IRENA
International Renewable Energy Agency
WORLD ECONOMIC FORUM

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Enabling Measures Roadmap for Green Hydrogen

Europe

Japan

Version: *January 2022*

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Contents

Version: *January 2022*

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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

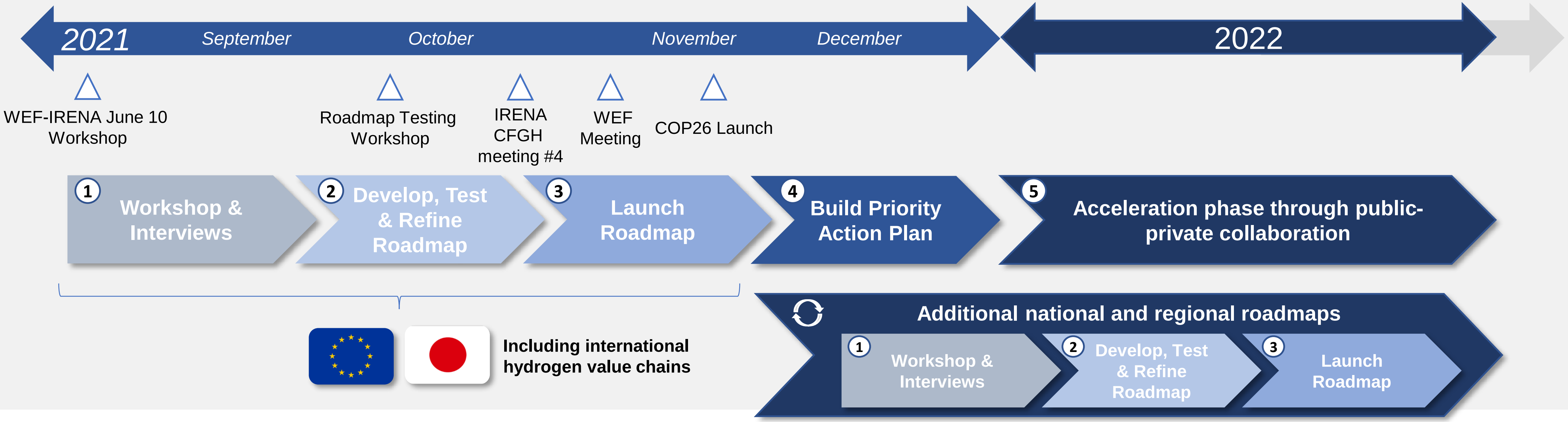
Activities under the joint initiative:

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

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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

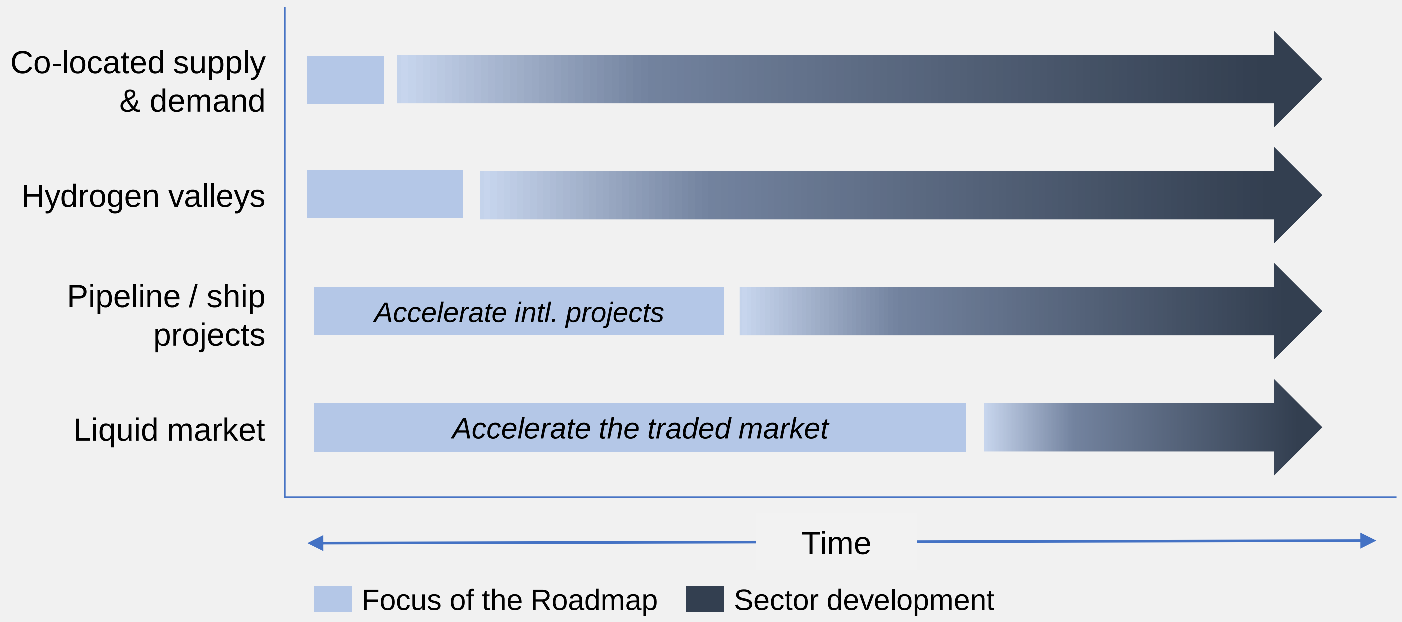
10th June 2021	July - September 2021	21st October 2021	Tuesday 26th October 2021	4th November 2021	Ongoing Programme
Joint IRENA-WEF Workshop *on Enabling Measures for Green Hydrogen*	**Consultations** with industry and international organisations on key enabling measures for green hydrogen	**IRENA 4th 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

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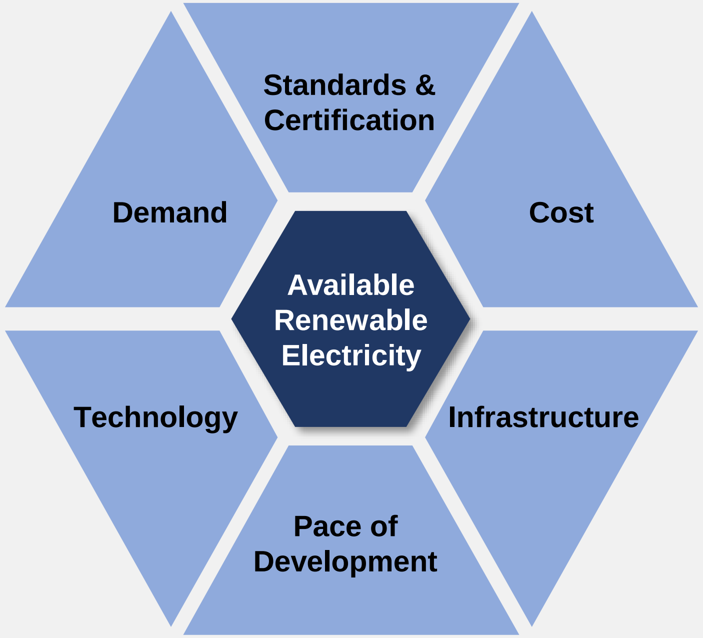
Building the Roadmap framework: Barriers to Scale

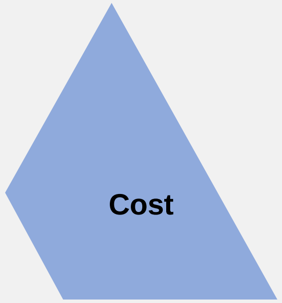
STEP 1 – Identify Barriers

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

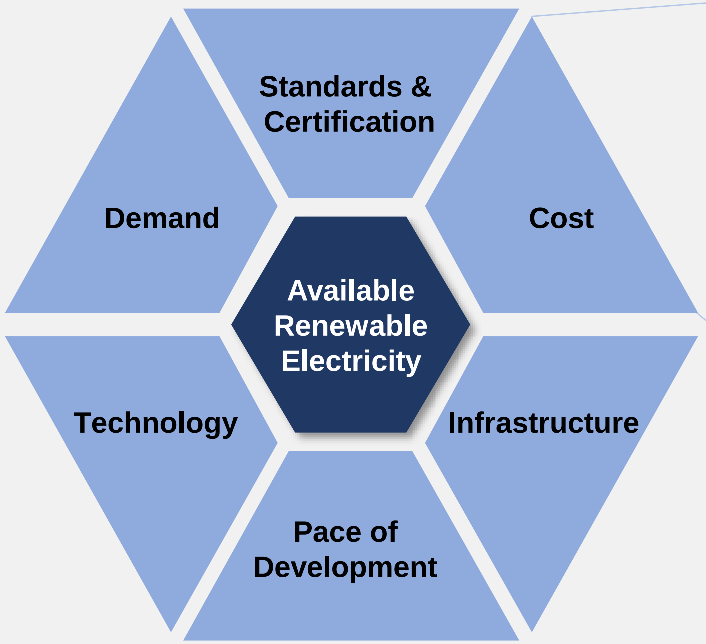
See appendix for Level 2 breakdown

Building the Roadmap framework: Enabling Measures

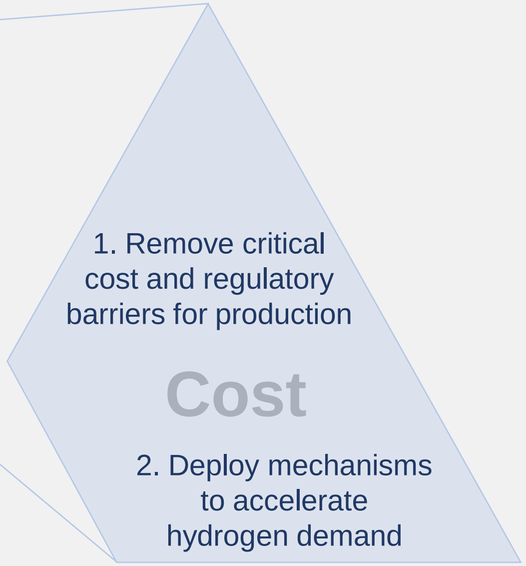
STEP 3 – Identify Objectives

STEP 4 – Identify Enabling Measures

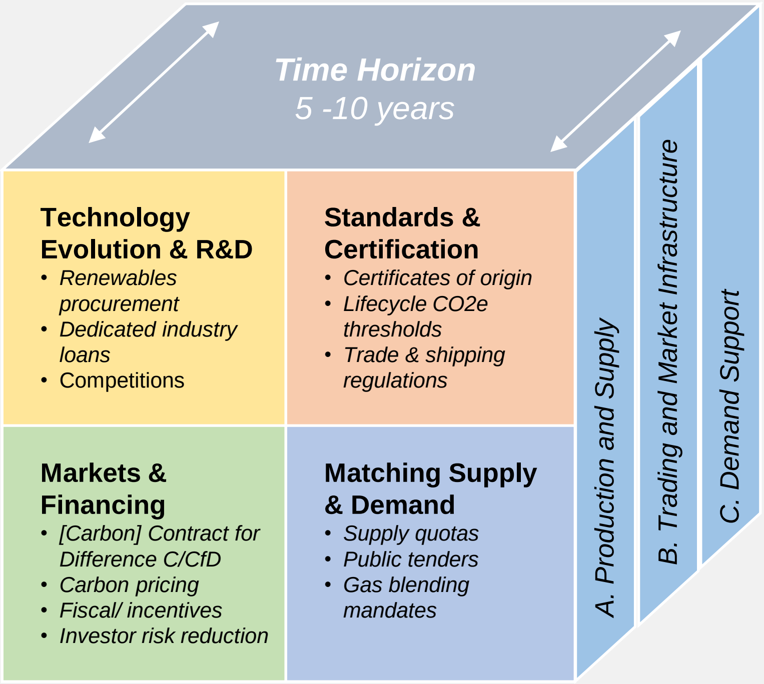
BARRIERS



OBJECTIVES



ENABLING MEASURES



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

Contents

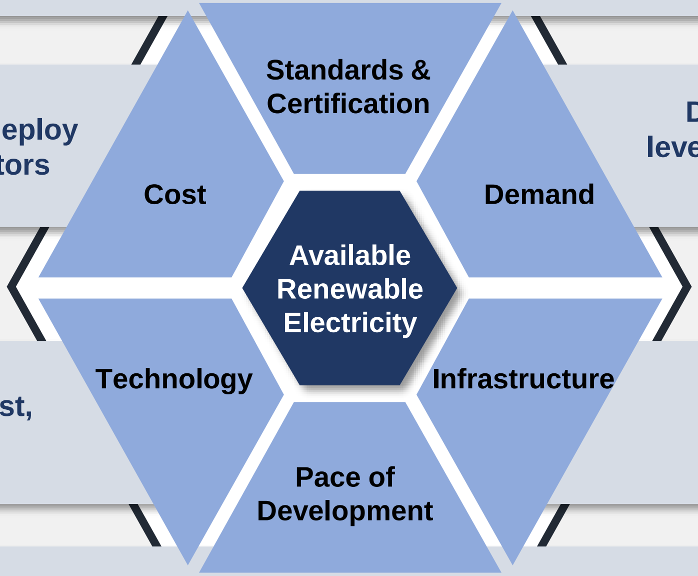
KEY: Barrier | Objectives

Key Objectives per Barrier

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

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

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



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

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

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

Available Renewable Electricity

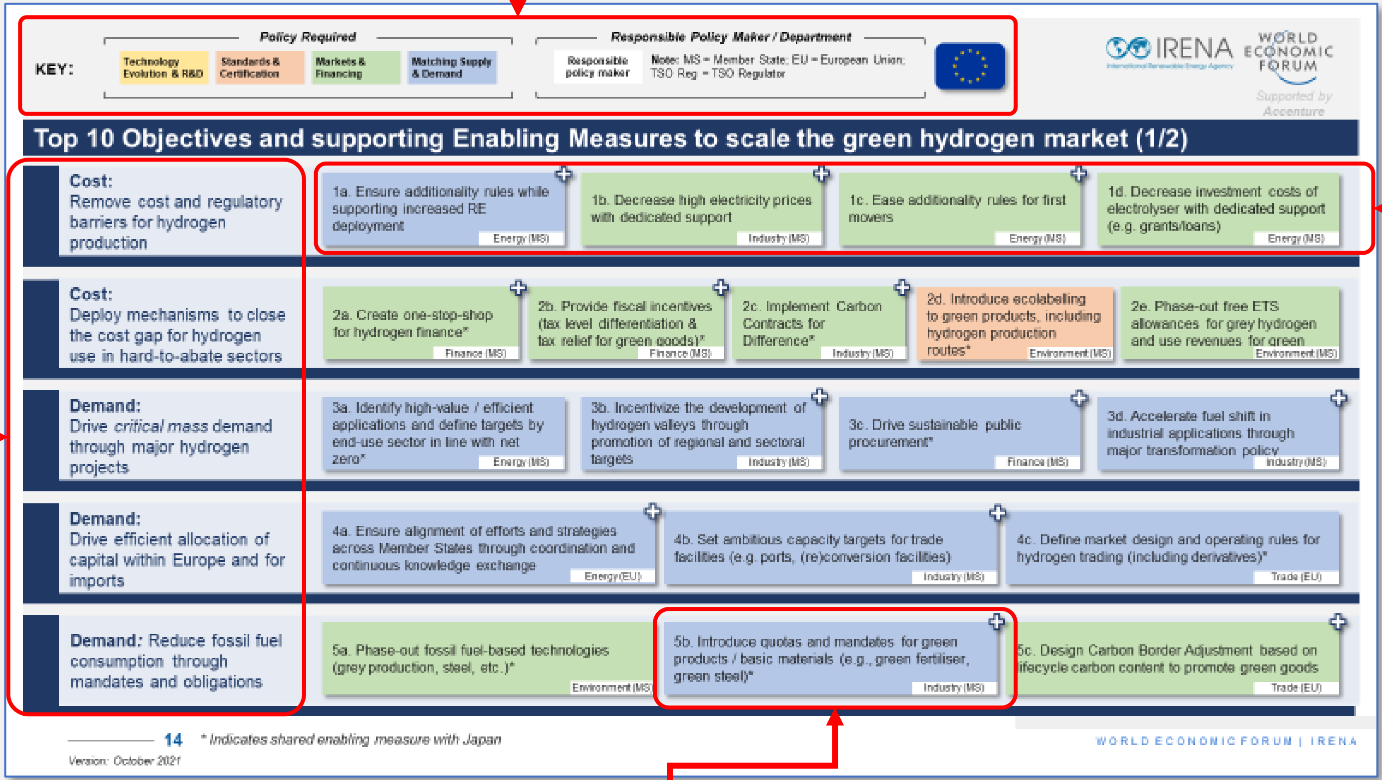
Significant ramp up and deployment of renewable generation through ambitious targets, incentives and energy system design

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)

Objective	Enabling measures				
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 electrolysers 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.

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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 specific 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. Deploy pilot projects to build experience with commercial-size facilities* — Research (EU)
- 10c. Identify possible long term supply chain bottlenecks by value chain component — Research (EU)

* Indicates shared enabling measure with Japan.

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KEY:

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

Barrier

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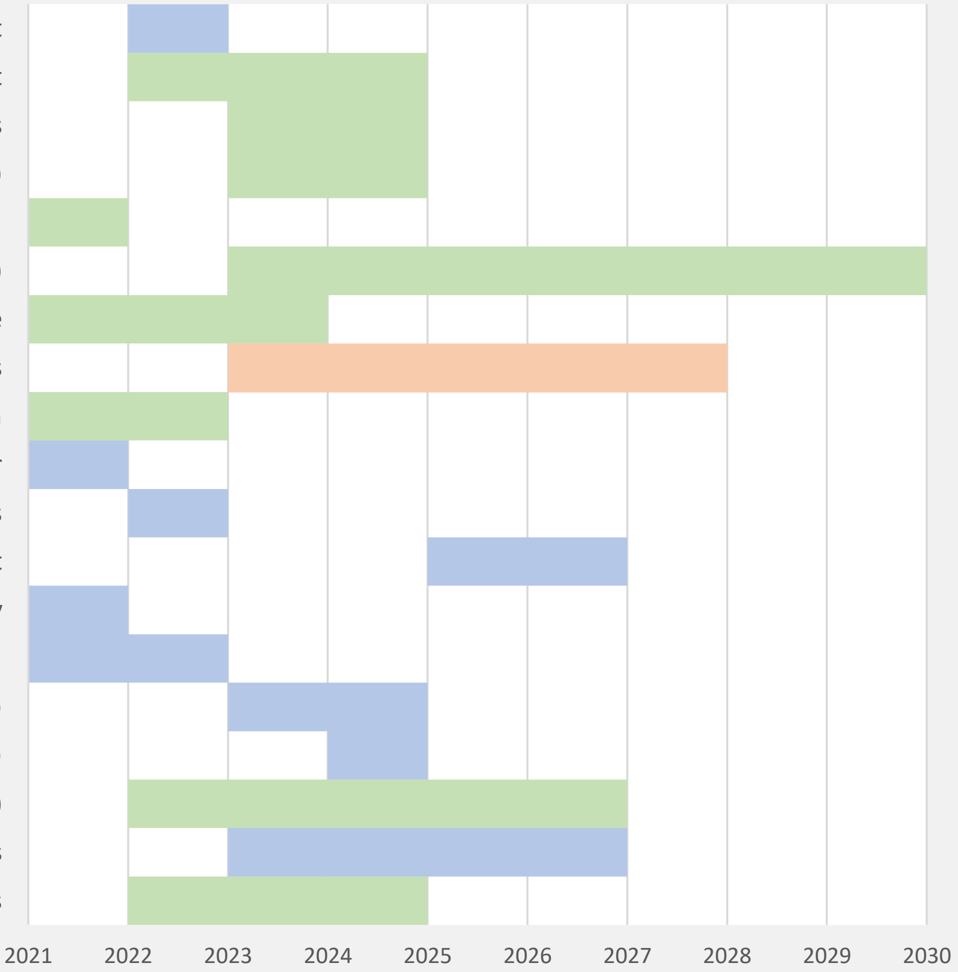
Enabling measures: target timeline for implementation (1/2)

Cost

1a. Ensure additionality rules while supporting increased RE deployment
1b. Decrease high electricity prices with dedicated support
1c. Ease additionality rules for first movers
1d. Decrease investment costs for electrolyser with dedicated support (e.g. grants/loans)
2a. Create one-stop-shop for hydrogen finance
2b. Provide fiscal incentives (tax level differentiation & tax relief for green goods)
2c. Implement Carbon Contracts for Difference
2d. Introduce ecolabelling to green products, including hydrogen production routes
2e. Phase out free ETS allowances for grey hydrogen and use revenues for green

Demand

3a. Identify high-value / efficient applications and define targets by end-use sector
3b. Incentivize the development of hydrogen valleys through regional and sectoral targets
3c. Drive sustainable public procurement
3d. Accelerate fuel shift in industrial applications through major transformation policy
4a. Ensure alignment of efforts and strategies across Member States
4b. Set ambitious capacity targets for trade facilities (e.g. ports, (re)conversion facilities)
4c. Define market design and operating rules for hydrogen trading (including derivatives)
5a. Phase out fossil fuel-based technologies (grey production, steel, etc.)
5b. Introduce quotas and mandates for hydrogen, green products, basic materials
5c. Design Carbon Border Adjustment based on lifecycle carbon content to promote green goods



KEY:

Policy Required

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

Barrier

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

Infrastructure

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

Standards & Certification

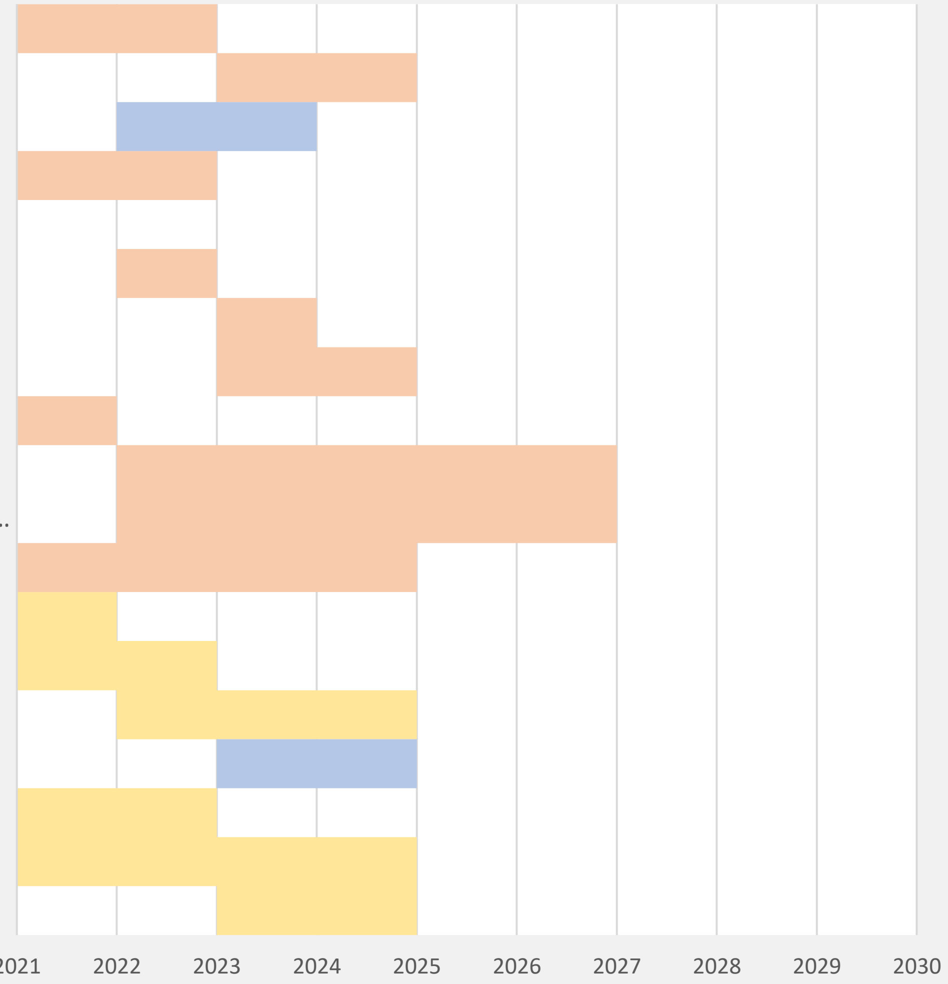
7a. Define technical standards for new parts of the value chain beyond production
7b. Define technical standards for hydrogen derivatives (e.g. ammonia, synthetic fuels)
7c. Develop safety standards for new hydrogen carriers
8a. Set clear carbon intensity definitions, thresholds, boundaries for hydrogen production
8b. Ensure Member States, EU, exporters use the same methodology and scope for carbon intensity
8c. Define carbon intensity standards for hydrogen derivatives (ammonia) and liquid…
8d. Introduce environmental externalities (water, land, etc) in the certification process

Pace of Development

9a. Set electrolyser manufacturing capacity targets
9b. Set specific targets for electrolyser components
9c. Drive automation of electrolyser production and increase raw material efficiency
9d. Identify critical skills and develop strategy to ensure availability of qualified workforce

Technology

10a. Focus R&D to improve technology performance of electrolysers
10b. Deploy pilot projects to build experience with commercial-size facilities
10c. Identify possible long term supply chain bottlenecks by value chain component



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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

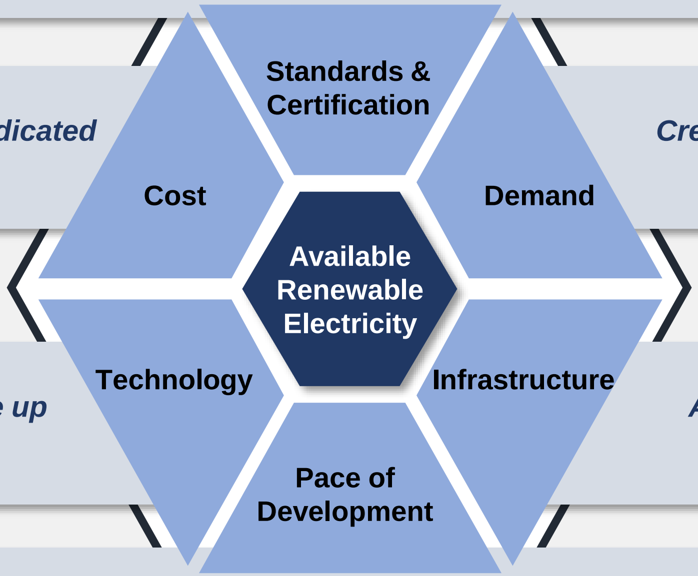
KEY: Barrier | Objectives

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

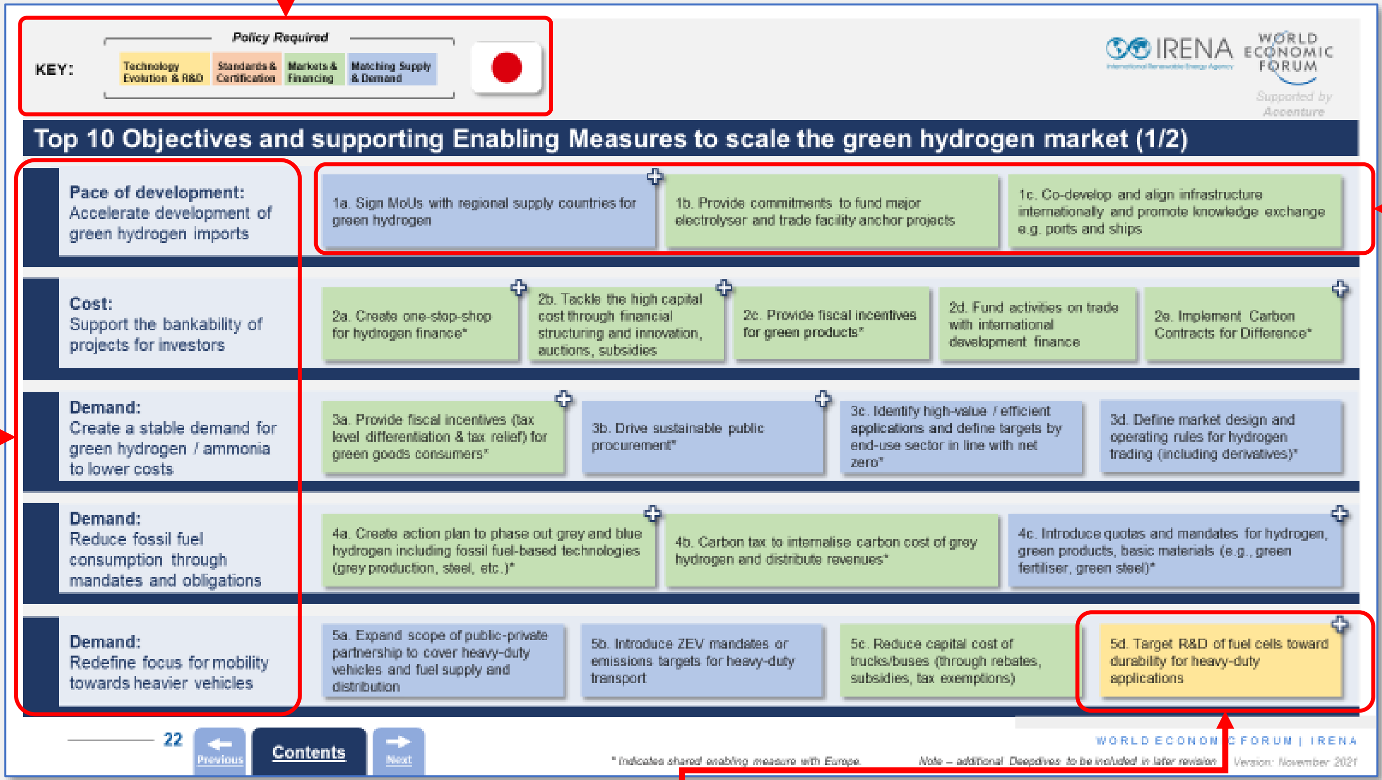
Significant ramp up and deployment of renewable generation in supply countries through ambitious targets, incentives and energy system design

Available Renewable Electricity

Navigating the Roadmap

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

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

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

Objective	Enabling Measures			
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. Decrease investment costs for electrolysers with dedicated support (e.g. grants/loans)	2c. Fund activities on trade with international development finance	2d. 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.

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. Introduce 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 to improve technologies for shipping
- 10b. R&D to reduce energy consumption of ammonia cracking / LOHC dehydrogenation
- 10c. Deploy 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.

Version: January 2022

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

Barrier	Enabling measure	Policy type	Start	End
Pace of Development	1a. Sign MoUs with regional supply countries for green hydrogen	Matching Supply & Demand	2021	2022
Pace of Development	1b. Provide commitments to fund major electrolyser and trade facility anchor projects	Markets & Financing	2021	2022
Pace of Development	1c. Co-develop and align infrastructure internationally and promote knowledge exchange	Markets & Financing	2025	2030
Cost	2a. Create one-stop-shop for hydrogen finance	Markets & Financing	2021	2022
Cost	2b. Decrease investment costs for electrolyser with dedicated support (e.g. grants/loans)	Markets & Financing	2023	2025
Cost	2c. Fund activities on trade with international development finance	Markets & Financing	2023	2030
Cost	2d. Implement Carbon Contracts for Difference	Markets & Financing	2021	2024
Demand	3a. Provide fiscal incentives (tax level differentiation & tax relief) for green goods consumers	Markets & Financing	2023	2028
Demand	3b. Drive sustainable public procurement	Matching Supply & Demand	2025	2027
Demand	3c. Identify high-value / efficient applications and define targets by end-use sector	Matching Supply & Demand	2021	2022
Demand	3d. Define market design and operating rules for hydrogen trading (including derivatives)	Matching Supply & Demand	2024	2025
Demand	4a. Create action plan to phase out grey and blue hydrogen including fossil fuel-based technologies	Markets & Financing	2022	2024
Demand	4b. Carbon tax to internalise carbon cost of grey hydrogen and distribute revenues	Markets & Financing	2021	2023
Demand	4c. Introduce quotas and mandates for hydrogen, green products, basic materials	Matching Supply & Demand	2023	2027
Demand	5a. Expand scope of public-private partnership to cover heavy-duty vehicles	Matching Supply & Demand	2021	2022
Demand	5b. Introduce ZEV mandates or emissions targets for heavy-duty transport	Matching Supply & Demand	2021	2022
Demand	5c. Reduce capital cost of trucks/buses (through rebates, subsidies, tax exemptions)	Markets & Financing	2023	2027
Demand	5d. Target R&D of fuel cells toward durability for heavy-duty applications	Technology Evolution & R&D	2022	2023

KEY:

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

Barrier

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

Standards & Certification

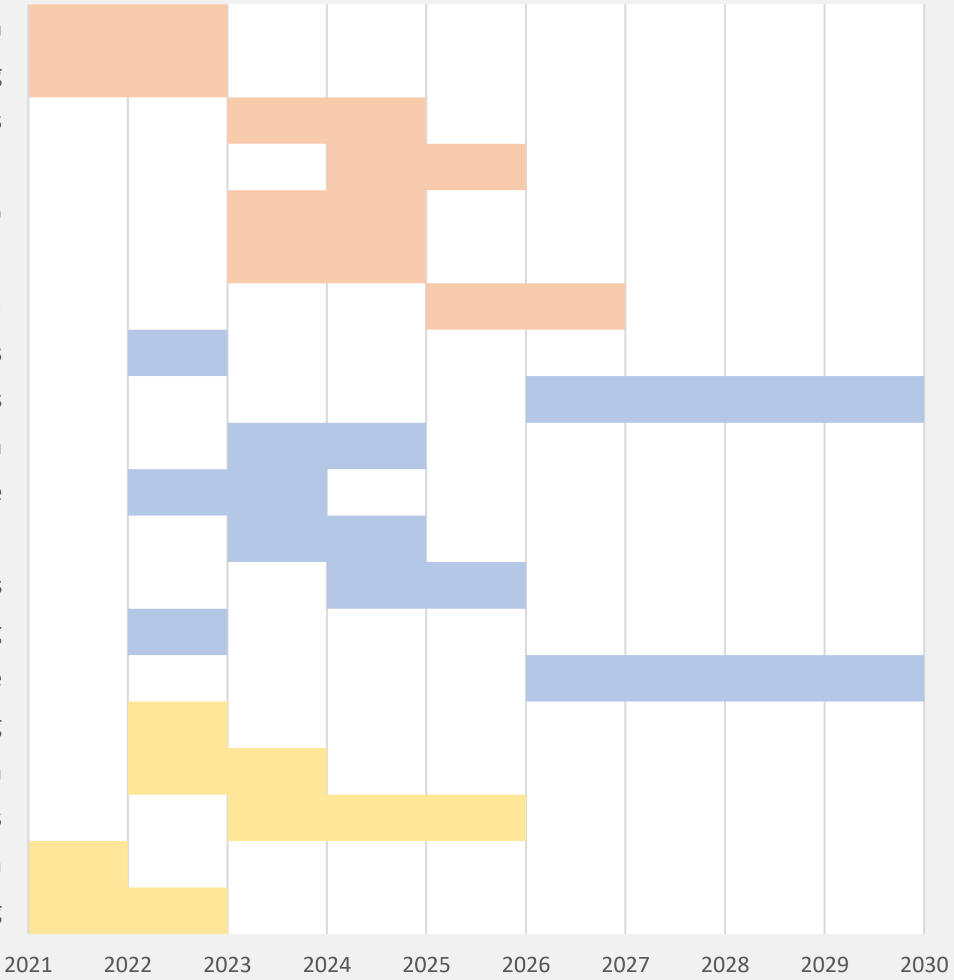
6a. Set clear carbon intensity definitions, thresholds, boundaries for hydrogen production
6b. Drive carbon intensity metrics across all industries and embed metrics in policy making
6c. Extend ecolabelling to green products, including hydrogen production routes
7a. Define technical standards for new parts of the value chain beyond production
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

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
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 development for terminals, tanks, trading
9e. Introduce capacity payments to support ramp up of infrastructure

Technology

10a. Develop moon-shot programme to improve technologies for shipping
10b. R&D to reduce energy consumption of ammonia cracking / LOHC dehydrogenation
10c. Deploy 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



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.

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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
- IRENA's Project Navigator is an analogous tool for renewable projects

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Fund activities on trade with international development finance

Description: Collaborate with international institutions to provide financing mechanisms that reduce the cost of capital for hydrogen projects and achieve national goals

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

Key actions:
- Engage with export credit agencies (ECA) and development finance institutions (DFI) in major projects developments.
- Support ECA's and DFI's ability to provide innovative low-cost finance across the value chain.
- Collaborate with financial players during research or pilot phases to develop industry knowledge of project risk profiles.
- Allocate specific funding to invest in international hydrogen projects for import-export.

Ongoing work and examples:
- Shearman and Sterling report – Japan Bank for International Cooperation (JBIC) Act was amended in January 2020 to enable JBIC to offer a range of financial products in support of its clients' upstream, midstream and downstream hydrogen and low-carbon ammonia projects
- The Development Bank of Japan has boosted target to focus on ESG investing including hydrogen

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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 from additional payments designed for decarbonisation of the power system.
- Incorporate spatial and temporal correlation between renewable energy generation and green hydrogen production as parameters to be tracked in the certification schemes (not necessary for off-grid 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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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 first movers, adopt transitional measures regarding temporal and spatial correlation requirements between renewable electricity and hydrogen 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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Introduce ecolabelling to green products, including hydrogen production routes

Description: An ecolabel shows the environmental information of products through life cycle stages e.g. from the extraction of resources to manufacturing, assembly, distribution, use, discarding and recycling

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

Key actions:

- Introduce or assist the introduction of systems to collect data and track products to inform the public of the quality and sustainability of production.
- Enlarge or assist the enlargement of the current scope of ecolabels to include green hydrogen routes.
- Use ecolabels for recognition of support schemes (product-based instruments, sustainable public procurement) or to inform consumers.

Ongoing work and examples:

- National governments in Europe, such as Germany and United Kingdom, recognize that in order to kickstart demand-side policies supporting green goods, ecolabels will be necessary and are taking steps to implement them.
- The Ecoleaf (Japan) program was fully implemented in 2002 as a way of promoting an eco-conscious lifestyle among the Japanese populace through environmentally friendly goods and services. The label already certifies steel.
- Standards covering sustainability and lifecycle GHG emissions: ResponsibleSteel standard, World Steel Association lifecycle inventory methodology, ISO 20915

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Decrease investment costs for electrolysers with dedicated support (e.g. grants/loans)

Description: Electrolyser manufacturing volumes and sizes are still small resulting in high costs. Measures are needed to compensate the high capital cost during the initial phase until global capacity increases

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

Key actions:

- Establish dedicated funds or credit lines for hydrogen or specify explicit shares for hydrogen from broader economic and innovation packages.
- Provide concessional loans with favourable conditions (e.g. grace period, interest rate, payback period) for water electrolysis.
- Consider the use of convertible grants and loans to reduce the project risks.
- Provide support for project execution to decrease the construction costs.
- Promote knowledge exchange among financial institutions to facilitate understanding of project risks and mitigation measures.

Ongoing work and examples:

- IPCEI projects in Germany (supporting 2 GW of electrolysis) and the Netherlands (supporting 2.2 GW by 2025 and 4.6 GW by 2030).
- Dedicated funds from the Infrastructure Bill in the US.
- Energy Aid Program in Finland supports up to 40% of the electrolyser investment.
- National Innovation Program Hydrogen and Fuel Cell Technology in Germany provides up to 45% funding for electrolysis projects.
- 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 electrolyser size of at least 100 MW, enabling the construction of up to 500 MW.

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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 can be co-located or with several large hydrogen users.
- Bring together key industry players and policy makers to co-develop a regional strategy.
- Assess appropriate technologies for decarbonisation including Hydrogen, CCUS, system efficiency and circular economy.
- Include system value elements (e.g. jobs) beyond cost for the regional area.
- Define and agree targets and actions 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 hubs
- 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 including case studies e.g. Zero Carbon Humber

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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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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:
- Assess the impact of quotas on global competitiveness and profitability and identify measures to reduce impact.
- 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).
- Ensure the scope of the certification scheme is broadened in tandem to the commodities covered under the quotas.

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.
- Experience on quota is for now gathered in particular in the transport sector:
    - Update of the Renewable Energy Directive (EU) from July 2021 proposes 50% of renewable fuels of non-biological origin in industry by 2030.
    - RefuelEU Aviation (a proposed regulation in the EU) proposes explicit targets for sustainable aviation fuels and synthetic fuels from hydrogen from 2025 to 2050.

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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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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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Define market design and operating rules for hydrogen trading (including derivatives)

Description: Definition and implementation of practical market rules and infrastructure to support price formation, transparency, and liquidity

Barrier Level 1: Demand	**Barrier Level 2:** Availability of supply

Key actions:
- Support the development of intra-cluster matching services for hydrogen supply and demand including corresponding physical infrastructure.
- Develop a regulatory sandbox for hydrogen islands to trade internally to accelerate the development of a liquid market as infrastructure if built.
- Drive the creation of an index for price transparency working with market players and anchor projects for a trading hub that includes storage, quality conversion and marketability without barriers.
- Ensure commodity standardisation (quality, carbon intensity, final product, blending)
- Design and implement a digitally-enabled market with secured verification and transaction system, supported by guarantees of origin.

Ongoing work and examples:
- Deutsche Boerse's EEX to launch hydrogen index in 2022 which would be the first publicly-traded index tracking hydrogen as a commodity.
- EEX are running a hydrogen trading working group to accelerate trading and support the ramp up of the hydrogen economy. To date the working group is focused on transparency, indices and benchmarks.
- S&P Platts hydrogen pricing includes 10 US prices, Canadian, the Netherlands, Japan and the UK prices for blue and green hydrogen production routes.

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Identify high-value / efficient applications and define targets by end-use sector in line with net zero

Description: Assessment of hydrogen versus competing technologies (e.g. electrification) to ensure efficient choice of technology followed with definition of clear targets for implementation

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

Key actions:
- Assess the role of hydrogen within the domestic context (e.g. renewable resources, the maturity of its energy sector, the current level of economic competitiveness and the potential socio-economic effects).
- Consider a broad range of decarbonization alternatives (e.g. bioenergy, circular economy) to ensure that the role of hydrogen is not overestimated.
- Use System Value Analysis to inform technology choice.
- Identify "no-regret" cluster of end uses for which green hydrogen can give the larger and more immediate benefits.

Ongoing work and examples:
- National strategies like the Spanish, the German and the Portuguese ones identify industry as a critical sector for hydrogen.
- Multiple studies identified no-regret clusters. e.g. Agora Energiewende.
- Impact Assessment from the Fit for 55 package in the EU identifying hydrogen as essential for heavy industry and long-haul transport.
- The World Economic Forum has developed a holistic framework that evaluates economic, environmental, social, and technical outcomes of potential energy solutions called System Value Analysis.

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Phase out free ETS allowances for grey hydrogen and use revenues for green / Carbon tax to internalise carbon cost of grey hydrogen and distribute revenues

Description: Introduce a carbon tax (or broaden current scope) to include hydrogen production and use associated revenues to finance clean hydrogen

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

Key actions:
- Gradually reduce exemptions and allowances that do not expose grey hydrogen production to carbon prices.
- Alternatively, introduce a carbon tax that recognizes the externalities of grey hydrogen production.
- Provide visibility (either through volume-based or price-based targets) on the long-term carbon prices to improve certainty for investors and reduce project risk.
- Identify solutions (e.g. CCfDs) to distribute the revenues to green hydrogen producers or users.

Ongoing work and examples:
- The ETS system is already in place in Europe and has been revised in 2021.
- The "Fit for 55" package aims to further increase the share of EU emissions within a regulated trading system.
- The Netherlands plans to introduce an industrial carbon levy on every ton of CO_2 emitted exceeding a fixed reduction path in 2021 for major emissions sources in the industrial sector to complement the EU ETS and achieve a certain carbon price.
- 13 of the 17 major ETS cover industry and the scope could be adjusted to ensure hydrogen production is included and that free allowances are phased out.

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Expand scope of public-private partnership to cover heavy-duty vehicles and fuel supply and distribution

Description: There are multiple partnerships around the world that arose in previous interest cycles of hydrogen and still are targeted towards cars rather than trucks

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

Key actions:
- Expand the membership of partnerships to include relevant stakeholders (e.g. truck manufacturers) to cover heavy-duty applications.
- Ensure structure of the partnership is suitable for heavy-duty applications by creating new dedicated working groups.
- Adapt the targets of the partnership (e.g. target of vehicles deployed) to include heavy-duty applications.
- Provide a mechanism or process to incorporate feedback from partnership into incentives and targets for heavy-duty applications.

Ongoing work and examples:
- Multiple partnerships focusing on cars could expand or shift the scope to trucks including Japan Hydrogen Mobility, California Fuel Cell Partnership, Nordic Hydrogen Partnership, Hydrogen Mobility initiatives in the UK, the Netherlands and Switzerland, HyNet in South Korea, Clean Energy Partnership in Germany.
- Million Mile Fuel Cell Truck consortium in the US.
- European Clean Trucking Alliance in the EU to shift away from fossil fuels in vans and trucks (supported by public organisations).

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Introduce ZEV mandates or emissions targets for heavy-duty transport

Description: An indication of phase-out of fossil-based vehicles through mandates or CO_2 standards provides a clear signal and certainty to truck manufacturers accelerating the adoption of zero-emission vehicles

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

Key actions:
- Set at least one of: (1) Phase-out year for fossil fuels in trucks and buses; (2) CO_2 standards that reach zero; (3) Share of sales target for net zero vehicles.
- Introduce incentives for infrastructure, fuel supply, network expansion and capital cost in parallel.
- Update research plan and targets to enable the improvement in fuel cell performance in line with timeline of ZEV uptake.
- Put in place a platform to bring together truck manufacturers, fuel suppliers, infrastructure and refuelling stations.

Ongoing work and examples:
- Clean Truck Regulation in California targeting phase-out by 2045.
- Mobility Master Plan 2030 (Austria) targets 100% ZEV sales for HD trucks by 2035.
- Electric Mobility Policy Charter from Cape Verde targeting 100% zero-emission medium and heavy-duty trucks sales by 2035 and ZEV stock by 2050.
- Other (sub-national) jurisdictions are considering ZEV targets for trucks.
- MoU (during COP26) for 15 countries working together on 100% ZEV sales by 2040.

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Reduce capital cost of trucks/buses (through rebates, subsidies, tax exemptions)

Description: Incentives are needed to close the gap between fossil and FCEV trucks and buses due to the current low manufacturing volumes of fuel cells.

Barrier Level 1: Demand | **Barrier Level 2:** Lack of downstream support

Key actions:
- Relate fuel cell cost targets in the research agenda to specific duty cycles (e.g. hours of use) and performance point (e.g. voltage).
- Establish targets for fuel cell manufacturing capacity in line with fuel cell cost targets.
- Introduce purchase subsidies for trucks and buses and specify from the outset the guidelines for phase-out (e.g. number of trucks, purchase cost level, cost differential with respect to diesel trucks).
- Exempt (temporarily) of custom tariffs for manufacturing fuel cells or sales tax for sales of trucks.

Ongoing work and examples:
- Purchase subsidies for fuel cell buses in 12 European countries and for trucks in 10.
- UK. Subsidies of 75% of the CAPEX difference between FCEV bus and EuroV1 diesel bus and up to 20% (or 18.7 kEUR) for heavy-duty vehicles.
- Austria. Maximum subsidy of 130 kEUR for buses with max passengers of 120 and up to 50 kEUR for trucks above 12 tonnes.
- France. Subsidies of 50k EUR for heavy-duty vehicles and 30k EUR for buses.
- Sweden. 10% subsidy for buses and 20% for heavy-duty trucks.
- Ireland. Subsidies of 40-60% of the price difference for HDVs and buses.

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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. Hydrogen is not included in the list of industries exposed to carbon leakage but steel, fertlisers and chemicals are.
- 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.
- South Korea has a plan to develop infrastructure including liquefaction and liquid technology, hydrogen transportation vessel, and liquefaction plants in 2022.

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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

Deploy pilot projects to build experience with commercial-size facilities

Description: Sharing learnings from pilots in order to accelerate the scale up to commercial size facilities with significant scale

Barrier Level 1: Technology	**Barrier Level 2:** De-risking new industrial applications

Key actions:
- Develop hydrogen pilots across the value chain through innovation consortia.
- Ensure consortia are supported by sufficient government R&D and innovation funding.
- Ensure project learnings are shared through international groups such as FCH-JU, Missions Innovation etc.
- Invite finance players to monitor R&D progress to support project de-risking for commercial-scale facilities and enabling greater industry learning.
- Ensure sharing learnings is part of existing hydrogen partnerships either through dedicated working groups or within the existing organizational structure.

Ongoing work and examples:
- Mission Innovation members are required share members accessible summaries of their respective clean hydrogen research, development and demonstration efforts.
- The European Hydrogen Week led by the FCH-JU brings together European industry, policy makers, government representatives as well as the research community to discuss and steer the increased potential for clean hydrogen.
- The US DOE hold and Annual Merit Review (AMR) where hydrogen and fuel cell projects funded by DOE are presented, and projects and programs are reviewed for their merit.

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Identify possible long term supply chain bottlenecks by value chain component

Description: Take a long-term view on potential supply chain bottlenecks, developing scenarios and taking early preventative measures where required

Barrier Level 1: Technology	**Barrier Level 2:** De-risking new industrial applications

Key actions:
- Break down hydrogen value chain to identify core supply chain elements.
- Work with industry bodies across the value chain to assess manufacturing ramp up, skills and material requirements.
- Identify stakeholders or industry players with significant knowledge capital and roles.
- Develop scenarios for manufacturing competitiveness and potential bottlenecks in the supply chain.
- Stand up working group to continually assess challenges as the hydrogen market matures and execute recommendations to support industry.

Ongoing work and examples:
- The European Union's FCH-JU has mapped out the key industrial actors, knowledge centres, value chain and manufacturing competitiveness to provide key recommendations to support the scale up of hydrogen.
- The European Clean Hydrogen Alliance is meant to coordinate efforts at a European level to ensure competitiveness, development of the domestic industrial capacities and ensure technological leadership.

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Enabling Measures Deepdive

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

Develop moon-shot programme to improve technologies for shipping

Description: Hydrogen shipping is not done at commercial scale today and R&D is needed to improve the technologies and identify the conditions that favour each carrier

Barrier Level 1: Technology	**Barrier Level 2:** Technology Readiness

Key actions:

- Consult industry and academia to identify short- and long-term targets for hydrogen transportation pathways and associated technologies (e.g. conversion to carriers).
- Launch *'moon-shot'* programme for hydrogen (or derivatives) transportation via shipping with clear targets.
- Coordinate efforts globally and learn from early deployment.
- Support innovation through industry competitions and R&D funding.
- Track transportation technology cost reduction and efficiency at set intervals of time and share with industry.

Ongoing work and examples:

- US Department of Energy hydrogen *Earth Shot* initiative to accelerate breakthrough technologies to reach $1/kg in a decade ("1 1 1").
- The UK government provides a principles for science and technology *moon-shot* programme.
- Japan has a moon-shot programme that promotes high-risk, high-impact R&D aiming to achieve ambitious moon-shot Goals and solve issues facing future society such as super-aging populations and global warming.
- The shipping industry has a moon-shot programme to decarbonise.

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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 green hydrogen sustainability.
- Make a clear distinction between sustainability criteria (quantitative) and labels (qualitative) ensuring transparency.
- 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

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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

Define technical standards for new parts of the value chain beyond production (transportation, storage, conversion)

Description: Agreement on the technical standards in the new and emerging parts of the hydrogen value chain

Barrier Level 1: Standards & Certification	**Barrier Level 2:** Standardisation (design, safety, etc.)

Key actions:
- Engage with end-use organisations to create standards for hydrogen within industrial use cases along the value chain. (e.g. operating pressures for the transportation of hydrogen, operating conditions for the storage of hydrogen
- Work with standardisation bodies to form technical committees and create technical standards, ensuring that these standards are compatible and interoperable at an international level.

Ongoing work and examples:
- Working group on Regulation, Codes, Standards and Safety from IPHE.
- Standards database from the Fuel Cells and Hydrogen Observatory for each part of the value chain.
- CEN/CENELEC Sector Forum Energy Management – Working Group on Hydrogen covering Pre-Normative Research and R&D needs.
- ISO, IEC, CEN, CENELEC, OIML, SAE, NFPA all have Technical Committees working on hydrogen topics.
- Codes and standards databases from the US DoE (EERE) and the Fuel Cell and Hydrogen Energy Association (FCHEA) for the US

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Define technical standards for hydrogen derivatives (e.g. ammonia, synthetic fuels)

Description: Agreement on the technical standards for hydrogen, hydrogen carriers, and hydrogen derivatives

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

Key actions:
- Engage with end-use organisations to create standards for hydrogen and hydrogen derivatives within industrial cases (e.g. quality of hydrogen derivatives, etc.).
- Work with standardisation bodies to form technical committees and create technical standards, ensuring that these standards are compatible and interoperable at an international level.

Ongoing work and examples:
- ISO/ TC 47 is working on standardisation in the field of the chemical industry, working groups like these can be expanded to hydrogen derivatives.
- ISO 71.060.99 – Other Inorganic Chemicals (covers Liquefied anhydrous ammonia for industrial use).
- ICAO Global Framework for Aviation and Alternative Fuels (GFAAF).

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Enabling Measures Deepdive

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

Define carbon intensity standards for hydrogen derivatives (ammonia) and liquid hydrogen

Description: Agreement on the carbon intensity standards for hydrogen and hydrogen carriers

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

Key actions:
- Establish clarity on Life Cycle Assessment (LCA) and carbon emission standards for new parts of the hydrogen value chain, to minimise carbon leakage.
- Align certification standards and practices and make them interoperable.
- Establish carbon accounting frameworks that take into account the hydrogen value chain. (e.g. Scope 1 and 2 emissions).

Ongoing work and examples:
- IPHE is expanding their Working Paper Methodology for Determining Greenhouse Gas Emissions to cover hydrogen and hydrogen derivatives.
- Key stakeholders are national and international standardisation bodies.
- Regulatory bodies and enforcement bodies within countries.
- Australia has proposed using the 'well-to-gate' carbon accounting methodology for its Guarantee of Origin scheme.

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Introduce environmental externalities (water, land, etc) in the certification process

Description: Extension of certification schemes beyond the carbon intensity of hydrogen production to additional environment impact categories

Barrier Level 1: Standards & Certification	**Barrier Level 2:** Lack of clarity on environmental impact beyond GHG

Key actions:
- Introduce in legislation sustainability requirements that go beyond additionality and direct GHG reduction, this can include:
  - GHG emissions due to indirect activities in the value chain,
  - Local socio-economic impact of water, electricity and land use
- Identify metrics to measures such requirements, ensuring their applicability and comparability across all hydrogen production forms.
- Assist certification bodies to add metrics in the certification scheme.

Ongoing work and examples:
- IPHE driving clarity on international standards for production and transport.
- Australia's guarantees of origin proposal include the later expansion metrics to include the water consumption and other factors.
- The Green Hydrogen Standard that the Green Hydrogen Organisation is planning to develop will include Environmental, Social, and Governance (ESG) impacts and alignment with Sustainable Development Goals (SDG).

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Enabling Measures Deepdive

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

Develop safety standards for new hydrogen carriers

Description: Agreement on the safety standards for hydrogen and hydrogen carriers such as liquid hydrogen, ammonia and liquid organise hydrogen carriers

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

Key actions:
- Invest and fund the research and development of safety standards for new hydrogen carriers.
- Expand and disseminate lessons learned and safety standards from pre-existing ammonia, methanol industries.
- Adapt existing transportation and storage conversion standards from natural gas to suit the hydrogen value chain.
- Create repositories and tools to log, track, and learn from safety incidents.

Ongoing work and examples:
- Key stakeholders are national and international standardisation bodies.
- Ongoing work include the formation of Technical Committees within standardisation bodies such as ISO, CEN, IEC, etc.
- H2Tools supported by the US DOE is a portal is to support implementation of the practices and procedures that will ensure safety in the handling and use of hydrogen in a variety of fuel cell applications.
- ANSI/ AIAA G-095 – Guide to Safety of Hydrogen and Hydrogen Systems.
- Directive 2014/34/EU of the European Parliament and of the Council - Equipment and protective systems intended for use in potentially explosive atmospheres.

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Ensure tradability and consistency of certificates across energy carriers (e.g. gas, electricity)

Description: With multiple hydrogen carriers such a ammonia, liquid hydrogen and liquid organic hydrogen carriers physical and non-physical attributes need to be aligned to ensure tradability

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

Key actions:
- Create standards for hydrogen and hydrogen derivatives for consistency and tradability (e.g. quality of hydrogen derivatives, etc.).
- Create design principles to align industrial standards and practices and make them interoperable and tradable.
- Engage with end-use organisations to create standards for hydrogen and hydrogen derivatives within industrial use cases along the value chain to ensure tradability. (e.g. operating pressures for the transportation of hydrogen, operating pressures for the storage of hydrogen, operating temperature of hydrogen, etc.).

Ongoing work and examples:
- Key stakeholders are national and international standardisation bodies.
- Ongoing work include the formation of Technical Committees within standardisation bodies such as ISO, IEC, JISC, JSA, etc.
- High Pressure Gas Safety Act in Japan
- The Ministry of Economy, Trade, and Industry (METI) are pushing for consistent regulations for hydrogen refuelling stations in Japan.

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Enabling Measures Deepdive

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

Drive carbon intensity metrics across all industries and embed carbon intensity metrics in line with a net-zero scenario within policy making

Description: Carbon intensity metrics define GHG emissions for processes and products and are required to track progress for carbon reduction

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

Key actions:
- Change language to focus on holistic carbon intensity reduction to avoid mere hydrogen-switching buzzwords.
- Kickstart in depth analysis of the emissions of each sector and the potential reduction and costs from all decarbonisation solution to identify the best solution for each sector.
- Drive the development of minimum criteria for of green materials and green goods to achieve a net-zero energy system.
- Refocus policy making aiming to reduce direct and indirect GHG emissions across the whole value chain (e.g.: prioritizing the public procurement of green products)

Ongoing work and examples:
- The EU national energy and climate plans (NECPs) outline how the EU countries intend to address the challenges of decarbonization holistically across all sectors.
- Netherlands SDE++ Scheme provides support to decarbonisation technologies based on their CO2 emission reduction potential.
- The UK industrial decarbonization strategy recognise the role of the government to drive change and compress emissions, providing technological solution for various industrial sectors, and proposing a combined use of ecolabelling, SPP and buyer support.

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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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Enabling Measures Deepdive

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

Clarify governance of the hydrogen transmission network

Description: Introduction hydrogen into existing gas networks will required changes and innovation to existing regulation

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

Key actions:
- Considering hydrogen networks as natural monopoly, clarify the regulatory principles as soon as possible to provide clarity on who and how will regulate the access to the grid.
- Implement rules for a gradual approach to the regulation of hydrogen infrastructure following market evolution
- Consider relaxed rules for initial, business to business, grids
- Monitor market evolution, to maintain fair access and avoid abuse of positional advantage.

Ongoing work and examples:
- ACER, the European Agency for the cooperation of Energy Regulators, provides guidance on the governance of the power and gas grid, with initial work on the hydrogen grid as well.
- Germany's government has approved in early 2021 a legislation regulating the hydrogen infrastructure. Gas and hydrogen infrastructure will be regulated separately, meaning that current grid fees will not automatically apply to hydrogen projects. In November 2021 Germany set the first in the world rate-based regulation on returns to investments in hydrogen grids.

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Set up a flexible regulatory framework with quality standards and definitions

Description: A flexible regulatory framework allows regulation to evolve over time as the industry matures as opposed to be set from the outset becoming a market blocker

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

Key actions:
- Implement the use of regulatory sandboxes to enable businesses to work with policymakers to develop new business models. Sandboxes allow the testing of ideas where existing legal or regulatory frameworks are restrictive for yet to exist.
- Implementation of regulatory sandboxes facilitate the establishment of early pilot and feasibility hydrogen projects whilst also help the development of future regulations.
- Establish funding to support early hydrogen pilot and feasibility projects and attract investor capital.

Ongoing work and examples:
- Key stakeholders are governments and ministries who must create these sandbox programs.
- Investors and businesses need also to be directly involved in the creation of early pilot and feasibility projects.
- Germany's BMWi has established 'flexibility' and 'experimentation' clauses in legislative texts and established projects under the Regulatory Sandboxes.
- The Energie.Frei.Raum (Austria) establishes the framework to develop sandboxes for the system integration of renewable energy sources, storage and energy efficiency technologies.

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

Integrate long-term planning of hydrogen, power and gas infrastructure

Description: Long term planning is required to ensure physical infrastructure across different existing industries aligns to create an efficiency holistic energy system

Barrier Level 1: Infrastructure | **Barrier Level 2:** Infrastructure uncertainty

Key actions:
- Plan and model the energy and hydrogen requirements for their future energy landscape.
- Recognise the minimum hydrogen infrastructure necessary to satisfy future energy and hydrogen requirements.
- Plan necessary hydrogen infrastructure that is required for the fulfilment of national energy and national hydrogen strategy. Strategies that have hydrogen targets will require 'no-regret' infrastructure to be built. (e.g. Ports, transmission stations, pipelines, etc.).

Ongoing work and examples:
- Governments Ministries and Departments will be responsible for the long term planning of the energy needs of their countries. This will involve the planning of 'no-regret' infrastructure.
- Governments will need to work with industry and TSO to plan and build 'no-regret' infrastructure.
- The Port of Rotterdam and the Port of Hamburg are also developing hydrogen hubs and terminals, consistent with their national hydrogen strategies and need for 'no-regret' infrastructure.

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Specify interoperable quality standards and definitions

Description: Create quality standards and definitions that allow for hydrogen infrastructure to be interoperable and compatible within and between countries.

Barrier Level 1: Infrastructure | **Barrier Level 2:** Infrastructure uncertainty

Key actions:
- Engage with end-use organisations to create standards for hydrogen and hydrogen infrastructure along the transportation and end-use value chain. (e.g. Minimum steel pipeline size, operating pressures for the transportation of hydrogen, operating pressures for the storage of hydrogen, operating temperature of hydrogen, etc.)
- Quality standards and definitions need to take into account hydrogen blending pathways as well.
- Work with standardisation bodies to form technical committees and create technical standards, ensuring that these standards should be compatible and interoperable at an EU and international level.

Ongoing work and examples:
- The German Gas and Water Association (DVGW) is leading work such as H2 Vor Ort and other Hydrogen Research Projects to ensure quality standards for use of hydrogen in the German gas grid.
- The European Hydrogen Backbone is a group of 23 gas infrastructure companies planning hydrogen transport infrastructure.

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Introduce capacity payments to support ramp-up of infrastructure

Description: Capacity payments support the cost of oversizing of infrastructure built today to ensure that it is suitable for future demand and use

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

Key actions:

- Evaluate the cost of hydrogen infrastructure, considering capital and finance costs under different assumption.
- Design capacity payment mechanisms seeking to ensure that there will be sufficient infrastructure in place to meet future trade reliably.
- Evaluate payment for capacity paid based on the loss probability in case the infrastructure capacity is not present when needed.
- Evaluate metrics to establish when capacity payments would not be anymore necessary.

Ongoing work and examples:

- Capacity mechanisms are not common for the gas grids but are common in the EU power systems. Lesson learnt can be replicated.
- The mechanism ensure the payment is proportionate to the underlying adequacy problems.
- Capacity payment are also based on the calculation of future supply-demand scenarios.

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Incentivize the aggregation of demand in hydrogen valleys

Description: Aggregating demand in hydrogen valleys supports production off take agreements by providing scale

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

Key actions:

- Support the building of demand centre consortia and define individual process for assessing future demand by industry.
- Drive for commitment of major players in the cluster to ensure base case anchor hydrogen demand at set intervals of time.
- Engage production centres to match supply and demand within the applicable time frames and phases for the engaged organisations.
- Build operating model framework for the consortium to interact as *one buyer* of hydrogen to accelerate off-take agreements.

Ongoing work and examples:

- Target of 100 hydrogen valleys by 2030 to reduce delivered costs to USD 2/kg by 2030 (Mission Innovation).
- The Chubu Hydrogen Utilization Study Group aggregates hydrogen demand from the Chubu region in Japan between 11 companies providing estimates overtime and by industry breakdown.
- The UK government is incentivising the aggregation of hydrogen demand through its industry clusters innovation competitions and support mechanisms.

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Enabling Measures Deepdive

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

Drive connecting and planning of localised refuelling stations and ports

Description: Initiative to physically connect delivery points for hydrogen import to end-use customers

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

Key actions:
- Integrate plan for hydrogen ramp up from imports to development of refuelling stations aggregating potential demand.
- Ensure quality standards are interoperable along the value chain and provide certification on hydrogen properties.
- Align strategy for hydrogen heavy vehicles and buses.
- Co-develop physical infrastructure in line with regulation and including international best practice.

Ongoing work and examples:
- The Clean Energy Ministerial launched the Global Ports Hydrogen Coalition in October 2021 to accelerate low-carbon hydrogen deployment in ports.
- The EU's hydrogen backbone considers the interconnection between ports and industrial clusters.
- In the Netherlands, the hydrogen backbone connects the port of Rotterdam to Groningen.
- The Delta Corridor which will connect Rotterdam with Chemelot (in the Netherlands) with North-Rhine Westphalia (Germany) and has a feasibility study ongoing with RRP (Shell and BP)

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Support the creation of an internal traded market for hydrogen

Description: Begin hydrogen trading between maturing industrial clusters to support the cumulative development of a traded market

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

Key actions:
- Support the development of intra-cluster matching services for hydrogen support and demand including corresponding physical infrastructure.
- Develop a regulatory sandbox for hydrogen islands to trade internally to accelerate the development of a liquid market.
- Develop digital twin of hydrogen supply and demand across industrial clusters to model potential for hydrogen excess.
- Develop business case for intra-cluster transport routes for expansion.

Ongoing work and examples:
- Deutsche Boerse's EEX to launch hydrogen index in 2022 which would be the first publicly-traded index tracking hydrogen as a commodity.
- EEX are running a hydrogen trading working group to accelerate trading and support the ramp up of the hydrogen economy. To date the working group is focused on transparency, indices and benchmarks.

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Identify critical skills and develop strategy to ensure availability of qualified workforce

Description: Long term planning for skills in order to avoid disruption to the develop of the hydrogen economy from the lack of talent available.

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

Key actions:

- Identify key engineering skills for the project development of major anchor projects with a key focus on renewables ramp up.
- Work with research organisation to assess skills required versus infrastructure choices and assess key supply chain requirements across the hydrogen value chain.
- Engage vocational institutions and the supply chain to develop long term skills strategy.

Ongoing work and examples:

- The UK's 2019 Offshore Wind Sector Deal lays out a strategy to ensure a suitable diverse and qualified workshop is in place establishing an Investment in Talent Group to identify skills needs across the sector, and develop curricula and accreditation to deepen the skills base.
- The NET-Tools project focuses on the development of new e-education methods on the topic of hydrogen.
- TeachHy is a university level programme to support the supply for graduate in hydrogen and fuel cell technology.

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Enabling Measures Deepdive

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

Set electrolyser manufacturing capacity targets

Description: Capacity targets indicate the goal for expected electrolyser manufacturing by a certain data and provide confidence to the market

Barrier Level 1: Pace of Development	**Barrier Level 2:** Slow electrolyser manufacturing

Key actions:
- Set targets within national hydrogen strategy, following consultation with industry.
- Design key industrial policy to scale up electrolysers into *gigafactories* supported by long terms targets of manufacturing capacity targets.
- Monitor progress of scale up and share learnings so solve mutually beneficial supply chain challenges.
- Provide clear roadmaps of electrolyser manufacturing ramp up to provide confidence to project developers of availability

Ongoing work and examples:
- In 2020, Thyssenkrupp announced plans to increase its annual electrolyser production capacity to 1 GW/year
- Haldor Topsøe has invested in a manufacturing facility that produces SOEC with a total capacity of 500 MW/year. The facility has the option to potentially expand to 5 GW/year.
- **See p27** IRENA's Green hydrogen supply: A guide to policy making for more detail

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Set specific targets for electrolyser components to support supply chains and reduce bottle necks (e.g. membranes, electrodes etc.)

Description: Electrolysers use multiple specialized components and disruption in the supply chain of any of these materials could compromise the manufacturing of electrolysers and pose a constraint to deployment

Barrier Level 1: Pace of Development	**Barrier Level 2:** TBC

Key actions:
- Identify the electrolyser components that have low production volumes or limited number of suppliers.
- Put strategy in place to deal with potential supply chain disruptions.
- Perform cost-benefit analysis of increasing European capacity of critical components.
- Establish a platform to coordinate manufacturers, suppliers, and testing facilities across the EU to ensure optimal allocation of resources.
- Set specific production targets by component in line with national and EU electrolyser capacity targets.

Ongoing work and examples:
- HySpeedInnovation to coordinate the work of Research and Technology Organisations in Europe and accelerate the deployment of electrolysis.
- Clean Hydrogen Alliance in Europe as a platform to coordinate the efforts of companies and electrolysers manufacturers.
- Analogous example for specific targets by sub-component for domestic manufacturing of batteries in India.

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Enabling Measures Deepdive

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

Provide commitments to fund major electrolyser and trade facility anchor projects

Description: First few trade projects are the riskier due to the technology maturity, demand uncertainty, and high costs. Public funding is needed for the these projects to create experience, develop confidence and attractive private capital

Barrier Level 1: Pace of Development	**Barrier Level 2:** Lack of private capital flow towards deployment

Key actions:

- Break down long-term trade targets into short-term milestones including capacities for trade facilities, investment needs, electrolyser capacities, transmission/distribution
- Identify funding gap for trade facilities considering R&D program and technology improvement over time.
- Establish dedicated funds or credit lines for trade facilities.
- Provide concessional loans with favourable conditions (e.g. grace period, interest rate, payback period) for trade facilities.
- Consider the use of convertible grants and loans to reduce the project risks.
- Provide support for project execution to decrease the construction costs.

Ongoing work and examples:

- USD 3 billion of public funding from Japan for a large-scale supply chain.
- USD 8 billion from the Infrastructure Investment and Jobs Act in the US to fund regional clean hydrogen hubs (that could potentially act as trade hubs in the future).
- HySTRA project (liquid hydrogen supply chain from Australia to Japan) receiving funding from both governments.
- Federal funding of AUD 314 million in Australia to develop regional hydrogen hubs (that could potentially serve as initial spots for trade).

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Co-develop and align infrastructure internationally and promote knowledge exchange e.g. ports and ships

Description: Coordinate the ramp-up of infrastructure capacity in importing and exporting ports in line with domestic development of the industry to prevent uneven paces of deployment that could hinder global trade

Barrier Level 1: Pace of Development	**Barrier Level 2:** Different paces across value chain

Key actions:

- Break down long-term import needs and export opportunities into shorter term capacity targets.
- Develop infrastructure plans that are flexible to research and market developments on different hydrogen carriers (i.e. robust for various carriers).
- Include financing and infrastructure development as a key component of international cooperation agreements and knowledge exchange programs.
- Ensure the participation of public and private sectors from importing and exporting countries in trade projects.
- Establish partnerships with multiple countries of similar profile (i.e. volumes, CO_2).

Ongoing work and examples:

- Japan has explicit targets for imported hydrogen (0.3 MtH_2 by 2030), which allows potential exporting partners to plan accordingly.
- South Korea plans to have a hydrogen demand of 5.3 MtH_2 by 2040 meeting 70% of that with eco-friendly, CO_2-free hydrogen.
- The Port of Rotterdam targets hydrogen flows of 1.2 MtH_2 by 2030 and 20 MtH_2 by 2050 (one third for domestic use and two thirds as transit to Germany).
- CEM Global Ports Hydrogen Coalition has a knowledge exchange component and represents a platform to align targets and visions for hydrogen trade.

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Contents

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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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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