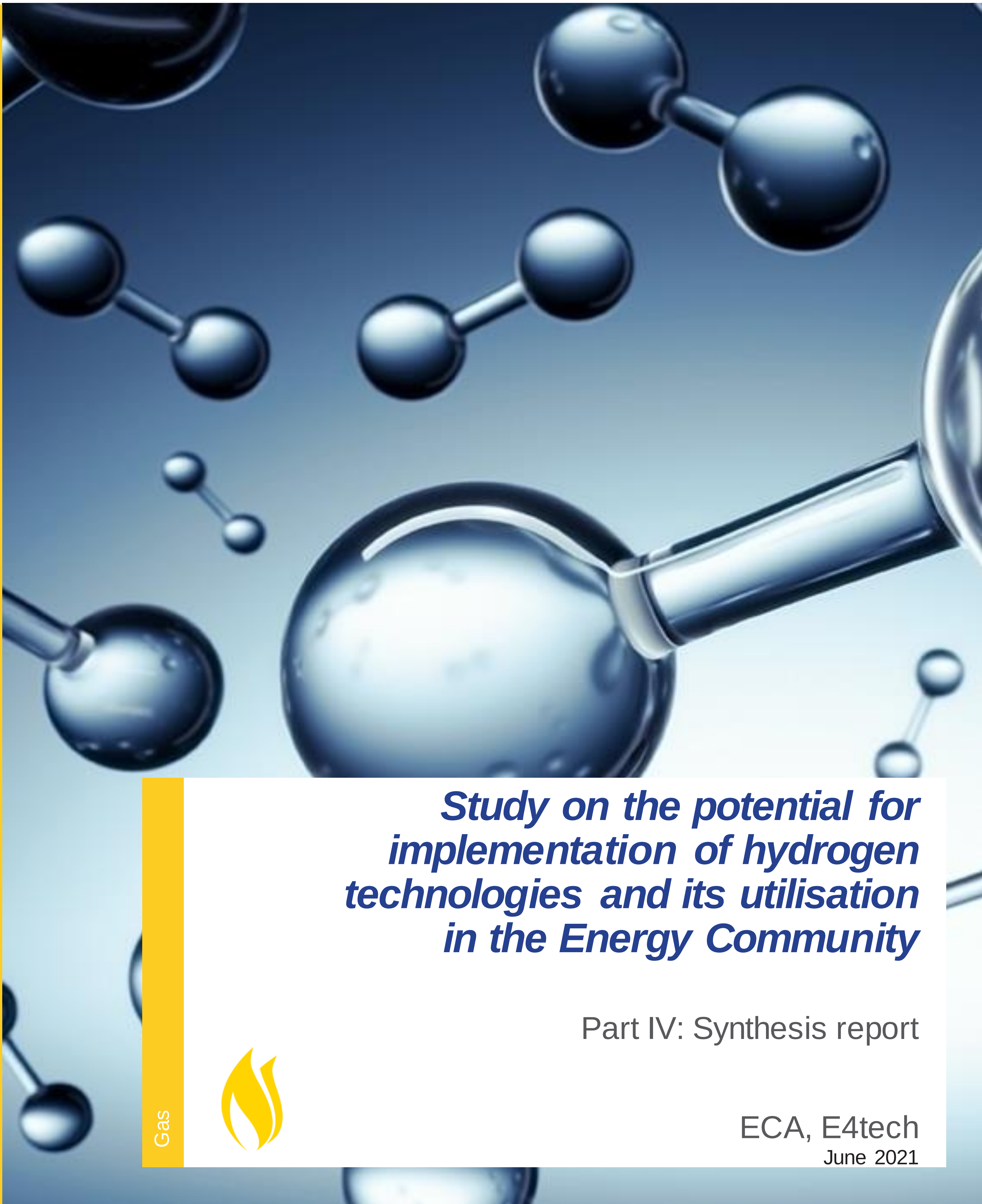

Study on the potential for implementation of hydrogen technologies and its utilisation in the Energy Community

Part IV: Synthesis report

Gas

ECA, E4tech

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Abbreviations and acronyms

AL	Albania
BA	Bosnia and Herzegovina
CCUS	Carbon Capture, Utilisation and Storage
CP	Contracting Party
DH	District heating
EAF	Electric Arc Furnace
ECA	Economic Consulting Associates Ltd
GE	Georgia
HRS	Hydrogen refuelling stations
IEA	International Energy Agency
IFI	International Financial Institute
LOHC	Liquid organic hydrogen carriers
MD	Moldova
ME	Montenegro
MK	North Macedonia
R&D	Research and development
RS	Serbia
XK	Kosovo*
UA	Ukraine

Executive summary

- International interest in the use of hydrogen is expanding both from demand side pull and supply side push effects. These drivers apply also to Contracting Parties (CPs) in the Energy Community both regarding domestic applications and to capture opportunities from integrating with the new European hydrogen economy.

- Hydrogen is expected to be a key contributor for delivering on the goals of the European Green Deal as evidenced through the European Commission's Hydrogen Strategy, which also foresees the promotion of cooperation with the Energy Community CPs. This provides the basis for international cooperation as well as potential financial support necessary to accelerate developments in the region.

- National hydrogen strategies have also become increasingly prevalent as governments seek to provide focus and coherence to their policy framework. Strategies emphasise different objectives (domestic decarbonisation and renewable energy sources (RES) integration; transport; export) dependent on the context of the individual country. This will also be the case for CPs.

- The different points of emphasis also reflect the range of hydrogen applications of interest. These include for long distance freight and bus travel, hydrogen used as a feedstock and in energy intensive industries, hydrogen for the storage of power, and in space heating. The economics of each are currently uncompetitive but expected to improve substantially with cost reductions in electrolyser manufacturing, access to low cost renewable energy and as commercialisation is achieved.

- Which application could become sufficiently economic to be of interest in each CP depends on the local context, but a wide range of plausible applications are considered to be potentially viable in the long-term (2035-2050) at carbon prices of under €200/tCO_2 – a figure in line with international price forecasts for carbon in that period.

- This study includes a stocktake and assessment of hydrogen developments and the readiness of each individual CP to integrate hydrogen into their energy system. This draws from interviews with national stakeholders together with information and data from public sources.

- Findings from this "CP assessment" were considered along with a detailed international review and an economic review of applications to develop a set of "cohorts" that relate to combinations of CPs and end-use application that show particular compatibility. These cohorts can then be compared with international examples for guidance on policy, strategy and pilot project formation.

- For each cohort, a fiche was developed that provides a summary of the actions to be considered by CPs as part of their national strategies and roadmaps for exploiting the opportunity presented by renewable and low carbon hydrogen, including high-level scoping of potential pilot projects.

- Realisation of the opportunities presented by the cohort analysis will benefit from national and regional strategies that provide the long term objectives and overarching framework within which the individual actions reside. A guide to developing such a roadmap and its constituent components is included in this Synthesis report.

- The substantial potential for hydrogen to develop into a cornerstone energy vector for assisting in delivering the Energy Community's decarbonisation agenda is clear. These remain early days and commercialisation will be a gradual process over the coming decade, learning from activity being undertaken internationally. The full role hydrogen will play will only become apparent as these developments occur. Nevertheless, due to the potential benefits from regional integration, knowledge sharing, and coordinated efforts, an Energy Community Hydrogen Coordination Group of responsible civil servants may help leverage both regional experience as it is gained, and ease alignment and cooperation with the wider European market developments.

1 Introduction

This is the final report delivered under the assignment *Study on the potential for implementation of hydrogen technologies and its utilisation in the Energy Community* by Economic Consulting Associates (ECA) and E4tech. It follows and draws upon three supporting reports:

- **International review** of the state of play of the global hydrogen sector;
- **Economic analysis** on the projected economic attractiveness of hydrogen across end-use applications;
- **CP assessment** giving a stocktake and assessment of hydrogen developments in the Energy Community and the readiness of each individual CP.

This Synthesis report provides a summary of the main findings and how these inform a set of policy recommendations and pilot project concepts within the Energy Community. Throughout, it focuses on hydrogen production from renewable or low carbon sources.

This report is structured as follows:

- Section 2 discusses linkages between the supporting analyses to help identify geography and application combinations of greatest interest for further investigation and development;
- Section 3 then describes these combinations in terms of a set of “cohorts” that seek to describe a set of CPs, end-use applications and areas of greatest promise, as well as deriving the framing of potential pilot projects from these;
- Section 4 then concludes with a guide as to how the findings of the cohorts may be used to develop a policy roadmap for the CPs.

2 Interlinkages between supporting analyses

The overall assessment of this study seeks to identify the potential and viability of producing and utilising hydrogen in different end-use sectors of the economies of the CPs and their potential integration with future EU production and consumption markets. The supporting reports therefore provide information on the international context for hydrogen development, the economic attractiveness of end-use sectors, and CP context, necessary to derive conclusions regarding hydrogen's potential and likely role within the Energy Community.

The consultant team has therefore developed a set of "cohorts" which examines the relative economic attractiveness of applications and the context of each CP to derive **combinations deemed to hold the greatest potential in the mid-term (defined as a ten-year horizon)**. Best practice policy strategy, practical steps, and initiatives are then drawn for each cohort from examples in the International Review to help frame actions that could be taken by policymakers to facilitate the realisation of the identified potential.

2.1 International review

Drivers of hydrogen demand[1]

Interest in the use of hydrogen is expanding both from demand side pull and supply side push effects. On the demand side, governments in various countries are seeking to accelerate the decarbonisation of their economies through net zero targets that require action across end-use sectors. Hydrogen is considered to hold significant potential for contributing towards such targets, in particular through its contribution in hard to decarbonise sectors including heavy goods transport and heating.

On the supply side, the increasing commerciality of hydrogen beyond its core current use as a feedstock for industrial applications has brought a range of potential alternative applications into focus. This has reinforced interest in the role it could play as an energy vector alongside electricity and biofuels through a developing hydrogen ecosystem.

These drivers apply also to CPs in the Energy Community. Transposition of European legislation and action taken by national governments gives rise to policy-driven demand that can combine with potential opportunities for supplying to and integrating with the new European hydrogen economy, as well as broadening the range of domestic applications.

Key advantages and drawbacks of hydrogen[2]

The focus on hydrogen and its ability to store and transport energy has accelerated in recent times, paving the way for it to play a growing and prominent role as a sustainable energy carrier of the future. Once produced, hydrogen can be transported and stored in multiple ways, allowing it to be utilised in different end use applications, such as transport, heat, industry or electricity generation. Moreover, hydrogen is envisaged as playing a part in energy storage and sector coupling, ensuring that the whole energy system can manage the challenges of

[1] Section 2 of the International Review.
[2] Section 1 of the International Review.

decarbonisation. This flexibility as an energy vector has therefore underpinned the argument for its use alongside the other major energy vector, electricity. The key advantages and drawbacks of hydrogen are summarised in Table 1 below.

Table 1 Advantages and drawbacks of using hydrogen

Advantages	Drawbacks
• Abundance and flexibility - hydrogen is found in many compounds from which it can be extracted and used • High gravimetric energy content - almost three times the energy density of traditional fossil fuels by weight • Clean emissions profile - hydrogen is free from CO_2 at the point of use • Storage potential compared with electricity - hydrogen can be fairly readily stored in large volumes and over relatively long periods of time in decentralised locations • Applicability to multiple end use sectors - hydrogen can be used for many different applications and is more practical than alternatives in many of these • Efficient end use applications (fuel cells)	• Low volumetric energy density creates challenges for storing hydrogen, particularly in places where space is at a premium • Need for better and more efficient infrastructure for distributing and transporting hydrogen to the end user • Overall efficiency and cost - the production of hydrogen requires the input of large amounts of energy to separate it from other molecules • Industrialisation of component manufacture - the component parts of electrolysers and fuel cells, for example, are relatively complex to manufacture and quite difficult to industrialise • Increased need for centralisation - significant use of hydrogen, for example in the heating network, is expected to require a rather centralised approach, e.g. mandated blending or wholesale network conversion if it is to be delivered successfully, which runs contrary to more market-based approaches to the deployment of new energy technologies

Strategies and policy frameworks[3]

The drivers described above have been reflected in European and national strategies and policies to promote and facilitate the scaling up of hydrogen in the coming decade. The European Green Deal provides an overarching framework for decarbonisation objectives and makes financing instruments available to Member States to achieve them. It is supported by revisions to key elements of European energy legislation including the revised Renewable Energy Directive (RED II) and the amended Energy Efficiency Directive both of which hold relevance for sectors offering business opportunities for hydrogen.

Hydrogen is expected to be a key contributor for delivering on the goals of the Green Deal as evidenced through the European Commission's Hydrogen Strategy, which also foresees the promotion of cooperation with the Energy Community CPs. This provides the basis for international cooperation as well as potential financial support necessary to accelerate developments in the region.

The EU Hydrogen Strategy is expected to be translated into new legislative proposals including a common low carbon threshold/standard for the promotion of hydrogen production installations, comprehensive terminology and European-wide criteria for the certification of renewable and low carbon hydrogen (i.e. Guarantees of Origin), and a review of the legislative

[3] Section 4 of the International Review.

framework to design a competitive decarbonised gas market to be fit for renewable gases (i.e. the gas *acquis* reform).

Both in Europe (driven in part by the above European level policy developments) and beyond, national hydrogen strategies have also become increasingly prevalent as governments seek to provide focus and coherence to their policy framework. Assessing these frameworks gives rise to three broad categories of strategy:

- Strategies focused on using renewable and low carbon hydrogen to support domestic decarbonisation, particularly in the industrial sector and via facilitating greater renewable energy integration into the supply mix. Germany and Netherlands are examples[4].

- Strategies focused on decarbonisation of transport and the opportunity for use of hydrogen in vehicles and shipping. Norway, Japan and South Korea are examples[5].

- Strategies focused on exploiting low cost renewable energy resources to convert to hydrogen and export. Australia and Morocco are examples[6].

Each of the above strategies may be of interest to CPs dependent on their context. The cohorts analysis seeks to identify and develop archetypes which could be transformed into the basis of a future strategy.

Pilot projects

In line with the strategy and policy frameworks, a range of pilot and early stage projects have been instigated internationally. The International Review report describes a subset of projects in detail (see Section 5.2 of that document), covering the different end-use applications in power delivery, transport, industry and space heating. These pilot projects present potential templates for CPs that consider similar applications to be of interest (as explored in the economic analysis and comparative assessment). Common takeaway lessons from the pilots of relevance for similar initiatives in the CPs include:

- Clear objectives and outcomes are essential – the rationale, specific applications and respective roles of involved entities must be clearly defined;

- Collaboration among varied stakeholders is integral including among players along the entire hydrogen value chain, the government and private sector, technology providers, research institutes and others;

- Hydrogen needs to be considered a safe, reliable, efficient and low cost fuel by consumers – social acceptance is vital and should involve minimal cost and

[4] The German case study is explored in Section 5.1.1 of the International review report while a brief overview of the Dutch strategy is provided in Section 4.3.
[5] The Norwegian case study is explored in Section 5.1.2 of the International review report while a brief overview of the Japanese and South Korean strategies is provided in Section 4.3.
[6] The Australian strategy is described in Section 4.3 of the International review report while Morocco is referenced in Section 2.

disruption to customers and, ideally, no change to their household appliances outside of the normal replacement cycle;

- The social and economic consequences of systemic transition to hydrogen need recognition and management – this is related to the concept of a "just transition" whereby potentially negative consequences of the energy transition are mitigated through active participation in the "greener energy future";

- Project outcomes can provide broader lessons that can apply to other countries and sectors, pointing to the benefits of a regional approach.

2.2 Economic analysis

The economic analysis evaluated four primary end-use sectors for hydrogen and the particular applications within each that might hold the greatest potential for the CPs, both in the short term and further into the future (2030s and beyond), considering forecast cost reductions.

- **Transport[7] –** greatest potential was identified in the use of hydrogen on long-haul trucking along dedicated routes ("corridors"). The attractiveness of switching from a consumer's perspective is currently dependent on diesel prices (which are comparatively high at present in Serbia and Albania) although it is noted this may not reflect the underlying economic benefit to the CP in question due to differences in taxation regimes by fuel type as well as environmental externalities (notably emissions costs).

- **Industry[8] –** focus placed on ammonia and methanol where fossil-based hydrogen is currently used as a feedstock as well as steel, an energy intensive sub-sector with limited decarbonisation options:

    - In the **steel** sector, direct reduced iron-electric arc furnace (DRI-EAF) using hydrogen offers the prospect of supplying carbon-free steel although at higher cost than traditional blast furnace production. Production across **all CPs** is currently predominantly based on blast furnace although efforts are being made to increase the role of electric arc furnaces in Ukraine. Under base RES cost assumptions, the necessary implied cost of carbon is lower where coal-based blast furnace rather than natural gas EAF represents the counterfactual[9]. However, should low-variable cost dedicated RES electrolyser-based production be an option, then in either case a 2050 carbon price of around €125 to €135/tCO_2 (in real terms) is estimated to be required.

    - It is understood that **ammonia** production outside of Ukraine is at a low level in the region. Where natural gas is available as in Ukraine, carbon capture, utilisation and storage (CCUS) technology may be the most cost-effective option since a switch to renewable hydrogen is estimated to

[7] Section 2 of the Economic analysis report.
[8] Section 3 of the Economic analysis report.
[9] Natural gas is either currently available or planned to be made available within the considered timeframe in almost all CPs and hence conversion to EAF is theoretically possible, although in many cases this will involve a change in plant location.

require a carbon price of over €200/tCO_2. However, this is dependent on CCUS technology being proven at sufficient scale and should this not be forthcoming then green hydrogen may present the only realistic means by which to decarbonise production. In addition, should low-variable cost dedicated RES electrolyser-based production be an option, the required carbon price may be reduced to around €115/tCO_2. This price is of a similar level to that projected by the International Energy Agency (IEA) for 2040 indicating economic competitiveness.

Furthermore, should CPs currently have any coal-based **ammonia** production and be without access to natural gas supply, electrolysers with dedicated renewables ideally underpinned with carbon prices could make renewable-based ammonia production economically competitive. We understand any such production is, however, currently at nominal levels in the region.

- Results for **methanol** were similar to ammonia but with higher implied carbon prices needed for renewable hydrogen to be considered competitive. A price of €420/tCO2 was estimated for base case RES cost to be competitive with unabated natural gas-based methanol production, or €145/tCO_2 equivalent should low-variable cost dedicated RES electrolyser-based production be an option. The equivalent carbon prices for coal-based methanol production were estimated to be €110/tCO_2 and €50/tCO_2 respectively although this is understood to be a marginal enterprise and hence would not represent a significant opportunity.

- **Power storage[10] –** hydrogen storage was considered to be a potentially competitive option for long-duration storage and discharge at peak periods. The levelised cost of energy proved to be lower than alternative clean energy sources other than pumped hydro for discharge durations above eight hours where the overall capacity factor is under 15%. Alternatively, a carbon price of €190/tCO_2 is considered necessary to be competitive with an unabated OCGT or CCGT plant at capacity factors of 5% and 15% respectively. More favourable conditions (higher natural gas prices and lower hydrogen production costs) could raise the capacity factor threshold towards 30%. This is dependent on the availability of geological storage – the CP assessment (see below) identified significant early stage potential across multiple underground sites in Ukraine and scoping (at differing levels of investigation) of a smaller number of specific sites in Serbia, Albania, Bosnia and Herzegovina, Georgia and Moldova.

- **Heating[11] –** hydrogen is considered of potential interest where existing or planned gas distribution networks are in place for space heating provision and where electricity production remains carbon intensive, making heat pumps unattractive (although it is recognised that in such circumstances there is likely to be significant scope for the direct replacement of fossil-based with renewable electricity generation). Each of Ukraine, Georgia and Moldova have domestic natural gas networks with planned roll-outs in other CPs, notably North Macedonia in the near-term. Not addressing network development of upgrade costs, the carbon price required for hydrogen to be competitive with gas boilers is estimated at around €130/tCO_2. This price is estimated to reduce to under €100/tCO_2 when

[10] Section 4 of the Economic analysis report.
[11] Section 5 of the Economic analysis report.

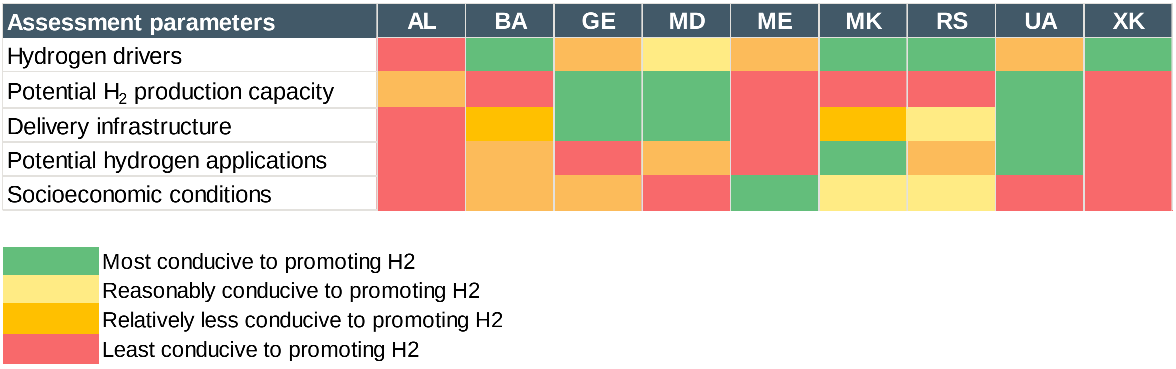
compared to electric heating options (including heat pumps) in a grid with an emissions intensity of 350 tCO_2/MWh, i.e., roughly equivalent to that of a high-efficiency CCGT.

2.3 CP assessment

This report provided a stocktake and assessment of hydrogen developments and the readiness of each individual CP to integrate hydrogen into their energy system. It drew from interviews with national stakeholders together with information and data from public sources.

A heat map score chart was developed against a set of key metrics to help identify where drivers were strongest among CPs and hence where activities could be prioritised. The chart is replicated below[12].

Figure 1 Relative assessment of CP prospects of introducing hydrogen



Source: ECA and E4tech

The intention of the heat map is to highlight areas where action might be needed and/or prioritised and to provide potential insights regarding the targeting of any required next steps for further promoting hydrogen in the CPs. The following key observations were drawn:

- None of the CPs scores unambiguously higher against the assessment parameters – each CP has its own relative “strengths” and “weaknesses” suggesting there is no “one size fits all” solution for the CPs and any policy prescriptions must be carefully targeted to the circumstances of the individual CPs. However, on this preliminary assessment, it appears the potential is relatively greater in Georgia, Moldova and Ukraine.
- Decarbonisation should be featuring as a priority for most CPs, that is, they score highly against the parameter ‘hydrogen drivers’ with the notable exception of Albania (given the predominance of hydropower).
- The theoretical potential for producing hydrogen from renewables appears to be medium to high in many CPs, with the greatest prospects seemingly being in

[12] See Section 3.3 of the CP assessment report for full details.

Georgia, Moldova and Ukraine (although we stress again that this is highly indicative and certainly does not denote potential economic viability).

- Matching producers and users of hydrogen is likely to be the largest challenge for most of the CPs given the lack of existing infrastructure that can be repurposed for distributing hydrogen; the better prospects for this (and therefore also for blending and heating applications) are in those CPs with existing and extensive gas distribution networks, notably Georgia, Moldova and Ukraine and to a lesser degree, Serbia, Bosnia and Herzegovina and North Macedonia.

- Many of the CPs have a significant share in their total output of industrial applications and freight transportation, two broad areas where the prospects of using hydrogen are potentially the highest. This is particularly the case for Ukraine and North Macedonia[13].

- The relative economic development status of the CPs could act as a constraint on promoting hydrogen. At the same time, the efficient establishment of a hydrogen economy could augment economic growth and hence increase economic convergence.

2.4 Towards the cohorts

Collating the key findings of each of the three supporting reports allowed a set of cohorts for further investigation to be identified. The cohorts relate to combinations of CP(s) and end-use application that show particular compatibility based on the findings presented. These cohorts can then be compared with international examples for guidance on policy, strategy and pilot project formation.

Figure 2 summarises five such cohorts developed through aligning the findings of each of the economic analysis and comparative assessment reports. **It is stressed that these are not mutually exclusive and indeed to maximise potential, projects may seek to stack revenue streams from more than one application**. This could either be with the identified application acting as the primary source of demand with other applications that are not specifically identified for that CP leveraging from that to improve overall utilisation, or the combining of two or more focus applications where a CP is identified within more than one cohort.

The following section then develops these cohorts to identify their scope and potential priority actions and pilot project framing.

[13] We note that the picture is somewhat distorted as no data were available for both transportation and industry for Kosovo*. Industry data was also unavailable for Georgia and Montenegro, and transport data is missing for Albania.

Figure 2 Identification of cohorts

Cohort	Application	Drivers	Priority CPs
1	Transport focus – focus on major freight corridors	Corridors with highest freight volumes	UA and RS (including through MK to GR border)
2	Industry focus – ammonia and steel production	Decarbonisation drive and notable domestic industry	UA & MK relevant industries large relative to GDP; policy driver high in RS, MK, BA and XK
3	Power generation and grid services	Need for RES balancing and strong policy drivers (coal dependency)	Reducing carbon intensity in RS, BA, XK and UA; capturing hydro spillage in GE
4	Blending or replacing natural gas for space heating	Delivery infrastructure (gas distribution networks and/or DH)	GE, UA and MD have networks; others in development (MK); DH in RS
5	Hydrogen production for export	Low cost green hydrogen production capacity	UA, GE and AL have significant RES potential

Source: ECA and E4tech

3 Cohort analysis and framing of pilot projects

This section includes a “fiche” for each cohort identified in Section 2.4. The intention is to provide a summary of the actions to be considered by CPs as part of their national strategies and roadmaps for exploiting the opportunity presented by renewable and low carbon hydrogen. Actions are listed under the following groupings:

- **Proposed strategic actions** – these include strategic initiatives and analyses that will help more closely define the potential role of hydrogen and how this can be optimised for the CPs within that cohort.
- **Improving awareness and stakeholder coordination** – for any strategy and roadmap to be successfully implemented, it is vital that it takes due consideration of the views and inputs of affected stakeholders. This includes industry, academia, the general public and other government ministries.
- **Regulatory framework and standards** – for most applications discussed, regulatory frameworks and standards will have been developed *without* hydrogen in mind. This could present unnecessary barriers as well as risk the deployment of unsafe equipment and practices. Suggested actions to mitigate these points are therefore provided.

The fiches also include high-level scoping of pilot projects for each cohort. These provide a framework on the key design points for establishing a project in relation to the specific cohort with commentary where possible on how these may be applied to the priority CPs. More detailed project identification and design will require developing a long-list of plausible locations based on these criteria (which may be supported by spatial analysis) and gaining further feedback from potential stakeholders in order to define a short-list for pre-feasibility analysis.

3.1 COHORT 1: Transport focus

Snapshot	
Key application(s) of interest	• **Primary application:** heavy-duty freight • **Secondary application:** Bus routes (particularly long distance)
Drivers	• Relative competitiveness is strongest for such long distance large vehicles • High volume routes enable focused infrastructure development to give cornerstone market; in cooperation with the EU these may be extended to encompass export and import to/from EU via RS and MK to Southeast Europe (BG, GR), Turkey and beyond
Priority CPs	• **Serbia and North Macedonia:** Based on data provided by the Transport Community, Serbia has the three busiest transport routes in the Western Balkans region (including route through North Macedonia to the Greek border) • **Ukraine:** Draft hydrogen roadmap cites several long distance routes of interest also potentially for bus transportation
Actions[14]	
Proposed strategic actions	• Consider role of hydrogen in transposition of the revised Renewable Energy Directive (RED II) and meeting the sub-target for renewables in transport. • Consider implications of implementation of EU CO_2 emission standards and zero/low emissions incentives schemes for heavy goods vehicles market (including potential future restrictions on cross-border operation into the EU). • Consider policy dialogue and memorandum of understanding with neighbouring markets for shared corridor routes (e.g. Serbia – North Macedonia – Greece). • Assess taxation regimes and carbon pricing for potential perverse incentives and barriers to fuel switching, considering using vehicle, road or fuel taxation as means of incentivising uptake. • Liaise with European programmes (e.g. Neighbourhood Investment Platform), EU Institutions (DG Near, DG Move), International Financial Institutes (IFIs) and the Transport Community for potential design and development of projects and funding mechanisms.
Regulatory framework and standards	• Assess, align and set standards across the supply chain of hydrogen production, transportation infrastructure and operation, and vehicle deployment in liaison with European partners.
Improving awareness and stakeholder coordination	• Government to work with industry representatives and academic groups to establish an advisory working group on hydrogen with transport focus. • Assess supply chain and infrastructure needs – a pilot will likely require involvement of an international vehicle manufacturer.

[14] The actions are common to both freight and buses apart from where specifically noted as being in relation to heavy goods vehicles. Similarly, they are applicable to both national and regional initiatives with the exception of the proposal to form a memorandum of understanding for the latter.

3.1 COHORT 1: Transport focus

	• Gain public confidence through ensuring and communicating safe deployment. • Provide support and establish programmes for vehicle servicing and user training.
Pilot project scoping	
High-level pilot project scoping	Experience from more developed markets suggests that initial projects are best focused on the introduction of hydrogen into a "captive" vehicle fleet. Successful trials have been initiated and are ongoing in bus (JIVE, Europe-wide) and taxi fleets (Hype, Paris) and involve the co-development of the vehicles and refuelling infrastructure. The benefit of taking this approach is that vehicles are return-to-base, allowing greater end-to-end control of the process. Similar projects could be implemented in the CPs since vehicles are commercially available and buses are ubiquitous forms of transport across the CPs (while not a target application themselves, taxis may be added to improve the economics of refuelling). A reasonably sized trial can be implemented around 1 or 2 hydrogen refuelling stations (HRS) which can be electrolyser-based and can therefore be implemented wherever there is a reasonably sized electrical connection available. In other trials, HRS are sometimes open to the public which can allow wider socialisation of fuel cell vehicle technology and improve station utilisation. While buses can be a very useful starting point for a trial, other examples could be fleets of delivery vehicles trucks or fleets of municipal vehicles (e.g. refuse trucks). These trials are probably best focused on larger urban areas where high density bus networks are available, and routes are of a manageable length. Careful consideration needs to be given to the siting of the HRS as it is critically important that journey times are not unduly extended as this adversely affects the economics of the trials. In addition, safety considerations and any restrictions on positioning HRS near public thoroughfares, for example, need to be considered. Experience from other countries will be able to inform this if local regulation is lacking.

3.2 COHORT 2: Industrial use focus

Snapshot	
Key application(s) of interest	• **Primary application:** steel and ammonia production • **Secondary application:** methanol and other industrial heat provision
Drivers	• Decarbonisation objectives for industry (including potential requirements for internationally traded products) • Sizeable domestic industry ready to exploit opportunity offered by commercialisation of renewable and low carbon hydrogen
Priority CPs	• **Ukraine:** Most significant producer of relevant products in Energy Community • **North Macedonia, Serbia, Kosovo* and Bosnia and Herzegovina:** Steel making in (currently) high carbon intensive energy systems (high coal dependency although with gas network developments)
Actions	
Policy actions for consideration	• Consider necessary investment support in light of internally competitive industrial sectors (inability to pass on full cost of emissions). Linkages to any nascent carbon market may be established (e.g. Germany is proposing a "contract-for-difference" to the EU ETS price). • Draw on working group discussions (see below) to consider possibilities for establishing tender mechanism for funding support to pilot project proposals. • Liaise with European programmes (e.g. Neighbourhood Investment Platform), EU Institutions (DG Near, DG Move) and IFIs for potential design and development of projects and funding mechanisms.
Regulatory framework and standards	• Undertake an assessment of the regulatory framework regarding barriers and bottlenecks that might prevent the acceleration of deployment. Where industrial clusters are under consideration these include aspects such as ownership restrictions, third party access rules, and price regulation.
Improving awareness and stakeholder coordination	• Government to work with local authorities, industry representatives and academic groups to establish an advisory working group for identifying the most promising locations for development. • Assess supply chain and infrastructure needs.
Pilot project scoping	
High-level pilot project scoping	Projects in the industrial sector have tended to focus primarily on the replacement of existing fossil-based hydrogen feedstocks with low carbon alternatives. In practice, issues around process and heat integration in the hydrogen production plant can complicate such projects and so the opportunities open can be quite plant specific. However, implementing a small scale project where a small proportion of renewable hydrogen is injected alongside fossil hydrogen into, say, a refinery could be a way to become conversant with the technologies involved without requiring major process re-engineering. For CPs with abundant renewables potential it would be worth considering whether a larger scale greenfield project combining renewable generation with, e.g. a fully green ammonia plant were feasible.

3.2 COHORT 2: Industrial use focus

Alternatively, another low impact way to demonstrate the feasibility of using renewable or low carbon hydrogen would be to consider blending with natural gas for heat production. Again, this could allow experience to be gained while having very little (if any) impact on the processes involved. Blends up to 20% by volume can usually be accepted without the need for major equipment and infrastructure modifications. This could be envisaged at any industrial site already using natural gas for heating, but especially where this can be effectively isolated from main gas transmission and distribution infrastructure.

3.3 COHORT 3: Power storage focus

Snapshot	
Key application(s) of interest	• **Primary application:** storage of renewable electricity for long-duration discharge uses • **Secondary application:** provision of ancillary services
Drivers	• Integration of high volumes of variable renewable energy • Decarbonisation objectives for power sector
Priority CPs	• **Serbia, Bosnia and Herzegovina, Kosovo* and Ukraine:** Drivers stemming from high carbon intensity of current power sector (system balancing needs also prominent due to inflexible coal and nuclear plants) • **Georgia:** Low cost renewable energy available from hydro for which hydrogen may help with seasonal storage avoiding imports
Actions	
Policy actions for consideration	• Power system scenario analysis to assess the likely future competitiveness and role of hydrogen storage for supporting high penetration of renewable energy. May be supported by network modelling to assess role in easing system constraints and ensuring system stability through provision of inertia and other ancillary services. • Work together with European partners (for example through ENTSO-E) and system operator to draw on EU experience and knowledge and its implications for CP infrastructure. • Consider integration of such balancing and grid services in any pilot project (possibly focused on industry – see Cohort 2). • Ensure fair treatment of storage with respect to any energy market levies or taxes (i.e. avoiding double taxation on charge and discharge).
Improving awareness and stakeholder coordination	• Work together with system operator, regulator and network companies. • Assess supply chain and infrastructure needs.
Regulatory framework and standards	• Detailed assessment of options to mitigate barriers within regulatory framework, for example around treatment of hydrogen storage; ownership restrictions, ability to trade and bid into appropriate markets, etc. [15] • Ensure market design of ancillary service provision fairly rewards value provided. • Ensure regulatory framework for safe use of hydrogen in gas turbines (may draw on EU experience such as from developments in Netherlands and Austria[16]).
Pilot project scoping	
High-level pilot project scoping	The relatively early stage of development of hydrogen power generation may make the CPs less suited to a trial in this area than in some other

[15] See International review report Section 5.2.3 for a case study on the H2Future project in Austria.
[16] Ibid.

3.3 COHORT 3: Power storage focus

geographies where decarbonisation efforts are further advanced. This may also be the case for hydrogen storage trials (especially those which involve reconverting hydrogen to power) taken in isolation. It may be more fruitful to consider how the energy storage and demand side response capabilities provided by electrolytic hydrogen could be combined with other trials in the transport or heating domains. In this way, the ability of a grid connected electrolyser with hydrogen demand / storage to provide ancillary services (through demand side response) could be explored. The current product categorisation and procurement approach to ancillary services in many CPs presents a barrier to hydrogen storage both gaining ancillary service contracts and being rewarded for the value it offers. A pilot project could work together with the system operator to trial new approaches to ancillary services market design and regulatory standards. Transposition of the EU Energy Balancing Guideline will create standardised packages for cross-border sales of balancing products, implementation of which may improve the opportunities for hydrogen storage through increased utilisation.

3.4 COHORT 4: Space and water heating

Snapshot	
Key application(s) of interest	• **Primary application:** Commercial and residential sector space heating through hydrogen-based in-building boilers • **Secondary application:** District heating (DH) drawing on hydrogen supply
Drivers	• Decarbonisation of heating for buildings • Difficulties in retrofit of adequately sized heat pumps for meeting high demand periods in existing buildings • More competitive where existing (or under development) gas distribution network is present
Priority CPs	• **Ukraine, Georgia and Moldova:** Existing gas distribution networks • **Serbia:** Limited distribution network for gas but notable DH scope • **North Macedonia:** Advanced development stage of distribution network – can consider integrating dual fuel potential from deployment to avoid future retrofit costs.
Actions	
Policy actions for consideration	• Assess long-term potential of hydrogen through Comprehensive Assessment of heating and cooling required at national level through Article 14 of the Energy Efficiency Directive. • Address taxation and incentive framework for low carbon heating to ensure carbon emissions reductions in this sector are treated fairly against those in the power sector. • Assess multi-family home decision rules for any perverse incentives or other barriers that may limit uptake.
Improving awareness and stakeholder coordination	• Support distribution system operators to assess technical and commercial implications of hydrogen distribution. • Work with appliance providers to understand market implications for potential roll-out of hydrogen boilers.
Regulatory framework and standards	• Work towards establishing a comprehensive framework for managing safe operation of hydrogen distribution networks and end-use appliances. • Consider implications for priority access to gas network for hydrogen and a detailed assessment of options to mitigate barriers within regulatory framework, for example ability to trade and bid into appropriate markets, etc. Germany obliges such priority access, network compatibility permitting, to biogas of which renewable hydrogen is included under the German Energy Industry Act (*Energiewirtschaftsgesetz*). • Ensure the regulatory framework for DH tariffs is cost reflective and thus treats alternative provision and/or upgrades fairly.
Pilot project scoping	
High-level pilot project scoping	A significant amount of work is already being undertaken in countries including the Netherlands and the UK to establish the feasibility, cost, emissions and safety implications of using hydrogen in the gas grid. As discussed in the International Review (see Section 3.5.3), this includes

3.4 COHORT 4: Space and water heating

end-to-end trials of both blending and 100% hydrogen to gain an understanding of the impacts at infrastructure, building and appliance level.

While the CPs will be able to benefit to some extent from the findings of these studies and investigations, in practice there are likely to be many local considerations that will need to be considered. The specific characteristics of the infrastructure, housing stock and end-use appliances will all be important factors affecting how hydrogen may be used. For example, the extent to which the natural gas network relies on steel pipework or the share of multi-occupancy buildings *versus* single family homes all have an effect on the use of hydrogen and its competitiveness relative to other forms of heating. With this in mind, any decision to use hydrogen more widely in the natural gas network would require a more structured programme of research and demonstration projects to be undertaken encompassing the whole system. It should be feasible, however, to envisage one or more small scale power-to-hydrogen projects which involve injection into the grid at low levels, once again to build familiarity with hydrogen systems.

3.5 COHORT 5: Hydrogen production for export

Snapshot	
Key application(s) of interest	• **Primary application:** potential to export to high demand EU Member States • **Secondary application:** consider opportunities for trade in hydrogen within Energy Community
Drivers	• Increasing demand for hydrogen internationally to aid decarbonisation combined with low cost renewable hydrogen production potential • Pipeline infrastructure for low cost transmission of exports
Priority CPs	• **Ukraine:** Has extensive renewable energy potential and existing export routes (may require upgrading) • **Georgia:** Low cost renewable energy available from hydro for which hydrogen may help with seasonal storage thereby avoiding imports (possibly also **Albania** given theoretical hydro power potential although this may be first for seasonal storage to mitigate imports)
Actions	
Policy actions for consideration	• Expand on existing energy partnerships (e.g. Germany and Ukraine's Memorandum of Understanding or the European Hydrogen Backbone Initiative) to explore possible routes for cooperation and funding of hydrogen export projects. • For planned, greenfield, transmission investments and interconnectors, assess the feasibility of constructing the infrastructure enabling dual fuel operation. • Undertake assessment of export pipeline infrastructure to ascertain possibility for use of hydrogen (either blended or dedicated) and commercial and technical repercussions for current use for natural gas.
Improving awareness and stakeholder coordination	• Involve pipeline owners and operators at an early stage in discussions to understand necessary technical and commercial analyses required to ascertain network's readiness for transporting hydrogen in blended or pure form. • Work with project developers within EU to explore potential for supplying with hydrogen (e.g. as per RAG of Austria's interest in Ukraine – see CP Assessment report Annex A9.5.6).
Regulatory framework and standards	• Consider implications for priority access to gas network for hydrogen and cross-border competition and consistency of these with Energy Community *acquis*.
Pilot project scoping	
High-level pilot project scoping	To date, projects to investigate the efficacy and potential for hydrogen trade have either involved the development of large consortia to evaluate the broad considerations of using hydrogen over major trade routes, e.g. the Blue Danube Project, or have focused on proving particular aspects of technical feasibility, e.g. Chiyoda's demonstration of liquid organic hydrogen carriers (LOHC) between Brunei and Japan. Ukraine, Moldova and Serbia may benefit directly from the findings of the Blue Danube project since they have access to that waterway, and projects to explore the feasibility of transporting hydrogen overland,

3.5 COHORT 5: Hydrogen production for export

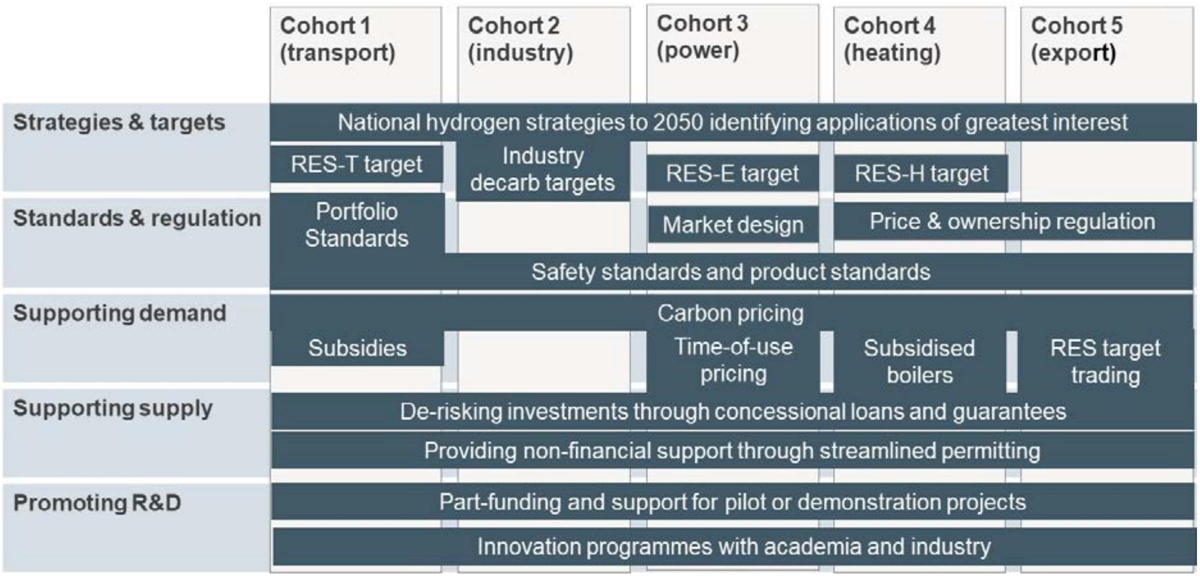
either by pipeline or by road / rail may be of particular interest. To a certain extent, this might mirror the work that is being undertaken to demonstrate the safety and feasibility of using hydrogen within the heat network. Other areas of interest would be a demonstration of long distance transportation by road / rail of hydrogen in liquid form or contained within a carrier, e.g. ammonia or LOHC.

4 Guide to developing a policy roadmap

Realisation of the opportunities presented by the cohort analysis will benefit from national and regional strategies that provide the long-term objectives and overarching framework within which the individual actions identified in Section 3 may sit. Such strategies will be cross-cutting but are likely to focus on, and be built around, those applications deemed most attractive to the CP in question. For example, Ukraine, as the CP with the most advanced interest in hydrogen, in cooperation with UNECE, published its draft roadmap in March 2021, identifying applications of interest, policy actions and potential pilot projects[17].

Figure 3 below draws on the IEA *The Future of Hydrogen* report[18] to outline the common policy elements for consideration in a hydrogen sector strategy and roadmap. This section summarises each component and the aspects which would be expected to be included in a national strategy and roadmap. The specific timetable that is appropriate will vary by CP although, in general, the period to 2030 is expected to largely consist of laying the policy and regulatory groundwork, strengthening the institutional structure, and rolling out demonstration and pilot projects, with commercialisation ramping up thereafter.

Figure 3 Potential elements of a hydrogen roadmap



Source: ECA/E4Tech informed by IEA *The Future of Hydrogen*

Strategy formulation, objectives and targets

1. **Development of a strategy should bring together policymakers, regulators, industry, academia and consumer group representatives**. A core advisory group with transparent membership meeting periodically can support and provide feedback on the development of the strategy ensuring it draws upon the necessary expertise. Wider stakeholder consultation should also be elicited for responding to draft documents. In addition, inter-ministerial buy-in and agreement on adoption is

[17] https://unece.org/documents/2021/03/reports/draft-roadmap-production-and-use-hydrogen-ukraine
[18] www.iea.org/reports/the-future-of-hydrogen

particularly important given the cross-cutting nature of hydrogen applications beyond the energy sector.

2. **Targets will often take a prominent place within a strategy in order to signal political commitment.** This provides industry players, including potential investors, developers and suppliers with a degree of long-term foresight as to future demand against which to develop their own business plans.

   Some targets may be relevant across all applications. These include emissions reduction targets and any general target for hydrogen usage (although caution is recommended before taking this latter approach to avoid undue distortion by favouring hydrogen over competing low carbon options – particularly given the nascent role in CPs' energy mix). Setting out scenarios for development as opposed to firm targets for hydrogen can also signal expectations to industry and the public while retaining policy flexibility.

   Other targets may be more specific to particular applications even if not directly aimed at hydrogen. These include the RED II targets which may help generate demand for hydrogen in the transport sector. Specific targets may also be useful for the roll-out of enabling infrastructure where technology lock-in effects within local monopolies prevent a new market from emerging. A network of HRS, or a zone for the use of hydrogen in gas distribution networks for space heating are such examples.

3. **Spatial analysis to identify areas of promise** such as industrial clusters, transport corridors or fleets operating out of industrial hubs, export routes, and domestic distribution networks of interest may form part of a strategy and help firm up pilot project identification. This is particularly important for distribution through gas networks and sign-posting any grid upgrade or conversion expectations to assist with capital investment planning and regulation.

Standards and regulation

1. **There are common regulatory issues across the cohorts.** The cohort analysis described some of the key areas of interest for regulation with respect to the focus applications. These include cross-cutting regulations around safety standards, taxation policies (avoiding double taxation where hydrogen is an intermediary energy vector) and operating standards for transmission and distribution systems (e.g. to ensure calorific value is not unduly compromised for blended supply with natural gas).

2. **Specific consideration is required concerning the potential development of localised hydrogen networks and thus potential for monopoly provision**. Third party access rules, the regulation of returns and potential for separation of responsibilities requires review. Hydrogen is likely to initially be developed as a patchwork of fragmented production sites and/or networks, limiting trading opportunities and the feasibility of unbundling. Furthermore, due to its relatively higher cost (at least in the early stages), renewable or low carbon hydrogen may require some form of preferred access to natural gas networks.

3. Other issues of standards and regulations relate to their **potential to act as barriers to development** in response to other technologies and fuel sources. Examples include rules on ownership of storage facilities for managing constraints in electricity networks, procurement structures for bidding into power markets, and the design of products

contracted in such markets. For example, if hydrogen storage is designated as a generation unit, then network entities may be restricted from owning projects themselves for managing constraints. In the transport sector, standards and regulations concerning refuelling equipment may require review.

4. **Standards can also be used to help stimulate demand**, for example through portfolio standards (limits) on vehicle emissions or requirements for set levels of blending in distribution networks. They can build consumer confidence and facilitate new product development.

Supporting demand creation

1. **Reflecting the full cost of competing fuels in pricing can help stimulate demand.** The development of national strategies, targets and certain standards and regulations can all assist in supporting the creation of demand for hydrogen. However, other targeted initiatives can help stimulate this further. Carbon pricing will help internalise the environmental externalities of competing fuels.

2. **Improved evidencing mechanisms and information on low carbon credentials of hydrogen** and derived-product supply. This also leads to a need to evidence the low carbon nature of renewable hydrogen production through instruments, such as "Guarantees of Origin". Similar certification systems can be considered to mark the end product (particularly in the industrial sector where hydrogen is a feedstock) as being low carbon.

3. Other demand stimulus measures include **supporting buyers or consumers of hydrogen and hydrogen services**. Public procurement rules and decarbonisation targets can help make this sector an exemplar and market maker. Subsidies may be considered for appliance users such as for hydrogen boilers or vehicles to help with market acceleration. Experience with energy efficiency products and services indicates subsidies (commonly in the form of purchase grants) are most effective at the initial stages of commercialisation before high penetration is achieved by the new products. Subsidies should be tailored to the specific market failures identified, which for domestic users typically revolves around lack of access to capital and lack of information. Any such subsidies will require checking for compliance with State Aid requirements.

Supporting supply

1. **Help de-risk project investments while in pre-commercialisation stage**. Hydrogen infrastructure investment is capital intensive. At a nascent stage in its development as an energy vector (as opposed to a feedstock in industrial use) there are many significant risks facing an investor and hence there is policy scope in helping de-risk projects. Examples include:

    a. Early stage development support through streamlining permitting or undertaking certain pre-feasibility studies.

    b. Off-take guarantees to improve revenue certainty and support lending.

c. Direct grant or subsidised loan schemes may also be considered as well as direct investment and part-funding.

Promoting research and development (R&D)

1. **Leverage wider international R&D efforts**. The increased interest in hydrogen is a global phenomenon and hence substantial R&D activity is occurring in various markets internationally. Direct project funding and other forms of involvement by the public sector may be more significant at this stage when risk is very high, particularly in relation to technical uncertainties. Energy Community CPs, including academic institutes and industry entities therein, may seek to join European or other international endeavours in collaborative activities.

2. **Demonstration projects can help gain public confidence and support**. Pre-commercial projects can be helpful in building domestic understanding and capacity within the involved entities as well as gaining public confidence and support. This is the case even if proof of technical concept may not be necessary due to drawing on experiences from elsewhere.