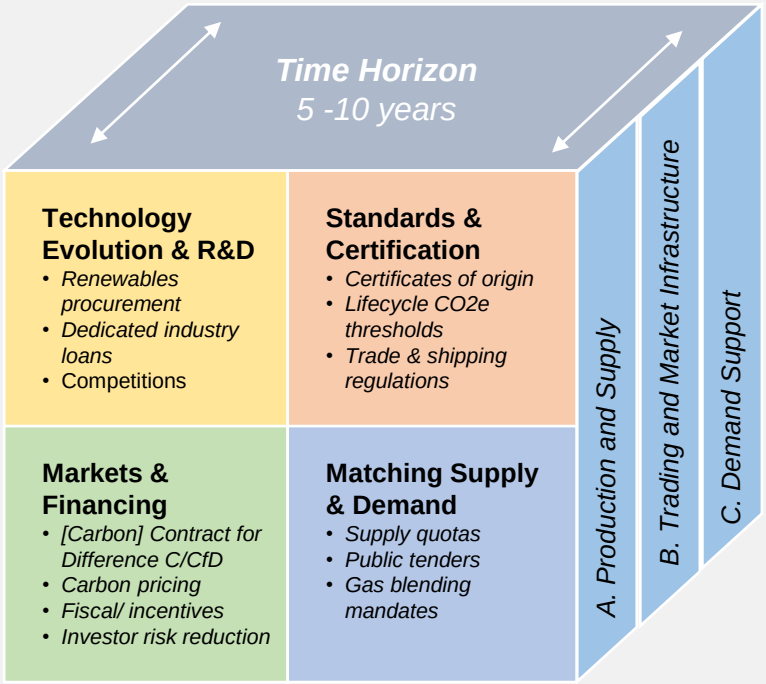
OBJECTIVES

1. Remove critical cost and regulatory barriers for production

Cost

2. Deploy mechanisms to accelerate hydrogen demand

ENABLING MEASURES



*The **Enabling Measures** focus on removing barriers through collaboration and policy*

Contents

KEY: Barrier Objectives

Key Objectives per Barrier

Standards & Certification

Ensure clarity on carbon intensity, safety and technical standards for projects across the value chain

Cost

Remove cost and regulatory barriers for production and deploy mechanisms to accelerate demand in hard-to-abate sectors

Demand

Drive critical mass demand through major hydrogen projects leveraging efficient allocation of capital, long-term certainty and sectoral targets

Available Renewable Electricity

Technology

Focus on innovation and R&D to enable improvement on cost, efficiency and durability of electrolysers

Infrastructure

Ensure early ramp up of *'no regret'* infrastructure, including transport, storage, conversion and trade facilities

Pace of Development

Accelerate scale-up of electrolyser manufacturing to drive economies of scale

Available Renewable Electricity

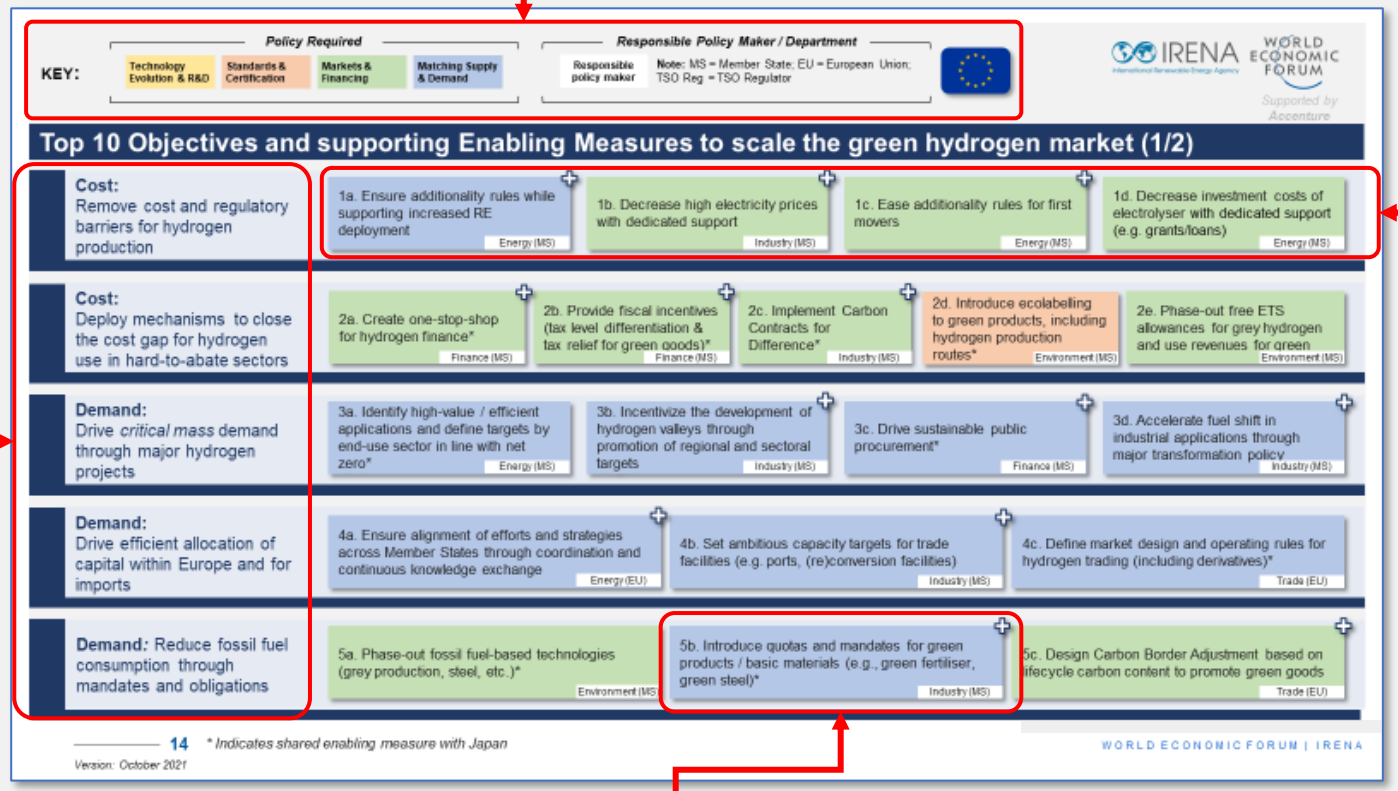
Significant ramp up and deployment of renewable generation through ambitious targets, incentives and energy system design

Available Renewable Electricity

Navigating the Roadmap

2 ***Key*** *of supporting information for the enabling measures*

1 **Top objectives** grouped by the relevant barrier to market development



3 **Key enabling measures** required to achieve the identified objective

4 ***'Click here'*** **link** to each Enabling Measure's Deepdive information

KEY:

Policy Required

- Technology Evolution & R&D
- Standards & Certification
- Markets & Financing
- Matching Supply & Demand

Responsible Policy Maker / Department

- Responsible policy maker

Note: MS = Member State; EU = European Union; TSO Reg = TSO Regulator

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Top 10 Objectives and supporting Enabling Measures to scale the green hydrogen market (1/2)

Cost: Remove cost and regulatory barriers for hydrogen production

- 1a. Ensure additionality rules while supporting increased RE deployment — Energy (MS)
- 1b. Decrease high electricity prices with dedicated support — Industry (MS)
- 1c. Ease additionality rules for first movers — Energy (MS)
- 1d. Decrease investment costs for electrolyser with dedicated support (e.g. grants/loans) — Energy (MS)

Cost: Deploy mechanisms to close the cost gap for hydrogen use in hard-to-abate sectors

- 2a. Create one-stop-shop for hydrogen finance* — Finance (MS)
- 2b. Provide fiscal incentives (tax level differentiation & tax relief for green goods)* — Finance (MS)
- 2c. Implement Carbon Contracts for Difference* — Industry (MS)
- 2d. Introduce ecolabelling to green products, including hydrogen production routes* — Environment (MS)
- 2e. Phase out free ETS allowances for grey hydrogen and use revenues for green — Environment (MS)

Demand: Drive *critical mass* demand through major hydrogen projects

- 3a. Identify high-value / efficient applications and define targets by end-use sector in line with net zero* — Energy (MS)
- 3b. Incentivize the development of hydrogen valleys through promotion of regional and sectoral targets — Industry (MS)
- 3c. Drive sustainable public procurement* — Finance (MS)
- 3d. Accelerate fuel shift in industrial applications through major transformation policy — Industry (MS)

Demand: Drive efficient allocation of capital within Europe and for imports

- 4a. Ensure alignment of efforts and strategies across Member States through coordination and continuous knowledge exchange — Energy (EU)
- 4b. Set ambitious capacity targets for trade facilities (e.g. ports, (re)conversion facilities) — Industry (MS)
- 4c. Define market design and operating rules for hydrogen trading (including derivatives)* — Trade (EU)

Demand: Reduce fossil fuel consumption through mandates and obligations

- 5a. Phase out fossil fuel-based technologies (grey production, steel, etc.)* — Environment (MS)
- 5b. Introduce quotas and mandates for hydrogen, green products, basic materials (e.g., green fertiliser, green steel)* — Industry (MS)
- 5c. Design Carbon Border Adjustment based on lifecycle carbon content to promote green goods — Trade (EU)

** Indicates shared enabling measure with Japan.*

Note – additional Deepdives to be included in later revision

KEY:

Policy Required: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Responsible Policy Maker / Department: Responsible policy maker

Note: MS = Member State; EU = European Union; TSO Reg = TSO Regulator

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Top 10 Objectives and supporting Enabling Measures to scale the green hydrogen market (2/2)

Infrastructure: Ensure early ramp up of '*no regret*' infrastructure

- 6a. Clarify governance of the hydrogen transmission network — TSO Reg (EU)
- 6b. Set up a flexible regulatory framework adjustable based on market developments — TSO Reg (EU)
- 6c. Integrate long-term planning of hydrogen, power and gas infrastructure — TSO Reg (EU)
- 6d. Specify interoperable quality standards and definitions — TSO Reg (EU)
- 6e. Introduce capacity payments to support ramp-up of infrastructure — TSO Reg (EU)

Standards & Certification: Ensure clarity on technical and safety standards for project development

- 7a. Define technical standards for new parts of the value chain beyond production (transportation, storage, conversion)* — Industry (EU)
- 7b. Define technical standards for hydrogen derivatives (e.g. ammonia, synthetic fuels)* — Industry (EU)
- 7c. Develop safety standards for new hydrogen carriers* — Industry (EU)

Standards & Certification: Ensure clarity on carbon intensity standards through a guarantee of origin scheme

- 8a. Set clear carbon intensity definitions, thresholds, boundaries for hydrogen production* — Environment (EU)
- 8b. Ensure Member States, EU and exporters use the same methodology and scope for carbon intensity — Environment (EU)
- 8c. Define carbon intensity standards for hydrogen derivatives (ammonia) and liquid hydrogen* — Environment (EU)
- 8d. Introduce environmental externalities (water, land, etc) in the certification process — Environment (EU)

Pace of Development: Hyperscale electrolyser deployment and remove barriers to growth

- 9a. Set electrolyser manufacturing capacity targets — Industry (EU)
- 9b. Set targets for electrolyser components to support supply chains (e.g. membranes, electrodes etc.) — Industry (EU)
- 9c. Drive automation of electrolyser production and increase raw material efficiency (e.g. recycling) — Industry (EU)
- 9d. Identify critical skills and develop strategy to ensure availability of qualified workforce* — Research (EU)

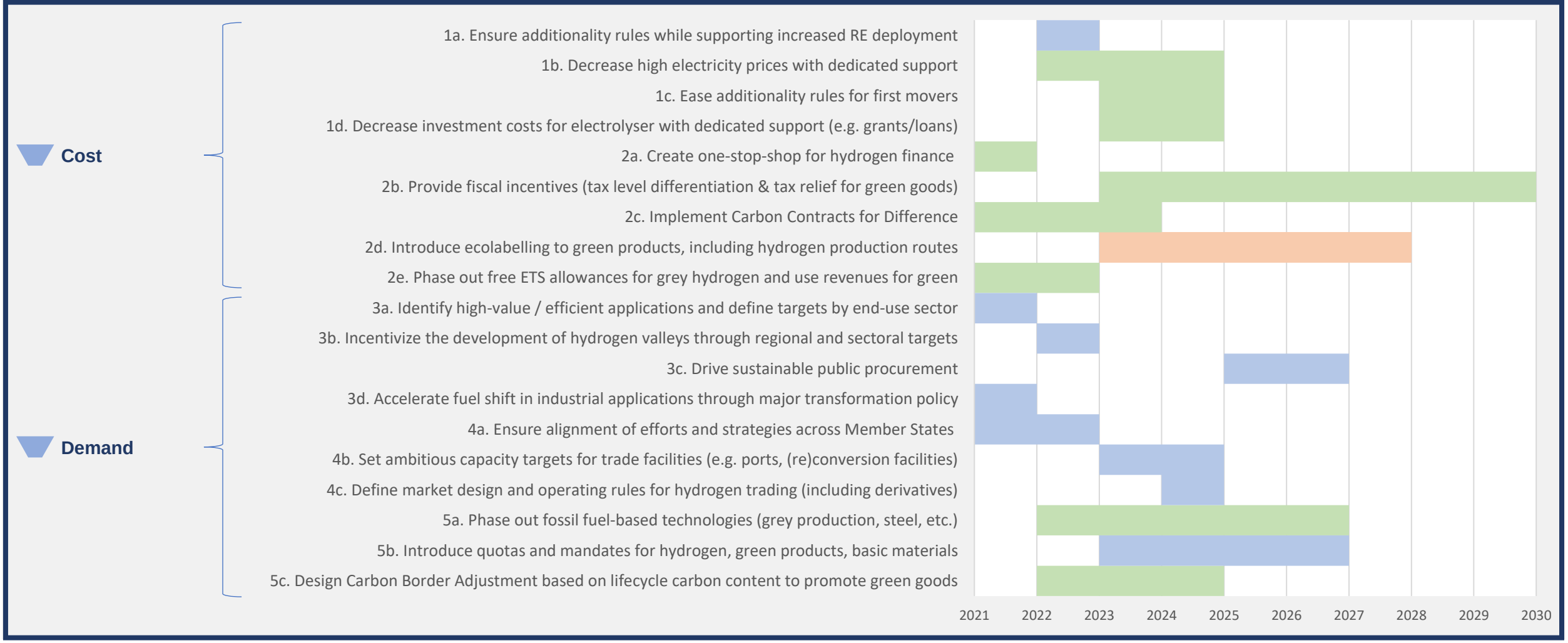
Technology: Focus innovation and R&D to enable technology scale up

- 10a. Focus R&D to improve technology performance of electrolysers including, durability, cost and efficiency — Research (EU)
- 10b. Scale and share pilot projects to build experience with commercial-size facilities — Research (EU)
- 10c. Identify possible long term supply chain bottle necks by value chain component — Research (EU)

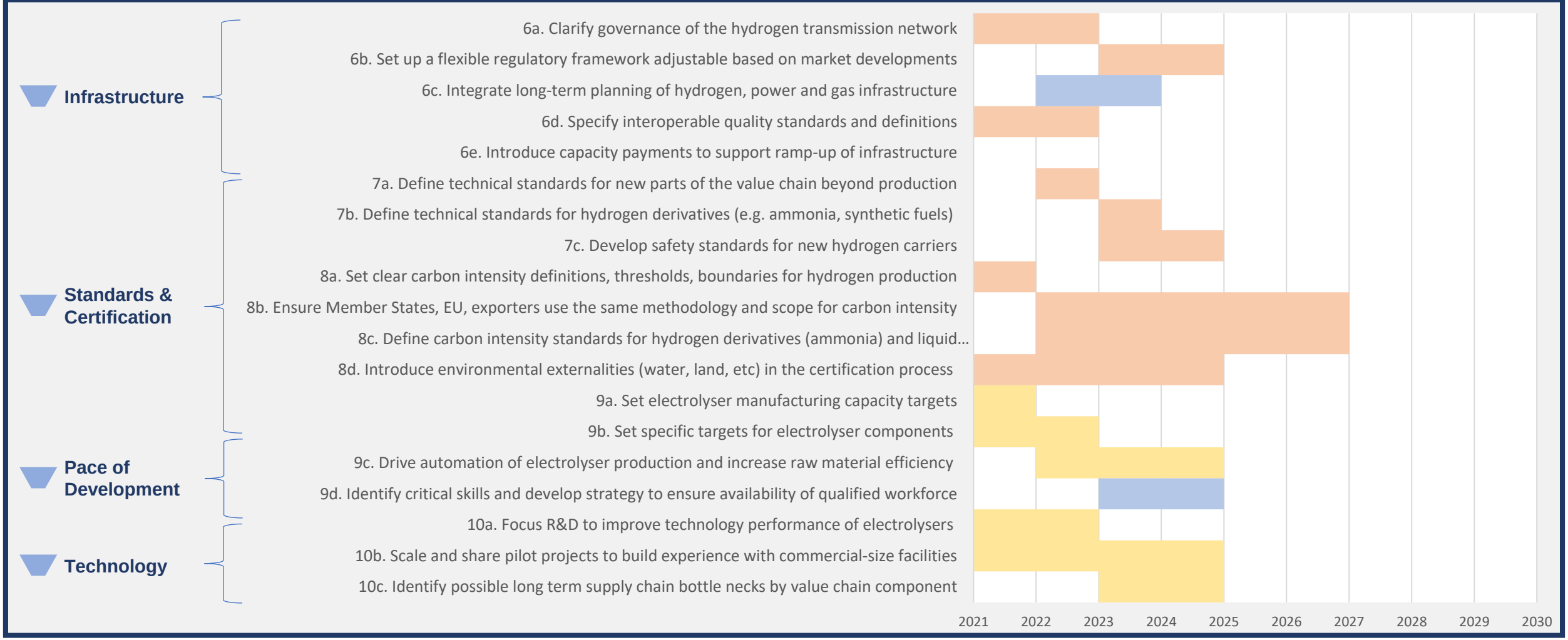
** Indicates shared enabling measure with Japan.*

Note – additional Deepdives to be included in later revision

Enabling measures: target timeline for implementation (1/2)



Enabling measures: target timeline for implementation (2/2)



Outcomes per Barrier for Europe

Indicative outcomes if enabling measures are implemented and objectives achieved

Barrier	Outcome 2021 - 2023	Outcome 2023 - 2026	Outcome 2026 – 2030
Cost	Clarity on type (grants, CCfD, auctions), magnitude (i.e. level of support) and time horizon for policy instruments to cover the cost gap of green hydrogen and imported products.	Policy instruments are fully in place at the EU and Member State level, providing confidence for business cases across multiple applications.	Demand growth has spurred cost decrease across the value chain combined with ambitious GHG targets make hydrogen the most attractive for new facilities across industry and long-haul transport.
Demand	Policy instruments to promote hydrogen uptake have been identified by sector and Member State, and has been set in legislation.	Green hydrogen is replacing fossil-based hydrogen in industrial applications and its use is rapidly increasing across new applications.	The value of hydrogen is recognized across applications and uptake has been enough to decrease costs to competitive levels and develop experience through deployment.
Infrastructure	Clarity on governance of hydrogen infrastructure, financing mechanisms (including cost recovery) and regulation.	First few hydrogen clusters are being connected with pipelines. Largest ports are ready to receive multiple hydrogen carriers and distribute further inland.	Major industrial sites across Europe are interconnected with hydrogen pipelines. Largest ports across Europe are developing commercial-scale hydrogen import projects.
Standards and certification	Basic scope defined including criteria (what is being measured), levels (how much reduction), methodology (including boundaries), certifying bodies, auditing, traceability, issuing and cancelling processes, risk management and communication.	Full consistency between EU's standards and potential exporting countries. Full consistency between energy carriers. Certification has been extended to cover derivatives (including ammonia, synthetic fuels and steel).	Internationally agreed standards being used for first few commercial projects.
Pace of development	The electrolyser value chain has been mapped to ensure there are no bottlenecks in specific components. Electrolyzer manufacturers have a platform to coordinate efforts (e.g. Clean Hydrogen Alliance).	Cash flow for electrolyser manufacturers is positive and are able to fund manufacturing capacity expansion. Capacity is ahead of deployment and does not represent a bottleneck for deployment.	Burgeoning market growth has spurred competition and triggered innovation. Manufacturers have expanded capacity and have also greatly reduced cost to stay competitive resulting in lower capital costs.
Technology	Europe has aligned R&D agenda of the Clean Hydrogen Partnership with other leading hydrogen economies targeting electrolyser, conversion, shipping and re-conversion technologies.	The performance (cost, efficiency, and durability) of electrolysers have improved towards long-term goals. All the integrated pathways for hydrogen carriers have been demonstrated with multiple pilot projects. There is clarity on the conditions that favour one carrier over another that facilitates focused efforts and further progress.	R&D has been successful in bringing energy consumption of liquefaction, ammonia cracking, liquid organic hydrogen carriers dehydrogenation down. Solid oxide and anion exchange membrane have been added to the portfolio of commercial technologies.
Available Renewable Electricity	Clarity and certainty on the additionality rules have been provided with criteria for changes over time (in case of progressive tightening) and adjustment of renewable targets.	Green hydrogen deployment is not displacing more effective uses of renewable electricity and it is not constrained by an overly-restrictive additionality criteria.	Renewable targets, renewable deployment rates and capital mobilized have been increased to account for green hydrogen deployment.

Contents

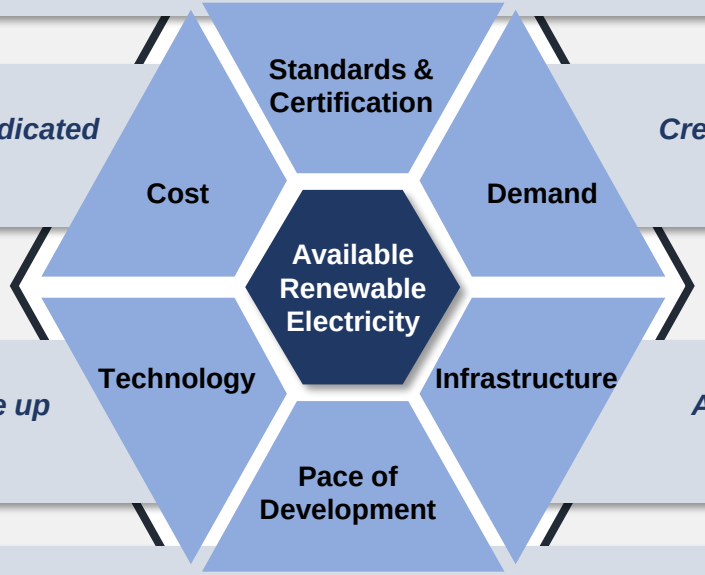
KEY: Barrier Objectives

Key Objectives per Barrier

Emphasize decarbonisation in policy making and ensure clarity on standards through a certification scheme

Support the bankability of projects for investors through dedicated supply mechanisms, financial innovation and incentives

Create a stable demand for green hydrogen / ammonia to lower costs while embedding carbon intensity standards



Focus innovation and R&D to reduce cost of shipping, scale up electrolysers and drive fuel cell efficiency

Align hydrogen hubs and infrastructure with market creation through matching supply and demand

Accelerate development of green hydrogen imports

Available Renewable Electricity

Significant ramp up and deployment of renewable generation in supply countries through ambitious targets, incentives and energy system design

Available Renewable Electricity

Navigating the Roadmap

2 ***Key*** *of supporting information for the enabling measures*

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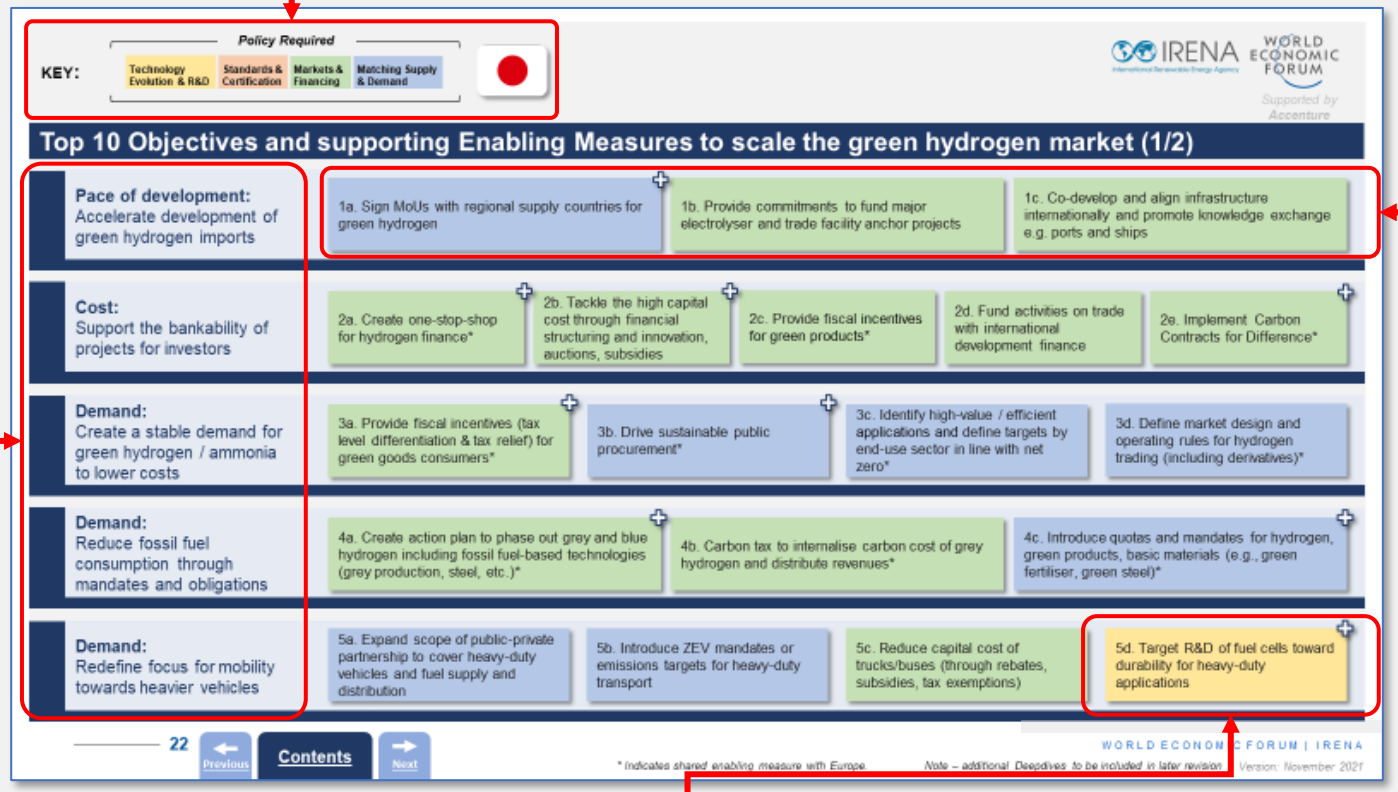

3 **Key enabling measures** required to achieve the identified objective

4 ***'Click here'*** **link** to each Enabling Measure's Deepdive information

KEY: Policy Required

Technology Evolution & R&D	Standards & Certification	Markets & Financing	Matching Supply & Demand

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Top 10 Objectives and supporting Enabling Measures to scale the green hydrogen market (1/2)

Pace of development: Accelerate development of green hydrogen imports

- 1a. Sign MoUs with regional supply countries for green hydrogen
- 1b. Provide commitments to fund major electrolyser and trade facility anchor projects
- 1c. Co-develop and align infrastructure internationally and promote knowledge exchange e.g. ports and ships

Cost: Support the bankability of projects for investors

- 2a. Create one-stop-shop for hydrogen finance*
- 2b. Tackle the high capital cost through financial structuring and innovation, auctions, subsidies
- 2c. Provide fiscal incentives for green products*
- 2d. Fund activities on trade with international development finance
- 2e. Implement Carbon Contracts for Difference*

Demand: Create a stable demand for green hydrogen / ammonia to lower costs

- 3a. Provide fiscal incentives (tax level differentiation & tax relief) for green goods consumers*
- 3b. Drive sustainable public procurement*
- 3c. Identify high-value / efficient applications and define targets by end-use sector in line with net zero*
- 3d. Define market design and operating rules for hydrogen trading (including derivatives)*

Demand: Reduce fossil fuel consumption through mandates and obligations

- 4a. Create action plan to phase out grey and blue hydrogen including fossil fuel-based technologies (grey production, steel, etc.)*
- 4b. Carbon tax to internalise carbon cost of grey hydrogen and distribute revenues*
- 4c. Introduce quotas and mandates for hydrogen, green products, basic materials (e.g., green fertiliser, green steel)*

Demand: Redefine focus for mobility towards heavier vehicles

- 5a. Expand scope of public-private partnership to cover heavy-duty vehicles and fuel supply and distribution
- 5b. Introduce ZEV mandates or emissions targets for heavy-duty transport
- 5c. Reduce capital cost of trucks/buses (through rebates, subsidies, tax exemptions)
- 5d. Target R&D of fuel cells toward durability for heavy-duty applications

** Indicates shared enabling measure with Europe.*

Note – additional Deepdives to be included in later revision

Version: November 2021

KEY: Policy Required

Technology Evolution & R&D	Standards & Certification	Markets & Financing	Matching Supply & Demand

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Top 10 Objectives and supporting Enabling Measures to scale the green hydrogen market (2/2)

Standards & Certification: Emphasize decarbonisation in policy making

- 6a. Set clear carbon intensity definitions, thresholds, boundaries for hydrogen production*
- 6b. Drive carbon intensity metrics across all industries and embed carbon intensity metrics in line with a net-zero scenario within policy making
- 6c. Extend ecolabelling to green products, including hydrogen production routes*

Standards & Certification: Expand scope of certification beyond hydrogen production

- 7a. Define technical standards for new parts of the value chain beyond production (transportation, storage, conversion)*
- 7b. Define technical standards for hydrogen derivatives (e.g. ammonia, synthetic fuels)*
- 7c. Develop safety standards for new hydrogen carriers*
- 7d. Ensure tradability and consistency of certificates across energy carriers (e.g. gas, electricity)

Infrastructure: Align hydrogen hubs and infrastructure with market creation

- 8a. Incentivize the aggregation of demand in hydrogen valleys
- 8b. Drive connecting and planning of localised refuelling stations and ports
- 8c. Support the creation of an internal traded market for hydrogen

Infrastructure: Ensure early ramp up of infrastructure

- 9a. Identify critical skills and develop strategy to ensure availability of qualified workforce*
- 9b. Develop national plan for resilient / seasonal hydrogen storage
- 9c. Specify interoperable quality standards and definitions*
- 9d. Leverage best practice from LNG market and infrastructure development
- 9e. Provide capacity payments to support ramp up of infrastructure*

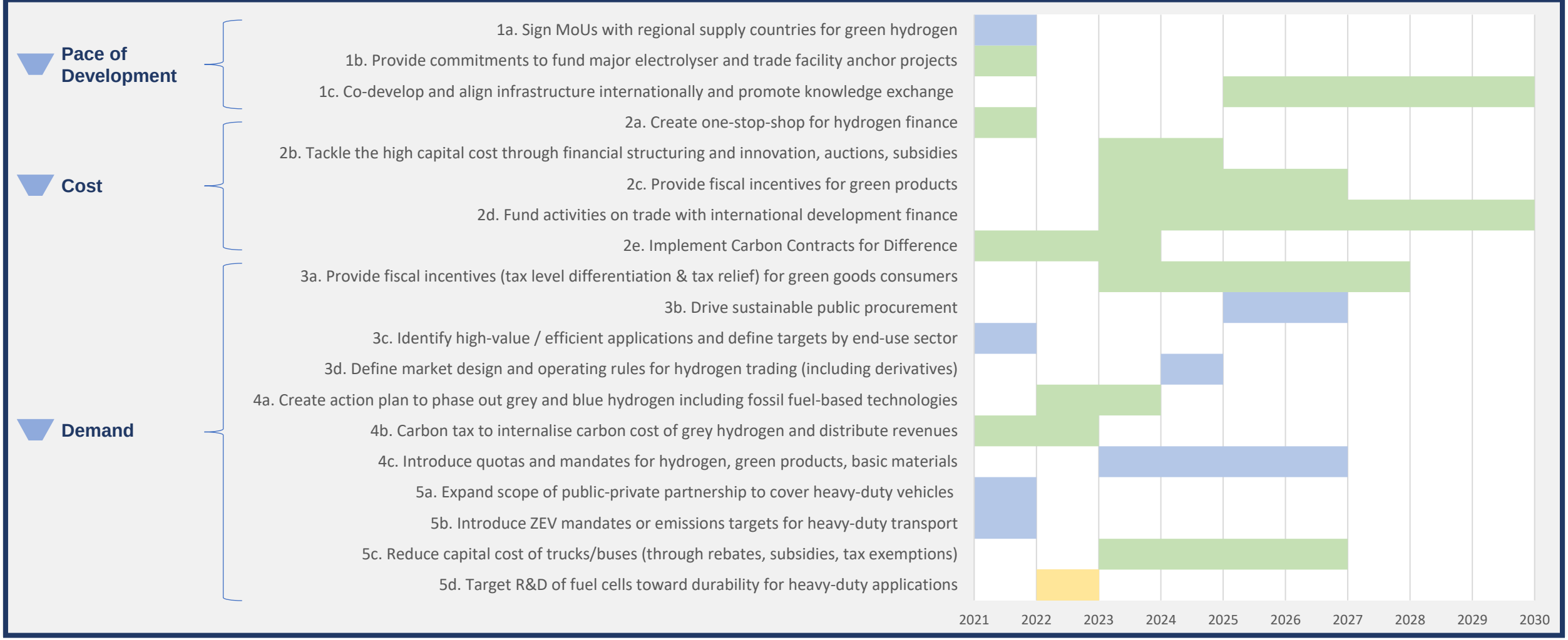
Technology: Focus innovation and R&D to reduce cost of shipping, electrolysers and fuel cells

- 10a. Develop *'moon-shot'* programme for shipping identifying key technology
- 10b. R&D to reduce energy consumption of ammonia cracking / LOHC dehydrogenation
- 10c. Scale and share pilot projects to build experience with commercial-size facilities*
- 10d. Introduce performance targets for hydrogen liquefaction
- 10e. Identify opportunities to couple power generation with ammonia cracking

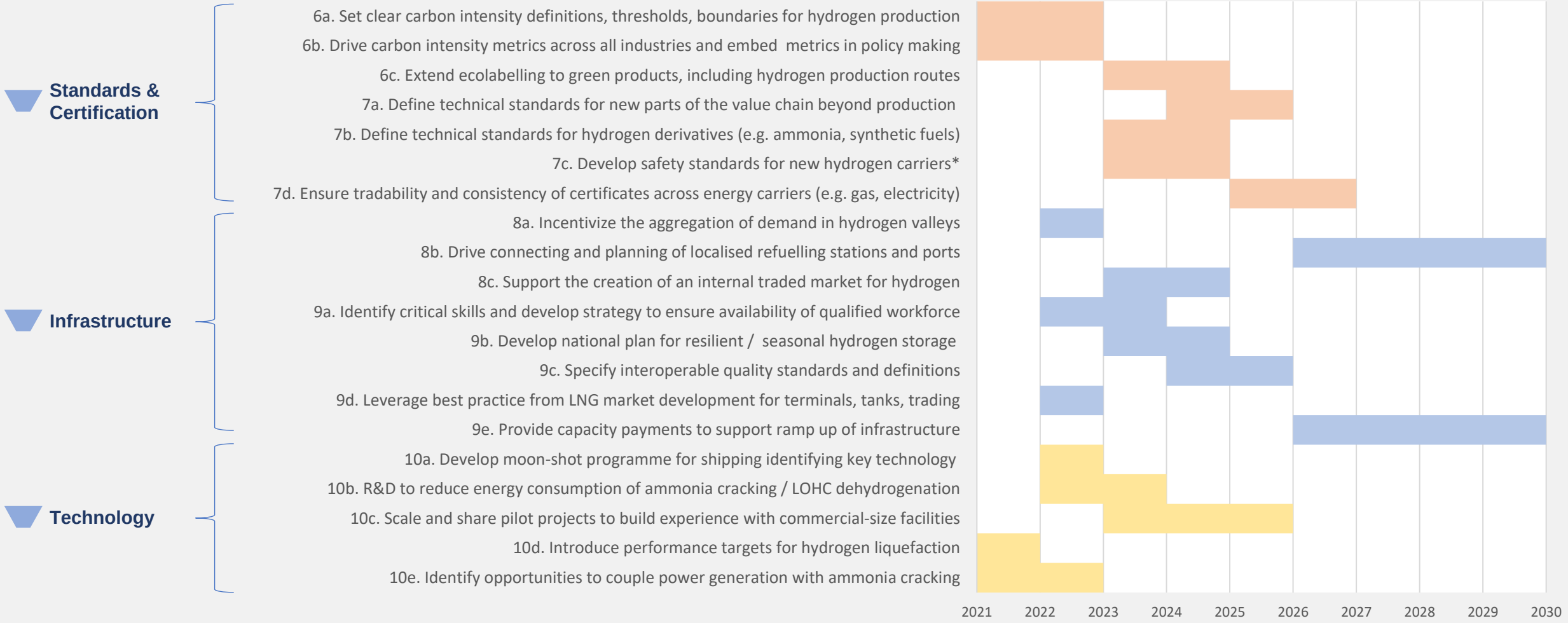
** Indicates shared enabling measure with Europe.*

Note – additional Deepdives to be included in later revision

Enabling measures: target timeline for implementation (1/2)



Enabling measures: target timeline for implementation (2/2)



Outcomes per Barrier for Japan

Indicative outcomes if enabling measures are implemented and objectives achieved

Barrier	Outcome 2021 - 2023	Outcome 2023 - 2026	Outcome 2026 – 2030
Pace of development	MoUs signed with potential supply countries to develop hydrogen value chains. Major renewable electricity and electrolyser anchor projects planned and supported by government funding.	Projects are being developed from pilots to feasibility studies for commercial (>300 ktpa) scale.	Knowledge sharing in place as infrastructure is co-developed across regions to standardise core trade facilities and infrastructure unlocking lower capital costs.
Cost	Central hub for hydrogen project finance created with clarity on CCfDs, magnitude (i.e. level of support) and time horizon for policy instruments to cover the cost gap of green hydrogen and imported products.	Policy instruments are fully in place at the national level making it a positive business case across multiple applications.	Demand growth has spurred cost decrease as per Japan's Hydrogen Strategy combined with ambitious GHG targets make hydrogen the most attractive for new facilities across industry and long-haul transport.
Demand	Application for hydrogen use revaluated with the highest value application based on technology trends prioritised. Carbon pricing developed to support conversion to lower emission technology.	Policy instruments to promote hydrogen uptake have been identified by sector with legislation in place.	Green hydrogen is replacing grey hydrogen in industrial applications and is rapidly increasing across new applications.
Standards and certification	Basic scope defined including criteria (what is being measured), levels (how much reduction), methodology (including boundaries). In conjunction, policy makers drive carbon intensity metrics across business in line with net zero targets and pathways per industry.	Ecolabelling extended across all industries to support consumer demand for green products. Standards for transportation, storage, and derivatives aligned between industry and governing authorities such that they do not hinder financing of early major projects.	Internationally-agreed standard being used for first few commercial projects.
Infrastructure	Demand in critical hydrogen valleys aggregated with local government support where required. Strategy developed to support skills development for the supply chain, learning from the LNG industry.	Early hydrogen hubs begin to develop localised intra-hub trading mechanisms, supported by defined criteria for infrastructure tradability across carriers. Strategy for seasonal storage developed.	Capacity credits in place supporting underutilised infrastructure with connection developing between ports, refuelling stations and industrial hydrogen hubs in regional locations.
Technology	'Moon shot' programme for hydrogen or derivative transport in place. R&D focus on core technologies in place for LOHC dehydrogenation and ammonia cracking.	Learnings from pilot project scale up shared to accelerated development of commercial facilities. All the integrated pathways for hydrogen carriers have been demonstrated with multiple pilot projects. There is clarity on the conditions that favour one carrier over another and allow focusing efforts and making progress.	R&D has been successful in bringing energy consumption of liquefaction, ammonia cracking, liquid organic hydrogen carriers dehydrogenation down and adding solid oxide and anion exchange membrane to the portfolio of commercial technologies.
Available Renewable Electricity	Green hydrogen projects identified with supply countries with specific measures to ensure sustainability agreed.	Pilots projects for green hydrogen prove successful leading to scale up and FiD of major green hydrogen anchor projects enabled by additional renewable energy.	Renewable targets, renewable deployment rates, and capital mobilized are being increased to account for increased green hydrogen deployment and demand.

Contents

The full set of enabling measure Deepdives will be available in a later revision

Selected examples are provided in this document

Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Create one-stop-shop for hydrogen finance

Description: Initiative to bring together project developers, private finance, development finance and government support under one roof to accelerating project FiDs

Barrier Level 1: Cost	**Barrier Level 2:** Lack of upstream / downstream support

Key actions:

- Create a forum that connects private finance with policy makers to share perspectives on what is stopping FiD for hydrogen projects.
- Develop a framework and toolkit for the efficient allocation of capital for investors e.g. cost vs carbon reduction vs system value of hydrogen above LCOH.
- Provide technical assistance and grant funding for project development and document preparation
- Support project development through provision of project initiation and facilitation tools
- Accelerate the use of the EU taxonomy for sustainable finance for hydrogen.

Ongoing work and examples:

- European Hydrogen Funding Compass - an online guide for stakeholders to identify public funding sources for hydrogen projects.
- EU funding mechanisms:
  - IPCEI
  - Innovation fund
  - Recovery and Resilience Fund
  - Horizon Europe

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Tackle the high capital cost through financial structuring, auctions, subsidies

Description: Suite of policies and initiatives to tackle the second largest cost component of green hydrogen: the electrolyser cost

Barrier Level 1: Cost	**Barrier Level 2:** Lack of upstream support

Key actions:

- Provide a forum to support the bankability of hydrogen supply project including governments, financial institutions, development finance institutions, export credit agencies (e.g. Development Bank of Japan (DBJ), Japan Bank for International Cooperation (JBIC), Nippon Export and Investment Insurance's (NEXI).
- Create support mechanisms to support national and international electrolyser capacity (e.g. auctions for grants).
- Change support methodology and language to focus on carbon intensity reduction as opposed to sales and profitability for return on investment.

Ongoing work and examples:

- The German government has launched the H2Global initiative which is a double auction scheme with total funds of EUR 900 million. It promotes projects with an electrolyzer size of at least 100 MW, enabling the construction of up to 500 MW.
- Grant for a 100-MW electrolyzer in the EU under the Horizon 2020 Programme with funding from the Innovation Fund.
- Net Zero Hydrogen fund in the UK with a size of GBP 240 million.
- In Guangzhou (China), a 3-year discount of up to RMB 5 million per year is given to corporate loans for hydrogen projects

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Implement Carbon contracts for Difference

Description: Contracts that provide certainty on the costs for a hydrogen consumer by paying the difference between the carbon market price and an agreed strike price

Barrier Level 1: Cost	**Barrier Level 2:** Lack of downstream support

Key actions:
- Identify target industry and high-value hydrogen application for CCfD pilot scheme.
- Ensure suitable CO2 pricing mechanism or emissions trading system is in place for target industries.
- Engage industry stakeholders on CCfD scheme design.
- Leverage best practice from renewable electricity Contracts for Different (CfD) schemes and floating Feed in Premiums (FiP).
- Scale up programme in line with National Hydrogen strategy and net zero targets.

Ongoing work and examples:
- Germany announced in its Hydrogen Strategy that it will launch a new Carbon Contracts for Difference (CCfD) pilot programme to support the use of hydrogen from renewable energy sources in the steel and chemical industries.
- Netherlands SDE++ Scheme provides opex support for low carbon technology similar to a commercialisation contract like a CCfD.
- UK Government Contracts for Difference (CfD) for low carbon electricity generation.
- Support to offshore wind farms in Denmark is provided by a floating feed-in premium, providing a guaranteed price level.

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Ensure additionality rules while supporting increased renewable energy deployment

Description: Clear rules surrounding the additionality principle of renewables to support hydrogen project developers

Barrier Level 1: Cost	**Barrier Level 2:** Unfit market design

Key actions:
- Ensure renewable energy capacity developed for green hydrogen and energy from electricity producers serving electrolysers do not benefit of additional payments designed for decarbonisation of the power system.
- Incorporate spatial and temporal matching between renewable energy generation and green hydrogen production as parameters to be tracked in the certification schemes (not necessary for non-grid connected electrolysers).
- Accelerate the deployment of renewable energy in the power sector and address the barriers still faced by renewable energy developers to ensure a smooth transition.

Ongoing work and examples:
- DG ENER:
  - RED II: Additionality rules are included for the recognition of synthetic fuels as renewable.
  - The "Fit for 55" package proposes to extend these provisions to every sector.
- CertifHy: Compliance with RED II renewable fuels for transport, which requires additionality rules to be followed.
- Lessons to be learned from CDM, CO_2 offsets and biofuels.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Decrease high electricity prices with dedicated support

Description: Reduction in cost of electricity used specifically for water electrolysis

Barrier Level 1: Cost	**Barrier Level 2:** Lack of upstream support

Key actions:
- Exempt electrolysers from taxes and fees to reduce the cost of electrolytic hydrogen, strengthening its business case.
- Assess if low taxes on tariffs can also be justified by the use of the power system during periods of high VRE production and relatively low load (when wholesale electricity prices are low).
- Find the best solution to levelling the playing field among flexible resources and avoiding excessive burdens on consumers.

Ongoing work and examples:
- New South Wales (Australia) is considering exempting green hydrogen production from charges for the NSW Energy Savings Scheme, Peak Demand Reduction Scheme, Electricity Infrastructure Roadmap and GreenPower program.
- **Power system regulator**: Regulators routinely decide how consumers will pay taxes and fees. Industrial players are often partially untaxed.
- For the effect of reduced taxes and hydrogen costs see IRENA (2021).

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Ease additionality rules for first movers

Description: Allow first movers a partial exemption from additionality rules to reduce the first mover risk

Barrier Level 1: Cost	**Barrier Level 2:** Unfit market design

Key actions:
- To benefit the first movers, adopt transitional measures regarding temporal and spatial correlation requirements between renewable electricity and production.
- Assess how to implement temporal requirements that allow the operation of the electrolysers at their optimal utilization rate, limiting the need for immediate larger renewables-based electricity generation capacity (e.g hourly correlation instead of strict simultaneity).
- Assess the long-term benefits of co-locating production and generation in the same bidding zone, considering expected grid reinforcement due to increased electrification.

Ongoing work and examples:
- DG ENER:
  - RED II: Additionality rules are included for the recognition of synthetic fuels as renewable.
  - The "Fit for 55" package proposes to extend these provisions to all sectors.
- The Netherlands's SDE++ scheme includes electrolytic hydrogen produced with grid electricity as a potential recipient of subsidy, with relaxed additionality regulations.
- LCFS in California uses average hourly grid emissions factors to estimate CO_2 footprint from electricity which could be used in early stages of deployment.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Provide fiscal incentives (tax level differentiation & tax relief) for green goods

Description: Fiscal incentives refer to lower tax rates or tax relief for consumers who use green products (e.g. green steel, green fertiliser)

Barrier Level 1: Demand	**Barrier Level 2:** Global competitiveness

Key actions:
- Introduce product-related economic instruments such as tax differentiation and tax relief to nudge consumers and businesses towards green products.
- Introduce tax differentiation (tax design under which rates on goods are adapted to reflect a government objective, such as climate impact), to reduced profitability for producers or incentivize the switch to green alternatives.
- Introduce tax reliefs (schemes where the expense incurred to buy a green product can be partially or totally deducted or from taxes) to encourage consumers to invest in more expensive green goods.

Ongoing work and examples:
- Finance ministries: Taxes on goods are already occasionally shaped to mirror government objectives (e.g., luxury goods with higher VAT rates).
- OECD: OECD assesses the effect of taxation on final products and provides guidance for policy makers.
- Enhanced Capital Allowance all UK businesses can benefit from the scheme, which provides 100% tax relief on any investment in new or unused energy-saving equipment in the same tax year as the purchase is made.

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Incentivize the development of hydrogen valleys through regional and sectoral targets

Description: Specific measures and initiatives to support the development of hydrogen valleys, where supply and demand are located nearby

Barrier Level 1: Cost	**Barrier Level 2:** Hydrogen uptake uncertainty

Key actions:
- Identify target industrial clusters or hydrogen valleys where supply and demand are or can be co-located.
- Bring together key industry players and policy makers to co-develop a regional strategy.
- Assess appropriate technology for decarbonisation including Hydrogen, CCUS, system efficiency and circularity.
- Include system value elements e.g. jobs over and above LCOH for the regional area.
- Define and agree targets for the region and sectors in line with national net zero goals.

Ongoing work and examples:
- Industrial Clusters Plan (Netherlands) identifies a net zero pathway for six clusters.
- Decarbonisation Strategy (UK) that identifies industrial clusters and hydrogen as a key lever for decarbonisation.
- USD 8 billion from the Infrastructure Investment and Jobs Act (US) for four hydrogen hubs until 2026.
- Mission Innovation's Hydrogen Valley's Platform provides an insight into the most advanced and ambitious hydrogen valleys.
- See World Economic Forum and Accenture report on Industrial Clusters.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Sign MoUs with regional supply countries for green hydrogen

Description: Government signing memorandum of understanding to either initiate specific projects for hydrogen trade or technology transfer and knowledge exchange

Barrier Level 1: Demand	**Barrier Level 2:** Hydrogen uptake uncertainty

Key actions:
- Identify potential exporting countries where green hydrogen can be produced sustainably.
- Sign MoUs for trade, aligned with national objectives and energy scenarios.
- Commit to assist exporting countries with major anchor projects, through both funding and R&D exchange.

Ongoing work and examples:
- **National strategies** across countries include import or export targets.
- **Private and public organisations** such as producers and ports are signing MoUs.
- Germany is signing multiple MoUs with prospected exporting countries, notably supporting the production of green hydrogen with dedicated funds.
- IPHE driving clarity on international standards for production and transport.

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Drive sustainable public procurement

Description: Government procurement of green products that limit GHG emissions

Barrier Level 1: Cost	**Barrier Level 2:** Hydrogen uptake uncertainty

Key actions:
- Introduce minimum requirements for green products in public authorities' procurement processes. Introduce green material requirements in policies, such as in auctions for renewable energy.
- Ensure presence of a verification and labelling system to guarantee sustainability of the products.

Ongoing work and examples:
- UNEP: The One Planet Network Sustainable Public Procurement (SPP) programme is a global multi-stakeholder platform of 130+ partners which support the implementation of SPP around the world. UNEP is a co-lead of the Program and is in charge of the Monitoring Interest Group.
- The Buy Clean California Act (BCCA) imposes a maximum acceptable Global Warming Potential limit for selected construction materials. The BCCA targets, among others, carbon emissions associated with the production of structural steel and concrete reinforcing steel.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Ensure alignment of efforts and strategies across Member States through coordination and continuous knowledge exchange

Description: Alignment of complimentary Member State hydrogen strategies across Europe

Barrier Level 1: Demand	**Barrier Level 2:** Hydrogen uptake uncertainty

Key actions:
- Promote European investment abroad (European Neighbourhood Policy) and drive down the cost of shared infrastructure
- Act as a cohesive single entity to bridge the gap between the EU Hydrogen Strategy, national strategies, and required policy to drive demand with country-specific nuance.
- Identify key roles within the European Commission to streamline activities to import hydrogen e.g. Hydrogen Envoy
- Ensure an aligned European approach to the Hydrogen backbone, focusing on the import market exploring opportunities.

Ongoing work and examples:
- EU-GCC Clean Energy Technology Network driving collaboration between Europe and GCC exporters.
- Numerous MoUs being signed between EU countries and exporting countries to explore trade opportunities (see Green hydrogen supply: A guide to policy p41)
- European Hydrogen Strategy.
- Member States' National Hydrogen Strategies.
- Coordination with supply country Energy Strategies e.g. Chile.

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Introduce quotas and mandates for hydrogen, green products, basic materials (e.g., green fertiliser, green steel)

Description: Introduction of a quota of green hydrogen in final hydrogen consumption and for green goods for large consumers of the same specific target

Barrier Level 1: Cost	**Barrier Level 2:** Hydrogen uptake uncertainty

Key actions:
- Implement green hydrogen use binding quotas or mandates for large hydrogen consumers.
- Complement existing targets by using quotas for sectors other than industry (e.g. aviation) or specific sub-sectoral targets for industry (e.g. steel).

Ongoing work and examples:
- Spain's hydrogen strategy, includes a 25% minimum contribution of green hydrogen with respect to the total hydrogen consumed in 2030 by all industries.
- **See** IRENA's Green hydrogen supply: A guide to policy making for more detail.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Accelerate fuel shift in industrial applications through major transformation policy

Description: Change industrial policy from a focus on incremental change from energy efficiency to step changing benefits from using low-carbon fuels like hydrogen

Barrier Level 1: Demand	**Barrier Level 2:** Global competitiveness

Key actions:
- Include hydrogen as possible energy carrier for industrial facilities in industrial policies and decarbonization strategies.
- Introduce specific measures that promote fuel shift in industry complementing energy and material efficiency:
  - Quotas/mandates increasing over time
  - Concessional loans/grants/dedicated funds
  - GHG emission intensity standard with tradeable certificates
- This measure is linked to carbon tax, CBAM, product labeling, which can all promote the uptake of new fuels

Ongoing work and examples:
- Target of 100 hydrogen valleys by 2030 to reduce delivered costs to USD 2/kg by 2030 (Mission Innovation)..
- GBP 220 million under the Industrial Energy Transformation Fund (UK) promoting low-carbon technologies.
- USD 8 billion from the Infrastructure Investment and Jobs Act (US) for four hydrogen hubs until 2026.

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Set ambitious capacity targets for trade facilities (e.g., ports, (re)conversion facilities

Description: Targets to provide clarity on scale up of facilities required to trade hydrogen internationally

Barrier Level 1: Cost	**Barrier Level 2:** Unfit market design

Key actions:
- Assess the maximum practical size for each step of the hydrogen value chain (conversion, storage, ships, re-conversion) by pathway (hydrogen carriers).
- Define milestones for size of individual facilities (that achieve economies of scale).
- Define targets for total potential imported and exported hydrogen (to give certainty to investors of market potential).
- Work closely with equipment manufacturers to reach a standardized design for the trade facilities.
- Participate in global initiatives that provide the opportunity to identify import-export matches for pilot project and scale-up process.

Ongoing work and examples:
- A project for importing hydrogen to the Netherlands using LOHC is targeting 100-200 ktpa by 2025 and 300-400 ktpa by 2030.
- The HySTRA project in Japan is targeting commercial scale by 2030.
- Multiple pilot projects (page 158) aiming for commercialization between 2025 and 2030.
- Japan had an explicit target of 300 ktpa of imported hydrogen by 2030 in their 2017 Strategy but this was not kept for the most recent update.
- Russia targets 200 ktpa export by 2024 and 2 Mt by 2035.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Target R&D of fuel cells toward durability for heavy-duty applications

Description: Focused R&D spending on fuels cells for heavy-duty applications such as trucks

Barrier Level 1: Demand	**Barrier Level 2:** Hydrogen uptake uncertainty

Key actions:
- Ensure there is knowledge transfer from medium-duty and stationary applications.
- Establish public-private cooperation for knowledge exchange on research
- Leverage efforts on cost reduction from light-duty transport.
- Improve catalyst performance to reduce stack oversizing needed for a certain lifetime.
- Reduce content of (or eliminate) platinum group metals (PGM) in catalyst/electrodes.
- Improve the durability of membrane electrode assemblies.
- Explore innovative manufacturing processes for fuel cells.

Ongoing work and examples:
- Million Mile Fuel Cell Truck consortium (US) targeting improved performance.
- FCH JU (EU) had dedicated less than 5% (Figure 6) of the transport pillar budget to trucks and does not have any explicit targets for heavy-duty.
- METI does not have any explicit targets for heavy-duty.
- Private sector has announced a target of 100k trucks in EU by 2030 which could trigger research on durability.
- US DoE has durability-adjusted cost targets for fuel cells in trucks.

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Phase-out fossil fuel-based technologies (grey production, steel, etc.)

Description: Phasing out fossil fuel-based industrial technologies in hard-to-abate sectors

Barrier Level 1: Demand	**Barrier Level 2:** Hydrogen uptake uncertainty

Key actions:
- Draft sectoral targets for decarbonization that use a holistic approach (including energy efficiency, electrification and shift to low-carbon fuels like hydrogen).
- Assess competing technologies to substitute the phased out ones.
- Bring together key industry players and policy makers to co-develop a phase-out strategy.
- Include system value elements e.g. jobs over and above LCOH for the regional area.
- Define and agree a national roadmap for the phase out of fossil fuel technologies.

Ongoing work and examples:
- The UK government has announced that by 2025, all new homes will be banned from installing gas and oil boilers and will be heated by low-carbon alternatives.
- In the Netherlands, new homes are not allowed to use gas boilers since 2017 and the country plans a complete phase-out of gas use in homes by 2050
- By June 2021, 14 countries and 3 jurisdictions in North America have announced explicit bans of ICE vehicles or 100% zero-emission vehicles targets by 2030-2050.
- Many EU national governments have announced their intention to phase out coal for a total of 35.4 GW by 2030 or earlier.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Design Carbon Border Adjustment based on lifecycle carbon content to promote green goods

Description: Import fee based on the carbon content of goods, to promote green hydrogen and avoid carbon leakage

Barrier Level 1: Demand	**Barrier Level 2:** Global Competitiveness

Key actions:
- Introduce import taxes in the form of carbon border adjustment (CBA) that account for the difference in carbon pricing policies across different countries to make polluters, even outside the importing jurisdiction, pay the same (or a similar) carbon price paid by local industry.
- Ensure the tariff to be carbon content-based, to favor green products and higher for grey products and facilitate the import of green products.
- Set the CBA for a large market, so to capture a large demand of goods and activate a "race to the top" among producers worldwide.

Ongoing work and examples:
- European Commission: The "Fit for 55" package proposes a CBA for Europe.
- California has a form of CBA in operation for the electricity sector. Importers of electricity are required to submit emissions permits for the Californian ETS system based on their reported emissions intensities.

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Drive automation of electrolyser production and increase raw material efficiency (e.g. recycling)

Description: Advance electrolyser production from a manual process to an automated factory process and reduce the need for key raw materials used in electrolysers stacks

Barrier Level 1: Technology	**Barrier Level 2:** Limited manufacturing capacity

Key actions:
- Identify opportunities for automation of the stack assembly building upon lessons for battery manufacturing.
- Establish explicit targets for critical raw materials use in electrolysers with attention to platinum group metals (PGM) in polymer electrolyte membrane electrolysers.
- Research on recovery and recycling of noble metals from electrolysers.
- Explore emerging catalyst deposition methods (e.g. slot-die) considering the speed of the coating process and the quality of the coated membrane.

Ongoing work and examples:
- The EU has an Action Plan on Critical Raw Materials and the European Raw Material Alliance that includes PGM US focuses more on rare earths and materials for batteries than PGM and has the Critical Materials Institute.
- The H2NEW consortium in US covers scale-up of manufacturing.
- Gigastack project in the UK.
- Multiple manufacturing capacity targets by industry (Box 1.2).
- FCH JU (EU) has explicit targets for critical raw materials use in electrolysers Technology roadmap from the Strategic Research and Innovation Agenda from Hydrogen Europe.
- HyTech Cycling roadmap for strategies to dismantle electrolysers and recycle.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

R&D to reduce energy consumption of ammonia cracking / LOHC dehydrogenation

Description: Focused R&D to make the conversion more efficient e.g. turning ammonia or a liquid organic hydrogen carrier back to hydrogen

Barrier Level 1: Technology	**Barrier Level 2:** (Re)Conversion to hydrogen carriers

Key actions:
- Establish explicit targets for energy consumption of ammonia cracking and LOHC dehydrogenation.
- Support the demonstration at large-scale (> 300 ktpa) projects.
- Support research of ammonia cracking catalysts with high conversion and low operating temperatures.
- Improve productivity of the LOHC dehydrogenation catalysts and reduce content of precious metals.
- Ensure environmental impact of the heat source for re-conversion is considered in lifecycle analyses.

Ongoing work and example:
- METI (Japan) has a cost target for the imported hydrogen and demonstrating various pathways but does not have targets for these two technologies.
- US DoE has cost and density targets for storage but does not cover energy consumption. The HyMARC project could be extended to cover this aspect
- TransHyDE project in Germany.
- Roadmap - Strategic Research and Innovation Agenda, Hydrogen Europe.
- Activity FCH-02-1-2020 from the FCH JU targeting less than 6 kWh/kg and other explicit performance targets as follow-up of the HySTOC project.

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Introduce performance targets for hydrogen liquefaction

Description: Establish technical efficiency targets for liquefying hydrogen to drive innovation and measure progress

Barrier Level 1: Technology	**Barrier Level 2:** (Re)Conversion to hydrogen carriers

Key actions:
- Assess the maximum practical size for liquefaction facilities and liquid hydrogen storage tanks.
- Update cost and efficiency targets for liquefaction/storage based on maximum sizes.
- Support the R&D of mixed-refrigerant cycles, different temperature ranges for each cycle, and alternative process configurations to reduce energy consumption.

Ongoing work and examples:
- National labs from the US are looking into hydrogen liquefaction for export.
- Japan is demonstrating liquefaction for import through the HySTRA project.
- Air Products is working with Hyundai Glovis for a hydrogen supply chain project.
- Liquefaction has not been part of the EU program since the IdealHy project.
- Japan has an explicit target of 6 kWh/kg for liquefaction efficiency.
- Japan has innovative designs for liquefaction as part of the strategy.
- Technology roadmap from the Strategic Research and Innovation Agenda.
- US DoE has a target of 6 kWh/kg and USD 340/kW for a 300 t/d facility.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Identify opportunities to couple power generation with ammonia cracking

Description: Use excess heat from power generation to maximise efficiency of converting ammonia to hydrogen

Barrier Level 1: Technology	**Barrier Level 2:** (Re)Conversion to hydrogen carriers

Key actions:
- Use ammonia directly where possible and reduce the scale of cracking needed.
- Map ammonia uses, import ports and heat sources to identify potential locations for heat integration.
- Perform feasibility studies for identified locations analysing heat integration, autonomous operation (with ammonia cracked), and renewable heat sources.
- This measure is linked to improved performance of ammonia cracking.

Ongoing work and examples:
- Research for heat integration between solid oxide fuel cells for power generation and cracking or direct use.

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Focus R&D to improve technology performance of electrolysers including, durability, cost and efficiency

Description: Focused R&D to accelerate the progress of electrolyser technology

Barrier Level 1: Technology	**Barrier Level 2:** Limited manufacturing capacity

Key actions:
- Increase current densities with limited degradation or efficiency loss.
- Improve mechanical properties of diaphragm/membrane to achieve a lower thickness without impacting too negatively the lifetime.
- Establish public-private cooperation for knowledge exchange on research.
- Remove expensive coatings and redesign the porous transport layers and bipolar plates of polymer electrolyte membrane electrolysers.
- Develop novel concepts for recombination catalysts.
- Increase the operating temperature and pressure of alkaline electrolysers.
- Moving electrode architectures into high-area electrodes.

Ongoing work and examples:
- FCH JU (EU) and US DoE have both fundamental research and demonstration for various pathways.
- The H2NEW consortium in the US targets improved performance for low and high-temperature electrolysis.
- METI (Japan) only has targets with limited funding towards electrolysis.
- Japan has an explicit efficiency target of 4.3 kWh/Nm^3 by 2030.
- US DoE has differentiated between stack vs. system efficiency, and distributed vs. centralized production.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Set clear carbon intensity definitions, thresholds, boundaries for hydrogen production

Description: Ensure that methodology and criteria for measurement of GHG emissions is standardized with quantitative thresholds by hydrogen source

Barrier Level 1: Standards & Certification	**Barrier Level 2:** No certification of hydrogen

Key actions:
- Create design principles to align certification standards and practices and facilitate interoperability between them.
- Drive the development of minimum criteria for the definition of sustainable hydrogen.
- Allow first shipments of certified green hydrogen even when full certification system has not been achieved

Ongoing work and examples:
- IPHE driving clarity on international standards for (1) 5 production pathways then (2) transport.
- National strategies across countries include certification e.g. Australia, UK, Europe (Certifhy, RED II updates).
- Private organisations are looking into certification e.g. Acciona's H2 Chain project

REDII (EU)
- Tradeable guarantees of origin for renewable energy expanded to hydrogen
- Sustainability certificates for hydrogen with mass balancing

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Ensure Member States, EU and exporters use the same methodology and scope for carbon intensity

Description: International participants in the traded hydrogen market using interoperable and translatable standards across borders

Barrier Level 1: Standards & Certification	**Barrier Level 2:** Incompatibility across borders

Key actions:
- Co-operate and engage with international standardisation bodies and organisations to adhere to same technical and carbon emissions standards for green hydrogen.
- Create carbon emission and environmental standards that are consistent with neighbouring, exporting, hub, and importing countries.
- Clarify the taxonomy and rules required for green hydrogen to be recognised as sustainable production of hydrogen.

Ongoing work and examples:
- EU Commission through its work on the European Green Deal, 'Fit for 55' Package, EU Sustainable Finance Taxonomy, Important Projects of European Interest (IPCEI), etc.
- IPHE Methodology for Determining Greenhouse Gas Emissions is a good starting point to make sure standards are inter-operable.
- EU Sustainable Finance Taxonomy outlines the emissions standards considered for sustainable energy.

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Enabling Measures Deepdive

KEY: Technology Evolution & R&D | Standards & Certification | Markets & Financing | Matching Supply & Demand

Develop national plan for resilient / seasonal hydrogen storage

Description: Planning for long-term storage capacity considering energy security, seasonal fluctuations of demand and geological formations

Barrier Level 1: Infrastructure	**Barrier Level 2:** Lack of long-term planning

Key actions:
- Determine needs of long-term storage for a decarbonized electricity system considering flexibility measures (grid expansion, hydropower/bioenergy, e-fuels).
- Assess suitability of geological formations for hydrogen storage.
- Identify the best strategy to ensure security of hydrogen supply (e.g. long-term contracts, underground storage, oversized on-ground storage).
- Build upon existing gas infrastructure assets (e.g. re-conversion).
- Establish the time horizon when seasonal storage will be needed.
- Perform the integrated planning of methane, electricity and hydrogen networks.

Ongoing work and examples:
- Review of the regulatory framework for decarbonized gases in the EU.
- Storage operators in the EU identifying the value, needs and potential for underground storage.
- Studies looking at the potential in the UK and the EU.
- National Hydrogen Infrastructure Assessment to be completed by 2022 in Australia to be reviewed and updated every 5 years.
- Inclusion of hydrogen in the TEN-E regulation (EU) to facilitate European-wide planning of infrastructure.
- Joint gas and electricity transmission network planning in the EU.

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Leverage best practice from LNG market development for terminals, tanks, trading

Description: Learn from the infrastructure and markets development of the LNG market to accelerate learning in the hydrogen market

Barrier Level 1: Infrastructure	**Barrier Level 2:** Lack of infrastructure support and development

Key actions:
- Learn from best practices and historical market development from the liquefied natural gas industry.
- Establish knowledge-sharing platforms between the incumbent gas industry and the developing hydrogen industry.
- Allow subject matter experts to guide the development of hydrogen infrastructure development, drawing on experiences from best practices and lessons learnt.

Ongoing work and examples:
- Energy and Trade Ministries are key stakeholders in ensuring co-operation and project development.
- The Port of Rotterdam and the Port of Hamburg are also developing hubs and terminals, leveraging best practices from LNG.
- H2Tools – Some best practices and lessons learnt are carried over from the natural gas industry.
- Hydrogen Energy Supply-chain Technology Research Association (HySTRA) is supported by the New Energy and Industrial Technology Development Organization (NEDO).
- Kobe LH2 Terminal by Kawasaki Heavy Industries.

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Breakdown of the barriers

Cost	No carbon cost internalisation Lack of upstream support Lack of downstream support Unfit market design
Demand	Hydrogen uptake uncertainty Global competitiveness Availability of supply
Infrastructure	Lack of infrastructure support and development Infrastructure uncertainty
Standards & Certification	No certification of hydrogen No certification of hydrogen derivatives Incompatibility across borders Lack of clarity on environmental impact beyond GHG Standardisation (design, safety etc.)
Pace of development	Slow renewable capacity deployment & unclear additionality Slow electrolyser manufacturing Industrial assets lifetime Fuel cell manufacturing capacity
Technology	Materials use in equipment De-risking new industrial applications Electrolyser and fuel cells performance (efficiency, power density etc.) Assessing compatibility of the existing gas grid De-risking integrated PtX pathways

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About IRENA

The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. An intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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