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*Research article*

## Financing low-carbon hydrogen: the role of public policies and strategies in EU, UK and USA

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### APPENDIX A

**Table A.1.** EU's 20 key actions presented in the EU H2 Strategy “A hydrogen strategy for a climate-neutral Europe”.

Scope	Key Action
An investment agenda for the EU	<ul style="list-style-type: none"><li>- Through the European Clean Hydrogen Alliance, develop an investment agenda to stimulate the roll out of production and use of hydrogen and build a concrete pipeline of projects (by end of 2020).</li><li>- Support strategic investments in clean hydrogen in the context of the Commission's recovery plan, in particular through the Strategic European Investment Window of InvestEU (from 2021).</li></ul>
Boosting demand for and scaling up production	<ul style="list-style-type: none"><li>- Propose measures to facilitate the use of hydrogen and its derivatives in the transport sector in the Commission's upcoming Sustainable and Smart Mobility Strategy, and in related policy initiatives (2020).</li><li>- Explore additional support measures, including demand-side policies in end-use sectors, for renewable hydrogen building on the existing provisions of Renewable Energy Directive (by June 2021).</li><li>- Work to introduce a common low-carbon threshold/standard for the promotion of hydrogen production installations based on their full life-cycle GHG performance (by June 2021).</li></ul>

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Scope	Key Action
Designing an enabling and supportive framework: support schemes, market rules and infrastructure	<ul style="list-style-type: none"> <li>- Work to introduce a comprehensive terminology and European-wide criteria for the certification of renewable and low-carbon hydrogen (by June 2021).</li> <li>- Develop a pilot scheme – preferably at EU level – for a Carbon Contracts for Difference program, in particular to support the production of low carbon and circular steel, and basic chemicals.</li> <li>- Start the planning of hydrogen infrastructure, including in the Trans-European Networks for Energy and Transport and the Ten-Year Network Development Plans (TYNDPs) (2021) taking into account also the planning of a network of fueling stations.</li> <li>- Accelerate the deployment of different refueling infrastructure in the revision of the Alternative Fuels Infrastructure Directive and the revision of the Regulation on the Trans-European Transport Network (2021).</li> <li>- Design enabling market rules to the deployment of hydrogen, including removing barriers for efficient hydrogen infrastructure development (e.g. via repurposing) and ensure access to liquid markets for hydrogen producers and customers and the integrity of the internal gas market, through the upcoming legislative reviews (e.g. review of the gas legislation for competitive decarbonized gas markets (2021).</li> </ul>
Promoting research and innovation in hydrogen technologies	<ul style="list-style-type: none"> <li>- Launch a 100 MW electrolyser and a Green Airports and Ports call for proposals as part of the European Green Deal call under Horizon 2020 (Q3 2020).</li> <li>- Establish the proposed Clean Hydrogen Partnership, focusing on renewable hydrogen production, storage, transport, distribution and key components for priority end-uses of clean hydrogen at a competitive price (2021).</li> <li>- Steer the development of key pilot projects that support Hydrogen value chains, in coordination with the SET Plan (from 2020 onwards).</li> <li>- Facilitate the demonstration of innovative hydrogen-based technologies through the launch of calls for proposals under the ETS Innovation Fund (first call launched in July 2020).</li> <li>- Launch a call for pilot action on interregional innovation under cohesion policy on Hydrogen Technologies in carbon-intensive regions (2020).</li> </ul>
The international dimension	<ul style="list-style-type: none"> <li>- Strengthen EU leadership in international fora for technical standards, regulations and definitions on hydrogen.</li> <li>- Develop the hydrogen mission within the next mandate of Mission Innovation (MI2).</li> <li>- Promote cooperation with Southern and Eastern Neighborhood partners and Energy Community countries, notably Ukraine on renewable electricity and hydrogen.</li> <li>- Set out a cooperation process on renewable hydrogen with the African Union in the framework of the Africa-Europe Green Energy Initiative.</li> <li>- Develop a benchmark for euro denominated transactions by 2021.</li> </ul>

## APPENDIX B

**Table B.1.** USA key targets.

Period	Production	Network	Use
2022– 2023	<ul style="list-style-type: none"> <li>- Electrolyser technology: 10,000 hours of high-temperature;</li> <li>- 1.25 MW of electrolyzers integrated with nuclear;</li> <li>- 3 pathways to meet Hydrogen Shot;</li> <li>- 3 assessed pathways of life cycle emissions;</li> <li>- 2 or more conditional loan program agreements.</li> </ul>	<ul style="list-style-type: none"> <li>- 10 kg/min average H<sub>2</sub> fueling rate (heavy-duty) (vs 2016);</li> <li>- 40% footprint reduction on liquid H<sub>2</sub> fueling stations (vs. current code);</li> <li>- 50% increase in seal and metal durability in H<sub>2</sub> service vs. 2018 baseline;</li> <li>- 400 kg/hr high-pressure compressors and cryopumps</li> <li>- 5% or better accuracy for H<sub>2</sub> flow meters at up to 20 kg/min flow.</li> </ul>	<ul style="list-style-type: none"> <li>- \$170/kW heavy-duty truck fuel cell cost vs. \$200/kW baseline;</li> <li>- 18,000-hr fuel cell durability (buses);</li> <li>- 1.5 MW of H<sub>2</sub> fuel cells for data center resiliency;</li> <li>- 1 MW scale electrolyser and fueling marine applications;</li> <li>- 15 fuel cell delivery trucks operating in disadvantaged community;</li> <li>- 1 or more integrated H<sub>2</sub> for ammonia demo.</li> </ul>
2024– 2028	<ul style="list-style-type: none"> <li>- 10 demos of renewables, nuclear and CCS systems (waste/fossil);</li> <li>- \$2/kg clean H<sub>2</sub> by 2026*;</li> <li>- Electrolyser technology: 51 kWh/kg efficiency 80,000-hr life, and \$250/kW (low temperature) and 44 kWh/kg efficiency, 60,000-hr life and \$300/kW (high temperature);</li> <li>- 20 MW of nuclear heat extraction, distribution and control for electrolysis.</li> </ul>	<ul style="list-style-type: none"> <li>- 7 kWh/kg efficiency for H<sub>2</sub> liquefaction;</li> <li>- 50% cost reduction of carbon fiber for H<sub>2</sub> storage vessels (vs. 2020);</li> <li>- 50% of membrane/ionomer material recovery;</li> <li>- 95% of platinum group metals (PGMs) recovery from fuel cell membrane electrode assemblies (MEAs);</li> <li>- 3 GW or more electrolyser manufacturing capacity.</li> </ul>	<ul style="list-style-type: none"> <li>- \$140/kW heavy-duty truck fuel cell cost;</li> <li>- 50% reduction of fuel cell PGMs vs. 2020 baseline;</li> <li>- 1 ton/week reduction of iron with H<sub>2</sub> and pathway to 5,000 tons/day;</li> <li>- 9 ppm NO<sub>x</sub> emissions for 100% H<sub>2</sub> turbines, 2 ppm with selective catalytic reduction;</li> <li>- 3 H<sub>2</sub> fuel cell Super Truck projects completed;</li> <li>- 2 or more pilot projects with tribes;</li> <li>- 4 template community benefit agreements;</li> <li>- 4 or more regional clean H<sub>2</sub> hubs using diverse resources.</li> </ul>
2029– 2036	<ul style="list-style-type: none"> <li>- 10 MMT per year of clean H<sub>2</sub> produced ;</li> <li>- \$1/kg clean H<sub>2</sub> production;</li> <li>- Electrolyser technology: 46 kWh/kg efficiency; 80,000-hr life; \$100/kW uninstalled cost (low temperature) and 80,000-hr life \$200/kW cost (high temperature).</li> </ul>	<ul style="list-style-type: none"> <li>- \$4/kg H<sub>2</sub> cost at scale</li> <li>- 70% of membrane/ionomer material recovery;</li> <li>- 99% of PGMs from fuel cell MEAs;</li> <li>- 3 or more pathways validated for emissions reductions, while meeting environmental and energy justice priorities.</li> </ul>	<ul style="list-style-type: none"> <li>- \$80/kW heavy-duty truck fuel cell cost;</li> <li>- \$900/kW and 40,000-hr durability fuel-flexible stationary fuel cells;</li> <li>- 4 or more end-use demos at scale;</li> <li>- 10 MMT per year or more of clean H<sub>2</sub> used in strategic markets at scale.</li> </ul>

Source: Adapted from DOE, 2022.

## APPENDIX C

**Table C.1.** Proposed policies aggregation upon IEA’s policy database policy, and measures types.

Policy strategy type	IEA’s typology designation
Fiscal and financing policy (F)	“Payments, finance and taxation”, “Payments and transfers”, “Grants”, “Finance”, “Investment in assets”, “Loans/debt finance”, “Taxes, fees and charges”, “Tax” credits and exemptions”, “Funds to sub-national governments”, “Operational funding for institutions”
Strategic plan (SP)	“Strategic plans”, “Technology roadmaps”, “Climate change strategies”
Targets and framework legislation (TFL)	“Targets, plans and framework legislation”, “Framework legislation”, “Targets”
Regulation (R)	“Regulation”; “Permitting processes”, “Prescriptive requirements and standards”, “Rights, permits and licenses”, “Compliance requirements”, “Use/ activity restrictions”, “Prohibition”, “Energy market regulation”
International cooperation (IC)	“International collaboration”, “Voluntary approaches”, “Public voluntary programs”

**Table C.2.** Proposed policies aggregation upon IEA’s policy database sectors.

Target sector	IEA’s typology designation
H2 Production and Supply (H2PS)	“Hydrogen production and supply”, “Hydrogen production”, “Hydrogen transportation”, “Hydrogen storage”
Power and Heat (PH)	“Power, Heat and Utilities”, “Power”, “Power generation”, “Combined heat and power”, “Heat and steam distribution (incl. district heating)”, “Heat generation”, “Heating and Cooling”, “Heat and Utilities” “Electricity and heat generation”
Fuel Processing (FP)	“Fuel processing and transformation”
Transport (T)	“Transport”, “Road transport”, “Air transport”, “Water transport”, “Passenger transport (Road)”, “Mass road transit”,
Transmission (TR)	“Power transmission and distribution”
Industry (I)	“Industry”, “Manufacturing”
Buildings (B)	“Buildings”
Mining (M)	“Metal ore mining”
Multi-sector (MS)	“Economy-wide (Multi-sector)”

**Table C.3.** Proposed policies aggregation upon IEA’s policy database technologies.

Technology type	IEA’s typology designation
Hydrogen production*(not specified) (HP)	“Hydrogen”
Hydrogen electrolysis (HE)	“Hydrogen electrolysis technologies”
Carbon Capture Systems (CCS)	“CO <sub>2</sub> capture and transport technologies”, “CO <sub>2</sub> Capture”, “CO <sub>2</sub> storage”
Transport (T)	“Road vehicles”, “Buses and coaches”, “Drive train or engine”, “Transport technologies”, “Vehicle type”, “Fuel cell”, “Hydrogen and other alternative fuels”
Infrastructure (I)	“Hydrogen refueling stations”, “Refueling and charging infrastructure”
Energy storage (ES)	“Energy storage technologies”
Power and Heat (PH)	“Combined heat and power (CHP)”, “Electricity generation and CHP technologies”, “Heating, cooling and climate control technologies”
Fuel processing (FP)	“Fuel transformation, transportation and above-ground storage technologies”
Industrial processing (IP)	“Industry sector-specific processes and technologies”, “Gas and CCGTs”, “Oil”, “Manufacturing technologies and systems”
Nuclear (N)	“Nuclear”, “Advanced fission reactors (incl. fast neutrons)”, “Nuclear fusion reactors”



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