frontier economics

MAINTAINING SECURITY OF SUPPLY WHILE DECARBONISING OUR INFRASTRUCTURE WITH RENEWABLE AND LOW-CARBON GASES

Report prepared on behalf of Gas Infrastructure Europe (GIE)

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Contents

Executive Summary

Gas Infrastructure Europe (GIE) commissioned Frontier Economics to assess how coordination could enable natural gas infrastructure operators to integrate more renewable/low-carbon gases in a cost-efficient way while maintaining security of supply (SoS) in the gas system.[1] The focus of the study lies on challenges to the transition to renewable gases, in particular hydrogen, arising in the short-term, until circa 2030, that can be addressed via better coordination between market players. **The findings presented in this study aim to inform stakeholders, policymakers, and industry players in the process of transitioning to a more sustainable and low-carbon energy future.**

A number of challenges were identified that infrastructure operators must address in order to manage a cost-effective transition while maintaining SoS in the methane (CH4) system. They can be grouped into five overarching themes (Figure 1):

Figure 1 There will be challenges to manage a cost-effective transition and ensure SoS

Source: Frontier Economics

Note: More details in Section 1.

- **Cross-vector coordination:** Challenges arise in relation to the coordination between stakeholders in the power, CH4 and hydrogen (H2) systems. They relate to the effective transition in the mindset and decision-making towards a cross-vector perspective at EU-level as well as among infrastructure operators to enable knowledge transfer from the CH4 industry to the H2 value chain and operators, and to combine the fulfilment of the H2 and biomethane decarbonisation potentials.
- **Cross-border coordination**: The coordination between stakeholders situated in different countries is challenging and, in this context, potentially contributes to suboptimal (insufficient or delayed) repurposing decisions due to country differences, or insufficient cross-border coordination around H2 storage planning.
- **(Re)-defining SoS**: The definition and operationalisation of SoS standards in the CH4 system will increasingly interact with the H2 system. Perceived risks posed by repurposing may delay decisions, whilst the impacts of system reconfigurations on existing CH4 customers will need to be managed.

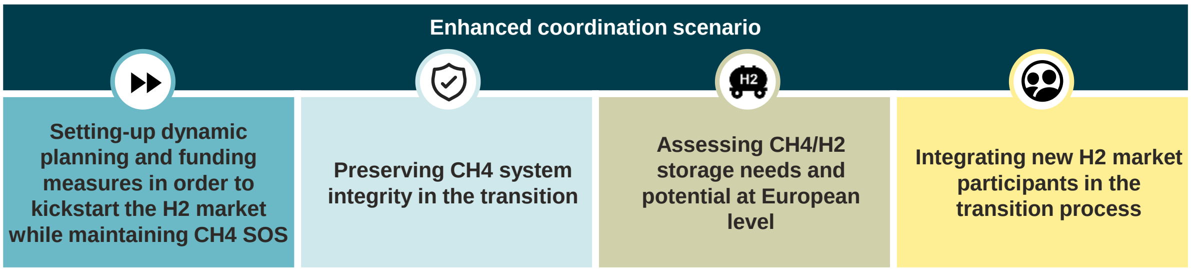
[1] In this study, the concept of security of supply for CH4 focusses on the transmission, distribution and storage of CH4. While there is also an aspect of security of supply of CH4 as commodity (i.e. whether enough CH4 volumes are being produced or imported), this is not at the centre of this study.

- **New governance for hydrogen**: Introducing a new energy carrier also includes challenges in relation to governance such as in this case a risk of insufficient integration of new H2 market participants into the existing system.
- **Aligning incentives to repurpose**: The transition will rely on coordinated investment decisions from stakeholders subject to heterogenous incentives. Risks in this area involve too little investment in H2 assets due to high investment risk stemming from uncertainty around H2 competitiveness, delays in H2 infrastructure cross-country corridors because of delayed allocation of EU-level support at member state level, insufficient cross-border alignment of infrastructure operator incentives to drive projects forward, or too little H2 infrastructure roll-out because of a focus on cross-border criteria in the award of EU-level support.

Ultimately, it is important to coordinate the CH4 and H2 infrastructure systems properly, as otherwise there is a potential risk of disrupting one or even both systems at the same time.

Enhanced coordination can play a pivotal role in overcoming these challenges in the short-term. The findings point to four areas in this respect:

Figure 2 Enhanced coordination can help address the challenges



Source: Frontier Economics
Note: More details in Section 2.2.

- **Setting-up dynamic planning and funding measures in order to kickstart the H2 market while maintaining CH4 SoS:** The multi-facetted and high uncertainty surrounding the further development of renewable and low-carbon gases markets could lead to delays in the roll-out or risks to the SoS. These risks can be mitigated through enhanced coordination, e.g. via:
  - Bi-/multilateral agreements, memoranda of understanding or binding mechanisms across the H2 value chain set-up to enable the uncomplicated development of first-mover H2 clusters;
  - Allocation of member state and EU-level funding (i) following a cluster/corridor perspective, (ii) simultaneously across a cluster/corridor, and (iii) faster;
  - Adjusted TYNDP procedures, aligned with the H2 system dynamics, and proactive communication and explanation of the ability of all H2 stakeholders to participate in the planning process.

- **Preserving CH4 system integrity in the transition:** A balance will need to be struck between establishing cost-efficient H2 infrastructure and ensuring CH4 SoS. In case infrastructure cannot (yet) be repurposed to H2 because of a risk to CH4 SoS, this also means building new infrastructure where needed for H2. Enhanced coordination in the following areas will help achieve the right balance:

- Regular publication of industry-led transparency and status reports on H2 projects and CH4 infrastructure repurposing plans, spanning the entire H2 value chain. If needed, a governance entity could be introduced to provide a safety net by allowing it to raise concerns to infrastructure operators;
- Where infrastructure needs change markedly and where the continuity of CH4 system services may be challenged as part of envisaged reconfigurations, development of logistical solutions by system operators to enable all relevant gas flows, and knowledge-sharing around the identified solutions amongst stakeholders; and
- Commitment by infrastructure operators to prove the absence of CH4 system integrity risks when developing H2 projects in a manner which will be proportionate to the level of CH4 SoS risk possibly entailed by the project.

- **Assessing CH4/H2 storage needs and potential at European level:** Storage is a pillar of SoS in energy systems and GSE has demonstrated the value that underground H2 storage will bring in the future.[2] An initial stepping stone towards storage needs being met across gaseous vectors is to assess the needs and the storage potential. Given the impact of geological conditions on storage capacities, it should not be taken for granted that these will be distributed homogenously across member states, let alone in a way that matches distribution of storage needs. Enhanced coordination to identify needs and potentials at a pan-European level is therefore required.

- **Integrating new H2 market participants in the transition process:** The introduction of a new energy carrier like H2 requires a shift in the behaviour of market participants and consumers. An example is the required switch of end consumer devices and applications, a process that needs to be aligned timewise with the roll-out of the relevant infrastructure to transport H2 to where it is demanded. One part of the required development is therefore to integrate new H2 market participants sufficiently into the existing system. This period of adjustment can potentially lead to delays in the overall transition process. Such delays could be mitigated by:
  - promoting inclusivity and accommodating the participation of new or evolving H2 players within existing coordination mechanisms. To efficiently integrate new or emerging H2 players, it is important to ensure that they can enter the established coordination mechanisms[3]. This can be achieved by streamlining entry procedures, providing guidance and addressing potential barriers, such as the small size of new entrants.
  - implementing H2-specific mechanisms where necessary: There may be cases where existing coordination mechanisms may not adequately address the unique

2 GIE 2022: Showcasing the pathways and values of underground hydrogen storages, available here.

3 For example TYNDP, PCI/IPCEI, EHB, GIE or ENTSOG. Note that existing coordination mechanisms might evolve in the future and the participation of H2 players will depend on upcoming regulation (e.g. gas package) and the future prevalence of coordination mechanisms.

coordination needs of the H2 sector. These needs could e.g. entail an increased frequency or an externally established platform service to match different players or share information. In such cases, it will help to establish dedicated H2-specific mechanisms that cater to the evolving H2 market.

Taken together, the suggested measures in this study leverage enhanced coordination to facilitate the transition to renewable/low-carbon gas while maintaining SoS of CH4.

By identifying these challenges and exploring potential solutions, this study contributes insights to the ongoing efforts to adapt and evolve European gas infrastructure to meet the ambitious sustainability goals.

Background and objective of the study

Rolling out H2 infrastructure requires a balance between cost-efficiency and SoS

The European Commission has set ambitious goals for H2 production and consumption in the coming years. Extensive use of H2 would require a new system alongside the existing CH4 infrastructure.

Within the context of establishing the H2 infrastructure it will pose a significant challenge to strike the balance between cost-efficiency and security of supply. This entails navigating the trade-off between repurposing existing gas infrastructure to H2, which is seen as a relatively cheap option to establish H2 infrastructure, and building new H2 infrastructure (see also Figure 3 below). On the one hand, repurposing offers potential advantages in terms of speed and cost-effectiveness (e.g. by developing an H2 network at lower cost because of using existing infrastructure) but requires rigorous evaluation to ensure SoS in the CH4 system. On the other hand, the creation of new infrastructure allows tailored solutions to H2-specific requirements but is expected to require ca. 2 to 4 times[4] higher initial investments.

The transition to low-carbon gases will need to leverage pre-existing infrastructure while upholding the resilience of the CH4 supply. The SoS in the CH4 system has been established and strengthened over time with the EU SoS regulation forming the legal basis for securing gas supply in the event of a crisis[5]. In addition to the long-standing legal basis, CH4 SoS is further backed by TSOs that are used to coping with short-term system management, both in everyday situations as well as in emergency situations[6]. Targeted regulation such as the cross-border cost allocation mechanism further ensures that TSOs have aligned incentives when working together on cross-border projects. Furthermore, CH4 infrastructure has been gradually rolled-out in response to the evolving demand for CH4, which is now resulting in some spare pipeline capacity (leading to increased SoS) as demand for CH4 decreases. These aspects, among others, will help overcome the challenge of upholding the resilience of the CH4 system also in the transition period to low-carbon gases. However, it is important to coordinate the CH4 and H2 infrastructure systems properly, as otherwise there is a risk of disrupting one or even both systems at the same time (e.g. in case the CH4 supply chain is disrupted in order to repurpose the infrastructure to H2 but the H2 supply chain is not fully in place yet)[7].

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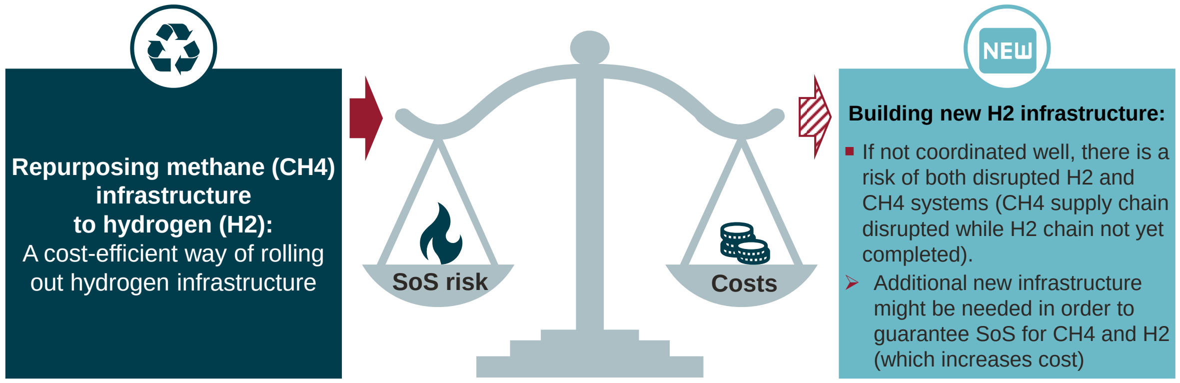
4 European Hydrogen Backbone 2022: A European Hydrogen Infrastructure Vision covering 28 countries, Table 2, available here.

5 EU regulation (EU) 2017/1938.

6 Preventive action plans and emergency plans, see here.

7 Note that raising this point does not preclude some countries or stakeholders already having or planning processes to avoid CH4 SoS risks.

Figure 3 Rolling out H2 infrastructure requires a balance between security of supply and cost-efficiency



Source: Frontier Economics

Coordination is key for the H2 market ramp-up as it can help reduce the risk of commitment and hold-ups in the value chain in an uncertain planning environment

The initial phase of any market ramp-up is riddled with uncertainty, and this holds particularly true for H2. This together with the fact that the different stages of the value chain inevitably rely on each other makes it difficult for players focused on a specific part of the value chain to independently take a decision and commit to it. Delays in one part of the value chain could affect all other parts of the value chain. This can lead to significant investment risks (e.g. due to potential hold-ups[8]) for all the stakeholders involved (see Figure 4 below).

Figure 4 The initial market ramp-up phase is characterised by high investment risks along the entire H2 value chain

1 H2 production/import	2 H2 transport (via pipeline/ship/train)	3 H2 storage	4 H2 demand/supply
High investment risk due to:	**High investment risk due to:**	**High investment risk due to:**	**High investment risk due to:**
Uncertainty in relation to availability of H2 transport and/or storage infrastructure			
Uncertainty in relation to H2 demand			
	Uncertainty in relation to H2 production and import		
Uncertainty in relation to H2 production technology (e.g. scalability, costs) and availability of RES	Uncertainty in relation to evolution of H2 transport methods and repurposing procedures	Uncertainty around which storage sites can be repurposed	Uncertainty regarding required (behavioural) changes for H2 switch

Source: Frontier Economics

8 Hold-ups arise when an investor at one level of the value chain cannot use their assets as planned, because investment may be lacking to complete the supply chain at other levels (e.g. H2 storage cannot be used because the connection to the H2 grid is still missing).

Coordination is therefore key in the H2 market ramp-up phase as it can help relieve the concerns related to the described interdependencies between the different parts of the value chain. Furthermore, effective coordination along the entire H2 value chain will play a crucial role in making sure that all necessary components for the transition are delivered as planned.

Objective and approach of the study

In this context, GIE commissioned Frontier Economics to investigate how infrastructure operators may – via coordination – integrate more renewable/low-carbon gas in a cost-efficient way (e.g. repurposing of assets) while maintaining SoS in the gas system.

The **focus of the study is on:**

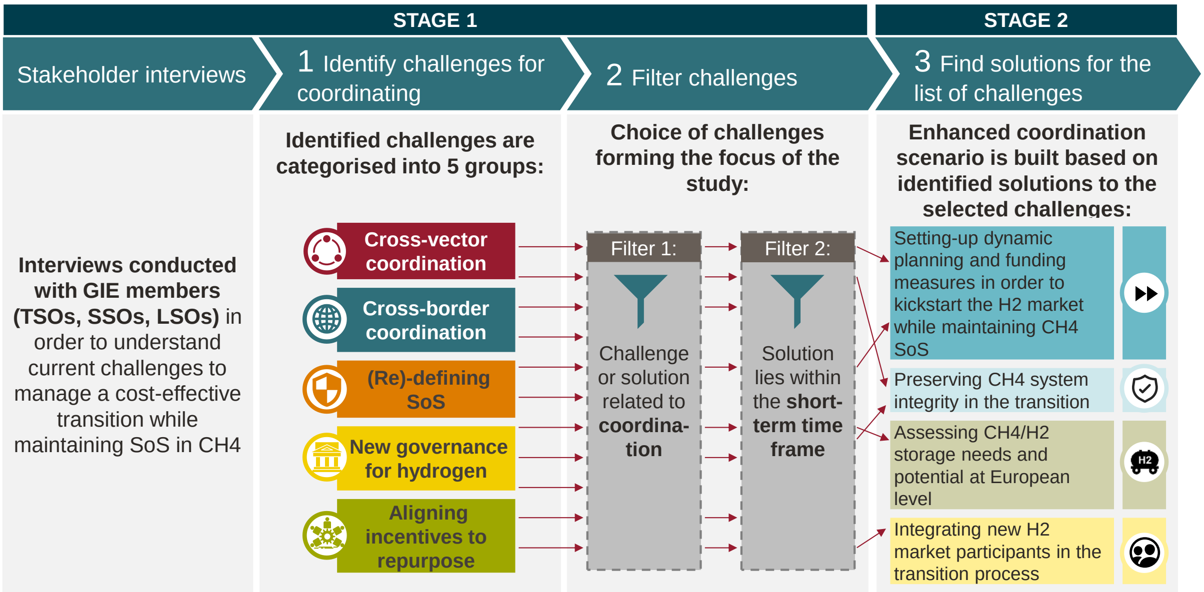
- **the short-term**, namely the first steps of the H2 infrastructure development. In the short-term time frame the H2 market is expected to ramp-up in the form of separate, not yet connected, local system developments (H2 clusters) as well as some initial parts of national backbones in some countries (e.g. the Netherlands); and
- **coordination** (i.e. challenges that can be mitigated through an enhanced coordination between stakeholders).

The study is structured in two stages:

- **Stage 1 –** The primary objective of stage 1 was to discern and outline the key challenges encountered by infrastructure operators in effectively managing a cost-effective transition while maintaining SoS in the gas system. To this end, we conducted comprehensive interviews with a diverse spectrum of GIE members, including Transmission System Operators (TSOs), Storage System Operators (SSOs), and LNG System Operators (LSOs).
- **Stage 2 –** The second stage of the study served to derive possible solutions to the challenges derived in the first stage. We identified coordination-related solutions for the different challenges and formed four categories of solutions.

Figure 5 below illustrates the described approach in more detail.

Figure 5 The approach entails identifying and matching challenges and coordination-related solutions



Source: Frontier Economics

This report is structured as follows:

- First, **Section 1** describes specific challenges identified to manage a cost-effective transition towards renewable and low-carbon gases such as H2 while ensuring SoS for CH4.
- Second, **Section 2** identifies solutions to the challenges described in Section 1 and summarises them in an enhanced coordination scenario. This section also describes which of the identified challenges are addressed with the suggested enhanced coordination measures.

1 Challenges identified to manage a cost-effective transition while ensuring SoS for CH4

The first step of the study relates to the identification of current and future challenges for the effective coordination of stakeholders needed to enable the integration of low-carbon gases into the energy infrastructure. In order to identify a list of challenges we assessed existing coordination mechanisms such as the Ten Year Network Development Plan (TYNDP), European Hydrogen Backbone (EHB), (important) projects of common (European) interest and projects of mutual interests for connection with third countries (PCIs/PMIs/IPCEIs) or more informal bi- and multilateral agreements and conducted interviews with a broad range of GIE members. We found that while these coordination mechanisms work well for CH4, there may be some challenges in the early days of being applied to the H2 context. More precisely, we have identified the following challenges when translating the existing coordination mechanisms to the H2 context:

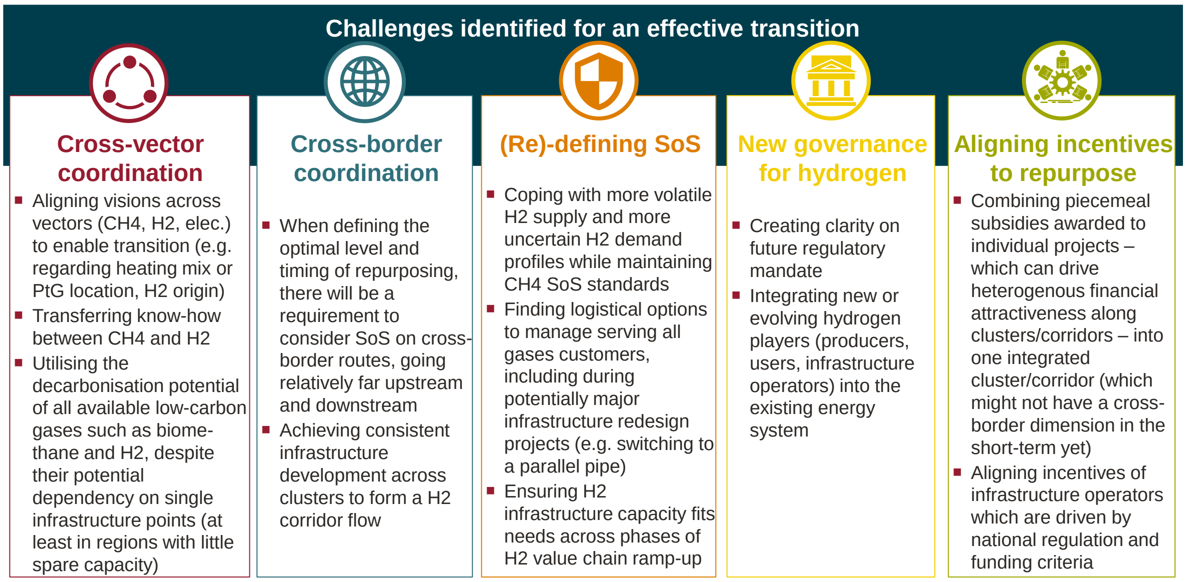
- **TYNDP:** H2 stakeholders other than ENTSOG members may not yet be sufficiently aware of the extensive stakeholder engagement process and possibilities to participate in the development of the TYNDP. Furthermore, the dynamics of the H2 system require more regular updates of the TYNDP project data base than the CH4 system.
- **EHB:** The EHB is an important vision of the TSOs, which is however not meant to be a cross value chain coordination mechanism so that this gap needs to be filled with other coordination processes.
- **PCI/IPCEI:** For PCI/IPCEI funding the targeted project needs to have a cross-border dimension, which poses potential challenges for H2 projects since projects are dependent on the successful development in other parts of the supply chain, cluster or corridor so that different funding timings per value chain step can slow down the whole supply chain development. Furthermore, a cross-border effect as strict eligibility criteria for funding might not be sensible for first H2 projects, that might not have a cross-border dimension despite having EU-wide kickstart value for a long-term cross-vector energy system.
- **Bi- and multilateral agreements:** Such agreements might be harder to implement for new H2 players. This is because their projects are smaller and coordination becomes harder with an increasing number of (small) players and projects and the fact that they are less familiar with existing CH4 players' coordination processes.

These challenges, together with the other identified challenges that arise independently from the status quo coordination mechanism can be grouped into the following five overarching themes (see Sections 1.1 to 1.5):

- Cross-vector coordination;
- Cross-border coordination;
- (Re)-defining SoS;
- New governance for hydrogen; and
- Aligning incentives to repurpose.

Figure 6 summarises the identified challenges within each of these five themes.

Figure 6 There will be challenges to manage a cost-effective transition while ensuring SoS for CH4[9]



Source: Frontier Economics on the basis of interviews with GIE members

The five overarching themes each contain specific challenges that will be described in the following.

1.1 Cross-vector coordination

The “Cross-vector coordination” theme contains challenges related to the coordination between stakeholders in the power, CH4 and H2 system. More specifically, the following three risks or challenges for the transition were identified:

- **Risk of insufficient cross-vector (electricity, CH4, H2) perspective at EU-level as well as among infrastructure operators:** The power and gas systems are and will increasingly be interlinked by technologies such as Power-to-Gas or gas turbines/CHP plants, which allow the conversion of energy carriers between vectors. The level of interdependencies also means that delays in one vector can drive delays in another. Extensive cross-vector coordination between infrastructure operators is therefore required to account for the interdependences between the infrastructure systems. Currently there is a risk that the extent of the coordination will be insufficient.

[9] We note that some of these challenges will be discussed and potentially in part addressed by the new gas package that is currently in the trilogue stage.

- **Risk of know-how loss when transferring the knowledge from CH4 to H2 infrastructure operators:** Players in the natural gas market, like TSOs, SSOs, LNG operators, traders, and shippers, have gained valuable expertise in managing gas infrastructure. This knowledge could be beneficial for operating H2 infrastructure. However, transferring this know-how from CH4 TSOs to H2 TSOs might be challenging due to factors like strict horizontal unbundling, which would prevent natural gas TSOs from also becoming H2 TSOs. This situation could lead to a loss of or complicated transfer of valuable expertise in the transition to H2 infrastructure.

- **Risk of non-fulfilment of combined H2 and biomethane decarbonisation potential due to competition for infrastructure:** Biomethane represents an alternative renewable energy carrier. On the one hand, in light of the enormous challenge to decarbonise the European economy it becomes clear that there is demand for any renewable energy carrier including all renewable and low-carbon gases. Therefore it is important to ensure that the different gases complement each other, considering the extensive potential for natural gas progressive substitution through all possible renewable and low-carbon gases solutions. On the other hand, without appropriate coordination, different gas types such as biomethane and H2 may potentially compete with each other for the existing gas infrastructure. Using the existing gas infrastructure to transport biomethane might in principle cause a delay in infrastructure repurposing for H2 as the pipelines continue to be utilised. An uncoordinated development might hinder the optimal transition, potentially impacting the combined decarbonisation potential of both H2 and biomethane.[10]

1.2 Cross-border coordination

The “Cross-border coordination” category contains challenges relating to coordination between stakeholders situated in different countries.[11] More specifically, the following risks or challenges within this category were identified:

- **Risk of suboptimal repurposing decisions (insufficient or delayed) due to country differences:** The extent and timing of repurposing gas infrastructure vary among European Union member states due to differences in existing infrastructure characteristics and in the demand profiles for CH4 and H2. This can lead to suboptimal outcomes for cross-border H2 infrastructure, such as an H2 backbone. The successful delivery of H2 might depend on establishing every part of the infrastructure chain, especially for cross-border corridors, following an initial phase of local H2 system developments. Some countries may have more available pipeline capacity for repurposing

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10 We note that given the decarbonisation targets, all renewable and low-carbon gases (and other renewable and low-carbon energy carriers) will be needed. In fact, the gases biomethane and H2 might complement each other nicely in the medium- and long-term. This is particularly the case if biomethane is more locally produced and therefore frees up capacity for H2 transmission and import. In the short-term however, there is a challenge around how to best use the existing infrastructure.

11 Note that the “cross-border” coordination does not only refer to member states that are direct neighbours but to all member state coordination also across several border or across the sea (such as between Ireland and mainland Europe.

due to their transition from L-gas to H-gas systems and the existence of parallel network lines. In contrast, other countries might face challenges due to partial pipeline loops and less repurposeable infrastructure. The realisation of an H2 corridor is dependent on the repurposing progress in each involved member state.

- **Risk of insufficient cross-border coordination on H2 storage planning:** Storage is a central component of security of supply in a number of energy systems. This is expected to be the case for H2, e.g. with rising need for flexibility due to increased renewable energy integration and therefore more volatile flows while requiring to reliably serve profiles of (industrial) consumers that deviate from the supply profile (e.g. largely flat demand profiles in the industrial sector). On the storage supply side, the potential for H2 storage depends on geological formations. This potentially leads to an uneven distribution of storage potential among European Union member states. In general, the repurposing of existing CH4 storages to H2 is technically feasible. However, an individual assessment of the suitability of each storage site for H2 has to be undertaken due to geological specifics. In case fewer storage sites are suitable for H2 compared to CH4 (e.g. because limestone caverns may not be appropriate for H2 storage) there may be a challenge to build up sufficient storage capacity.[12] Consequently, investment decisions into new and repurposed storage capacity, should they be made solely based on national SoS considerations, may not be optimal due to differing storage potential across countries. Some countries might have limited storage site potential, which could lead to the requirement for neighbouring countries to establish more H2 storage than what is ideal on a national level.

1.3 (Re)-defining SoS

The "(Re)-defining SoS" category comprises different challenges related to the definition of SoS standards in the CH4 system and how this affects the H2 system. More specifically, the following risks were grouped within this overarching theme:

- **Risk of untimely repurposing of assets due to ill-perceived risk of breach of existing CH4 SoS standards:** At present, SoS standards are established within individual energy carriers. For instance, SoS standards for CH4 are specifically derived from the CH4 context. This CH4-specific approach might lead to delayed repurposing of infrastructure, as it does not weigh in H2 SoS factors. To facilitate the transition, it is necessary to eventually develop new SoS standards for H2. However, these standards do not exist for H2 as of today.

- **Risk due to the fact that reconfiguration of the system might mean that infrastructure path/supply patterns for methane customers might need to change:** The SoS for existing CH4 customers could be at risk if an infrastructure asset is

[12] Also since H2 has a lower energy density compared to CH4, so that more storage capacity is needed to store the same amount of energy in H2 than in CH4 form.

repurposed before its utilisation reaches 0%.[13] If the remaining energy flow is not redirected to other assets before repurposing, the smooth transition is at risk.

- **Risk due to the fact that lead time is required to repurpose pipelines or storages:** The process of repurposing infrastructure, including pipelines and storage facilities, requires a certain amount of lead time during which the asset cannot be utilised. Consequently, in the absence of parallel and redundant pipelines, the demand for H2 cannot be immediately met once a CH4 asset is taken out of use. This potentially results in additional infrastructure assets being required during the transition phase. These new assets would need to bridge the gap and maintain a stable energy supply as the transition from CH4 to H2 infrastructure progresses.

1.4 New governance for hydrogen

Introducing a new energy carrier also includes challenges in relation to governance. The following challenges or risks are therefore summarised within the “New governance for hydrogen” category[14]:

- **Risk due to lack of clarity on national regulatory authorities for H2 infrastructure:** The establishment of National Regulatory Authorities (NRAs) specifically for H2 is still pending in many EU-countries.[15] Until this happens, , the existing NRAs responsible for the gas sector lack the authority to address various aspects related to H2. This temporary situation limits the guidance that can be offered to potential future H2 infrastructure operators.

- **Risk of insufficient integration of new H2 market participants into the existing system (e.g. producers, consumers):** The introduction of a new energy carrier like H2 will necessitate adjustments in the behaviour of market participants and consumers. These changes could take time for consumers to adapt, potentially causing delays in the transition process. This needs to be considered when planning and implementing the transition to a new energy carrier to ensure a smooth and efficient shift in the energy landscape.

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13 Note that a further challenge arises for member states that are not directly connected to another member state in terms of SoS. In case SoS in such countries strongly depends on other countries, there is a risk that national SoS standards used for repurposing decisions do not address this dependence sufficiently.

14 We note that the new gas package that is currently in the triloque phase might bring additional clarity to these challenges.

15 We note that the lack of clarity in relation to NRAs is not the only uncertainty with regards to the regulatory framework for H2. There is currently also a lack of EU regulation and its transposition into national legislation as well as outstanding gas quality standardisation at EU-level, but these are not at the centre of this study related to coordination.

1.5 Aligning incentives to repurpose

Some of the identified challenges to manage the cost-effective transition relate to differences in the incentives of relevant stakeholders. The "Aligning incentives to repurpose" category contains the following risks:

- **Risk of too little investment in H2 assets due to high investment risk stemming from uncertainty around H2 market development:** The uncertainty surrounding the pace of the H2 market development creates significant investment risks for H2 infrastructure assets particularly in the early phase of the market ramp-up. This situation creates a "chicken and egg" dilemma: Low investment in H2 infrastructure due to limited H2 demand, and conversely, low H2 demand due to insufficient infrastructure. Consequently, attracting investors during the initial market phase becomes challenging. This interdependence makes it difficult to kickstart both the investment cycle and the market expansion, requiring careful strategies to overcome this challenge and foster the development of H2 infrastructure.

- **Risk of delays in H2 infrastructure corridors because of allocation of EU-level support at member state level:** Currently, there is still limited precedent for the EC's allocation of funding to H2 infrastructure projects. The evaluation of the first round of PCI projects is ongoing. The allocation of EU-level funding on a member state basis rather than at a cluster or corridor[16] level could have potential drawbacks. It might hinder the realisation of comprehensive (cross-border) H2 projects since all parts of the value chain depend on EU funding in the initial market phase. This approach could also impede effective (cross-border) coordination among infrastructure operators for H2 infrastructure projects. Countries or infrastructure operators that are less likely to receive funding might become less appealing for coordination efforts. Thus, carefully considering funding allocation mechanisms is vital for fostering (cross-border) H2 infrastructure development.

- **Risk of insufficient cross-border alignment of infrastructure operator incentives:** Repurposing decisions regarding infrastructure entail considerations of feasibility and incentives for infrastructure operators. However, varying national regulatory frameworks can give rise to different incentives for infrastructure operators. These in turn can impede crucial collaboration needed to realise (cross-border) infrastructure projects for both CH4 and H2. This cross-border coordination is further complicated by evolving flow patterns in gas and electricity due to factors such as market coupling and renewable energy sources. Furthermore, the need for coordination also extends beyond EU borders, including interactions with non-EU countries like Switzerland or the UK or Energy Community members. Navigating these complexities is essential to efficiently advance H2 infrastructure.

[16] Clusters or corridors are meant to describe geographically concentrated and interconnected firms and stakeholders in the H2 field. Clusters are more local, less geographically spread out, but nevertheless could potentially reach across the border of a member state. A corridor has a larger geographic spread and can extend across several member states.

- **Risk of too little H2 infrastructure roll-out because of cross-border dimension as eligibility criteria for EU-level support:** The requirement to demonstrate a cross-border effect to receive PCI funding might not be conducive to the roll-out of first H2 projects that might not have a cross-border dimension despite having EU-wide kickstart value for a long-term and cross-vector energy system, such as in particular storage infrastructure. Storage projects, particularly those involving H2, may not always exhibit a significant cross-border impact as assessed currently as eligibility criteria. However, they may (soon) be crucial for energy system flexibility and stability. The current funding criteria might therefore hinder the development of storage projects even though they play a vital role in supporting the energy transition. Revisiting the funding criteria to better accommodate the unique importance of storage infrastructure could help address this issue. Furthermore, the cross-border eligibility criteria might also be challenging to fulfil for H2 infrastructure roll-out in countries that are not directly connected to other member states. This would need to be taken into account in order to avoid too little H2 infrastructure roll-out in these regions.

2 Design of an enhanced coordination scenario in which the identified challenges are mitigated

In this section, we give an overview of the different potential solutions to the previously identified challenges (see Section 2.1) and describe the solutions and crucial aspects of enhanced coordination in more detail (see Section 2.2).

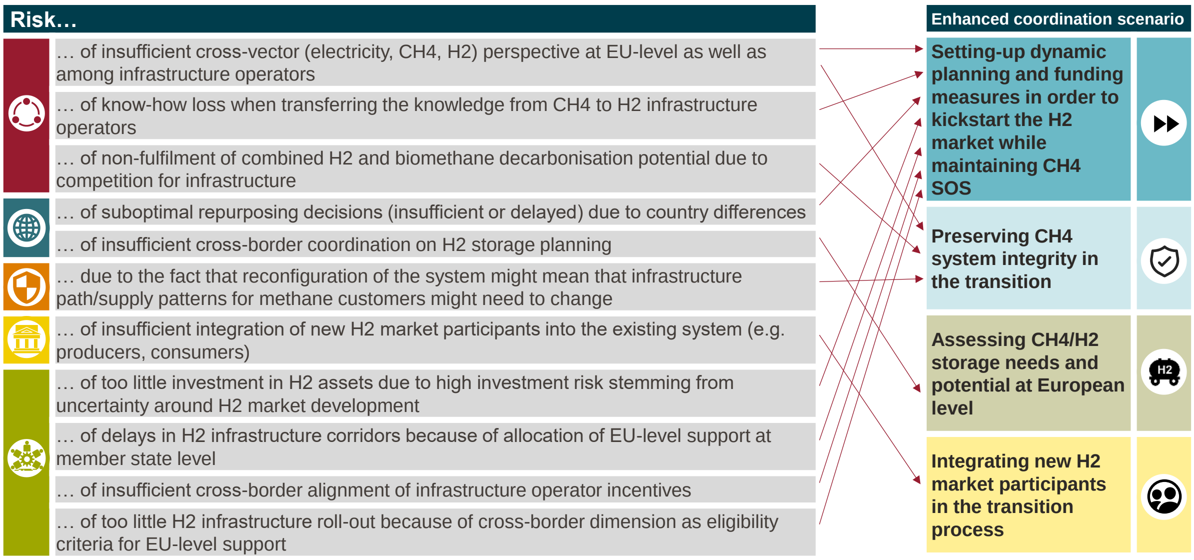
2.1 Four focus areas of enhanced coordination

Potential solutions were put forward for the challenges that are expected to be most critical in the short-term horizon and where enhanced coordination can help. These findings point to four areas of focus when enhancing coordination:

- Set-up dynamic planning and funding measures in order to kickstart the H2 market while maintaining CH4 SoS;
- Preserve CH4 system integrity in the transition;
- Assess CH4/H2 storage needs and potential at European level; and
- Integrate new H2 market participants in the transition process.

Figure 7 displays which of the four focus areas addresses which of the identified challenges that have been put forward. As can be seen in the figure, some challenges also call for enhanced coordination in different areas (e.g. the first challenge is matched to the first and second area of enhanced coordination).

Figure 7 The different challenges can be addressed by a combination of potential solutions related to enhanced coordination



Source: Frontier Economics

In the following, we describe each focus area of the enhanced coordination scenario in more detail.

2.2 Deep dives into the measures within each of the four focus areas

Each of the four focus solution areas comprise a range of measures. Figure 8 gives an overview of these measures and the relevant stakeholder groups they concern.

Figure 8 Each focus area of the enhanced coordination scenario entails specific components and relevant stakeholder groups

Enhanced coordination scenario		Relevant stakeholder group
Setting-up dynamic planning and funding measures in order to kickstart the H2 market while maintaining CH4 SOS	Make use of bi-/multilateral agreements, memoranda of understanding or binding mechanisms across the H2 value chain to enable the uncomplicated development of first-mover H2 clusters.	H2 TSO/SSO/LSO (Stakeholder)
	Ensure member state and EU-level funding is allocated (i) following a cluster/corridor perspective, (ii) simultaneously across a cluster/corridor, and (iii) faster.	EC/MS/NRAs/ National ministries (Authorities/institutions)
	Adjust the TYNDP procedures to match the H2 market dynamics and proactively communicate the ability of all H2 stakeholders to participate in the planning process	CH4 and H2 TSO/SSO/LSO (Stakeholder)
Preserving CH4 system integrity in the transition	Publish regular industry-led transparency and status reports of H2 projects and CH4 infrastructure repurposing plans across the entire H2 value chain	CH4 and H2 TSO/SSO/LSO as well as H2 producers/consumers (Stakeholder)
	Where there are temporary or medium-term challenges to the continuity of system services when reconfiguring energy system(s), system operators are to develop logistical solutions to enable all relevant flows of gases (e.g. switching to parallel pipeline or planning reconnections) and share the solutions with identified peers to enable cross-learning.	CH4 and H2 TSO/SSO/LSO (Stakeholder)
	Infrastructure operators to commit to demonstrating the absence of SoS risk in relation to H2 developments at project level	H2 TSO/SSO/LSO (Stakeholder)
Assessing CH4/H2 storage needs and potential at European level	SSOs to assess H2/CH4 storage needs and potential at European level in order to take into account natural differences in storage demand and potential across countries.	H2 SSO, CH4 SSO/LSO (Stakeholder)
Integrating new H2 market participants in the transition process	Facilitate access to existing CH4 coordination mechanisms for new/evolving H2 players. Where necessary, implement the required H2 specific coordination mechanisms for H2 market participants across the entire H2 value chain (including electricity as well as producers and end users of low carbon gas).	New H2 and existing CH4 market players (Stakeholder)

Stakeholder   Authorities/institutions

Source: Frontier Economics

Note: TSO : Transmission System Operator, SSO: Storage System Operator, LSO: LNG System Operator

In the following, we further elaborate on each of the four focus areas of the enhanced coordination scenario.

2.2.1 Setting-up dynamic planning and funding measures in order to kickstart the H2 market while maintaining CH4 SoS

As mentioned in Section 1, the emergence of the H2 market comes with several challenges. Most notably, the high level of uncertainty regarding the H2 competitiveness gives rise to substantial investment risks across the H2 value chain. Different market failures at the start of an emerging market[17] create a reliance on funding from member states or the EU. This makes H2 infrastructure development strongly dependent on the speed and allocation decisions of funding providers. Additionally, existing EU-level coordination mechanisms may need to be adjusted to address the fast and unpredictable dynamics of the emerging H2 market and to make H2 stakeholders other than ENTSOG members aware of the established stakeholder engagement processes and possibilities to participate in the development of the TYNDP.

In order to address these challenges the following three measures for enhanced coordination were developed as part of the first focus area:

- **Make use of bi-/multilateral agreements, memoranda of understanding or binding mechanisms across the H2 value chain to enable the uncomplicated development of first-mover H2 clusters** – In the initial phase of the H2 market development, (relatively) simple and quick coordination solutions may be prioritised over more complex or comprehensive solutions. Complex solutions are thought of as coordination concepts similar to those that have been developed over decades in the natural gas and electricity sectors. The advantage of these coordination concepts is that they (optimally) achieve a comprehensive solution design that can be implemented in a wide variety of situations. However, the comprehensive development comes at the cost of taking a long time to develop and prove their effectiveness. While these more comprehensive solutions might be efficient and even likely required in the long-term as they ensure a long-term alignment of the development across different emerging H2 hubs, simpler coordination is needed at the start to help stimulate the emergence of first-mover H2 system developments. Simple and quick coordination solutions are especially advantageous if they are no regret measures meaning that they do not endanger SoS of CH4 and do not have significant risks of creating lock-in effects (such as building a temporary H2 hub where it is already foreseeable that the built infrastructure will need to make place for a different infrastructure in the medium-term). The bi- or multilateral agreements should adopt an approach that spans the entire H2 value chain within clusters and corridors, encompassing production/import, transport, storage, and demand, to mitigate the substantial investment risks faced by each participant in the value chain. These initial agreements enable stakeholders to gain experience in a controlled environment before expanding to larger areas, fostering an evolutionary process in terms of coordination. In cases where regulatory authorities are not yet determined or require support, resolution bodies can step in to mediate disputes among stakeholders, promoting reliable planning and reducing risks for all involved parties.

- **Ensure member state and EU-level funding is allocated (i) following a cluster/corridor perspective, (ii) simultaneously across a cluster/corridor, and (iii) faster** – To support the success of first-mover H2 projects without impeding efficient

[17] such as first-mover disadvantages, i.e. hesitancy to start a project because the learnings generated from the first projects at high costs will spill over to the wider industry and lead to cost reductions second movers benefit from, so that first-movers pay the costs for the societal benefit.

coordination and the realisation of entire cross-border H2 clusters, funding from both the member states and the EU should adhere to the following principles:

- (i) Funding selection processes should entail a H2 cluster or corridor perspective, recognising that H2 projects rely on a functional value chain within a corridor or cluster. This requires consistent funding across the entire H2 value chain of a cluster/corridor (covering H2 production, import, transport, storage, and consumption) and across all participating member states (or between a member state and a non-EU country).
- (ii) Funding should be allocated simultaneously to the different parts of the value chain, as they are interdependent and rely on each other, i.e. different funding timelines for different parts of the value chain can slow down or even hinder the development of the entire supply chain. In contrast, simultaneous funding enables simultaneous final investment decisions and a consistent implementation of various parts of the value chain.
- (iii) The decision-making process for funding should be accelerated to align with the dynamic nature of the emerging H2 market. First-mover projects should not be unduly delayed due to slow funding decisions, taking also into account their kickstart value for subsequent H2 industry developments.

Furthermore, the funding levels should be adjusted to align with these objectives, ensuring that the financial support available adequately supports the coordinated development of H2 projects, clusters and corridors.

- **Adjust the TYNDP procedures to match the H2 market dynamics and proactively communicate the ability of all H2 stakeholders to participate in the planning process** – To support the evolving H2 market effectively, it is essential to enhance the TYNDP process by making it more dynamic and adaptable. This can be achieved through the following measures:
  - Frequent updates – Given the dynamic nature of the nascent H2 market, it is crucial to ensure that planning and decision-making processes remain up-to-date with the latest information. This can be facilitated by creating mechanisms within the TYNDP process to incorporate regular updates on H2 infrastructure and developments.
  - Inclusive participation – Opportunities for (new) H2 infrastructure operators to participate in the development of the TYNDP should be communicated more pro-actively. A strengthened participation of all infrastructure providers such as H2 TSOs, SSOs and LSOs in the scenario development step at the beginning of the network would facilitate the efficient coordination between CH4 and H2 stakeholders and foster a more seamless and consistent approach to coordination across energy vectors.

These measures aim to create a more adaptive and inclusive framework that can effectively support the growth and integration of H2 within existing energy infrastructure systems while maintaining efficient coordination with other energy vectors like CH4.

Taken together, these three measures will support the H2 market ramp-up via enhanced coordination and thereby provide more certainty on when and where to repurpose CH4 infrastructure to H2. In doing so, there is also a balance to strike between establishing H2 infrastructure needs and ensuring CH4 security of supply. The following section elaborates on how to achieve the latter objective.

2.2.2 Preserving CH4 system integrity in the transition

The development of the H2 market also presents a potential risk to the integrity of the CH4 system, especially in case infrastructure is repurposed from CH4 to H2. In order to minimise this risk, the following three measures to enhance coordination are suggested:

- **Publish regular industry-led transparency and status reports of H2 projects and CH4 infrastructure repurposing plans across the entire H2 value chain** – As the H2 market ramp-up is expected to initially take place in the form of local H2 developments, there is a risk that the integrity of the CH4 system could be hampered. One of the reasons is that the task of keeping oversight of different clusters and their development involves for example the challenge of keeping track of funding assignments, project development status and which potential projects/clusters are actually realised. Another reason is that different cluster developing independently and potentially not compatibly could make the future connection of the clusters more difficult.
  Therefore, if infrastructure operators established a system of regular status reports on H2 project development progress across the entire H2 value chain, with these being periodically reviewed, this would enhance transparency and oversight in the H2 industry. This could also have positive spill over effects outside of the different H2 clusters since in the interconnected energy system, (repurposing) decisions in an H2 context will also impact stakeholders outside of the H2 cluster. Furthermore, maintaining ongoing transparency regarding infrastructure usage and potential repurposing plans would allow stakeholders to stay informed and voice any concerns they may have. The Hydrogen Infrastructure Map[18] with the goal to gather all relevant H2 infrastructure projects and present the data in a publicly accessible and user-friendly way has already improved this industry-led transparency substantially. If needed, a governance entity could be introduced to provide a safety net by allowing it to raise concerns to infrastructure operators.

- **Where there are temporary or medium-term challenges to the continuity of system services when reconfiguring energy system(s), system operators are to develop logistical solutions to enable all relevant flows of gases[19] (e.g. switching to parallel**

[18] See https://www.h2inframap.eu/#keys. This is a joint initiative of ENTSOG, GIE, EUROGAS, CEDEC, GD4S, and GEODE.

[19] Note that the transport and storage of CO2 could become an additional and relevant topic in this area. While we observe that this topic is gaining momentum in several member states there are at the same time still numerous uncertainties and knowledge gaps. Assessing these would require a more in-depth analysis not foreseen within the scope of this study focusing on H2 repurposing/new built infrastructure and SoS. We therefore do not touch upon the CO2 transport and storage topic in this study.

pipelines or planning reconnections) and share the solutions identified among peers to enable cross-learning – Existing CH4 infrastructure could be used for several purposes in the future – options may include a continued use for CH4 with an increasing share of biomethane, repurposing for H2 or, depending on local circumstances, discontinue its usage. Changing needs of infrastructure (such as a situation with lower utilisation of a CH4 pipeline and rising demand for H2 transport) could require an answer to the question of how the pipeline will be of best use. Flexibility and options for adapting infrastructure to changing needs can be enhanced by creating a catalogue of short-term logistical solutions in case of a desire to change the infrastructure set-up. Such a catalogue could include options like:

- Keeping existing CH4 assets for biomethane in order to ensure a secure supply of CH4 and to increase the utilisation of the pipeline (while opting for new infrastructure to support the H2 market ramp-up); or
- Repurposing existing CH4 assets to meet H2 demand while ensuring CH4 flows are continued via alternative solutions. CH4 flows could be ensured by e.g. employing strategies such as utilising parallel pipelines, where CH4 and H2 pipelines operate concurrently. Other possible approaches are the use of satellite LNG plants to serve local CH4 customers (as e.g. in Portugal), or decentralised biomethane supply or mobile (non-pipeline) transport. These measures help safeguard the SoS for CH4 customers while facilitating the repurposing of infrastructure for H2.

- **Infrastructure operators to commit to demonstrating the absence of SoS risk in relation to H2 developments at project level** – In order to ensure SoS for CH4, infrastructure operators should commit to prove the absence of CH4 system integrity risks when developing H2 projects. A two-tier framework, designed proportionately to the extent of the potential SoS risk in each project, could enable systematic checks of the absence of SoS risks:

1. <u>Fast-track in case no infrastructure repurposing is needed:</u> In case no infrastructure repurposing is needed for the planned H2 project there should not be any negative impact on CH4 SoS so that a fast-track SoS assessment can be applied for efficiency purposes.
2. <u>Comprehensive framework in case infrastructure repurposing is required:</u> In case H2 projects involve the repurposing of existing CH4 infrastructure, SoS of CH4 needs to be assessed using a more comprehensive framework. This framework would be developed by infrastructure operators in order to help them assess (or demonstrate the absence of) SoS risks of a specific H2 project.

These three measures, all facilitated by concerted CH4 and H2 infrastructure operators' developments and operations, together leverage the benefits of enhanced coordination to help maintain the integrity of the CH4 system while allowing a cost-efficient development of the H2 market.

2.2.3 Assessing CH4/H2 storage needs and potential at European level

Storage is a pillar of security of supply in energy systems and GSE has demonstrated the value that underground H2 storage may bring in the future[20]. An initial stepping stone towards storage needs being met across gaseous vectors is to assess storage needs and capacities. Given the impact of geological conditions on storage capacities, it should not be taken for granted that these will be distributed homogenously across member states, let alone in a way that matches distribution of storage needs. Enhanced coordination to identify needs and potential at a pan-European level is therefore required. In the short-term, this concerns primarily new storages as there might be little potential for CH4 storages to be repurposed to H2 without endangering SoS for CH4. In order to address these storage-related challenges effectively, the enhanced coordination scenario suggests the following measure:

- **SSOs to assess H2/CH4 storage needs and potential at European level in order to take into account natural differences in storage demand and potential across countries –** The assessment and identification of storage demand and potential is still ongoing but it should not be taken for granted that demand and potential is distributed proportionally across member states. If storage needs assessments are conducted for each country separately and if demands and needs are not coordinated well between countries, there will be a risk for an inefficient allocation of H2 storages across border. SSOs could help reduce this risk by assessing and coordinating H2/CH4 storage needs and potential across member state borders and at European level.

This measure specifically aims at H2/CH4 SSOs and will facilitate the H2 market development as H2 storages have an important role for providing flexibility and balancing H2 flows.

2.2.4 Integrating new H2 market participants in the transition process

The introduction of a new energy carrier like H2 requires shifts in the behaviour of market participants and consumers. An example is the required switch of end consumer devices and applications, a process that needs to be aligned timewise with the roll-out of the relevant infrastructure to transport H2 to where it is demanded. Integrating new H2 market participants (including spin-offs from existing players widening their business to H2) sufficiently into the existing system is one part of the required development. This adjustment period can potentially lead to delays in the overall transition process. The last component of the enhanced coordination scenario focusses on reducing this risk by suggesting the following measure:

- **Facilitate access to existing CH4 coordination mechanisms for new/evolving H2 players. Where relevant, implement H2 specific coordination mechanisms for H2 market participants across the entire H2 value chain (including electricity as well as producers and end users of low-carbon gas)** – To promote inclusivity and

[20] GIE 2022: Showcasing the pathways and values of underground hydrogen storages, available here.

accommodate the participation of new or evolving H2 players within existing coordination mechanisms and adapt where necessary, the following steps could be taken:

- Facilitate access for new players – In order to efficiently integrate new or emerging H2 players, it is important to ensure that they can enter the established coordination mechanisms. This can be achieved by streamlining entry procedures, providing guidance and addressing potential barriers, such as the small size of new entrants. To overcome the barrier to participation caused by small size (e.g. because it is harder to find the overhead and capacity to engage in activities that are not at the very core of the business such as coordinating), there could be merit in establishing a dedicated coordination platform for regional smaller new H2 players.
- Implement H2-specific mechanisms – There may be cases where existing coordination mechanisms may not adequately address the unique coordination needs of the H2 sector. For instance, these needs could be an increased frequency or an externally established platform service to match different players or share information. In such cases, it will help to establish dedicated H2-specific mechanisms that cater to the evolving H2 market. These mechanisms should be designed to accommodate the specific characteristics and requirements of H2 infrastructure development while ensuring efficient coordination and integration with the broader energy landscape.

By adopting these strategies, the energy sector can better adapt to the changing H2 landscape, fostering inclusivity and effective coordination among both established and new H2 market players.

3 Conclusion

This study aims at presenting possible answers to the question, how infrastructure operators may – via coordination – integrate more renewable/low-carbon gas in a cost-efficient way while maintaining SoS in the gas system. The focus of the study lies on challenges to the transition arising in the short-term (i.e. the period until ca 2030) that can be addressed via better coordination between market players.

In the first stage of the study, we assessed existing coordination mechanisms and conducted interviews with a broad range of GIE members to identify a list of challenges that infrastructure operators must address in order to manage a cost-effective transition while maintaining SoS in the CH4 system. The identified challenges can broadly be groups into the five overarching themes cross-vector coordination, cross-border coordination, (re)-defining security of supply, new governance for hydrogen, and aligning incentives to repurpose assets. We then identified priority challenges that are tailored to the study's focus on short-term challenges that can be addressed via solutions related to enhanced coordination between market players. These challenges formed the basis for the second stage of the study.

In the second stage of the study, we identified potential solutions to the challenges and defined measures to enhance coordination in four focus areas:

1. Set-up dynamic planning and funding measures in order to kickstart the H2 market while maintaining CH4 SoS;
2. Preserve CH4 system integrity in the transition;
3. Assess CH4/H2 storage needs and potential at European level; and
4. Integrate new H2 market participants in the transition process.

Taken together, the suggested measures in this study leverage enhanced coordination to facilitate the transition to renewable/low-carbon gas while maintaining SoS of CH4.

By addressing these challenges and exploring potential solutions, this study contributes insights to the ongoing efforts to adapt and evolve European gas infrastructure to meet the ambitious sustainability goals. **The findings presented in this study aim to inform stakeholders, policymakers, and industry players in the process of transitioning to a more sustainable and low-carbon energy future.**