The role of LNG in the energy sector transition Regulatory recommendations

Frontier Economics study for GLE – Final results

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Study sponsors

Contents

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Context: Significant amounts of renewable and low-carbon gas/fuels need to be imported to achieve decarbonisation, via various potential pathways

Potential pathways

Pathway 1	Pathway 2	Pathway 3	Pathway 4
Upstream greenification	Downstream H2	Upstream H2	E-Fuels
Bio LNG, Syn LNG	SMR, Pyrolysis	Liquid H2, LOHC, Syn LNG, Ammonia	Ammonia, Methanol
BioLNG or SynLNG produced upstream, and **imported similarly to LNG today**	**LNG imported as today**, and used to produce low-carbon H2 in EU	**'Green' hydrogen** produced via electrolysis outside EU. Various **hydrogen carriers** are used for import to EU	**'Green' hydrogen** produced via electrolysis to produce ammonia or methanol **Import of e-fuels** similar to today

LNG import infrastructure can play a vital role in most pathways

Leveraging on expertise / skilled personal with transport of liquified gas and on location

	Pathway 1	Pathway 2	Pathway 3	Pathway 4
Shipping, import terminal, storage	Existing LNG infrastructure to import bio/syn LNG	Existing LNG infra to import LNG Possibly be active in CCSU (onsite) / CO_2 handling	Possibility to convert LNG infrastructure to facilitate some H2 carriers	Limited possibility to use/convert existing LNG infrastructure
Direct liquid consumption	Existing LNG bunkering / fuelling infra used with bio/syn LNG	Some of existing LNG bunkering / fuelling infra used for liquified H2	LNG bunkering / fuelling infra used for H2 carriers (e.g. liquid H2)	Some of existing LNG bunkering / fuelling infra used for e-fuels

Separate study on technical capability of LNG infra with other gases published by GLE soon

Challenge: All potential import pathways face significant barriers, which prevent these imports from happening without further policy action

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Policy recommendations: In the long run EU ETS is key, but near-term policies are needed to support renewable & low-carbon gas take-up

- All pathways require **cost support** for production of renewable and low-carbon commodities
  - Long-run: The **EU ETS should be expanded** to further sectors (e.g. heating, transport) to internalise cost of carbon emissions and enforce competition between carbon abatement technologies incl. renewable and low-carbon gas. This needs to be accompanied by measures to prevent carbon leakage (e.g. a **carbon border adjustment mechanism**)
  - Short-run: To kick-start exploitation of renewable and low-carbon commodities and overcome technology immaturity, further **support on upstream, infrastructure and/or downstream level** is needed.
- **Additional measures** are needed in the hydrogen pathways (2 and 3) due to limited existing hydrogen demand and the lack of a H2 T&S regulatory framework
- **Coordination between EU/non-EU states** is important for pathways where production takes place outside the EU (1, 2, and 4)
- **LNG terminals** are well placed to facilitate many of the pathways through utilising existing equipment, expertise, and personnel skills in relation to the transport of liquified gas.
  - EU policy should provide **clarity of roles** and ensure there are no unnecessary barriers, including supporting competition between alternative import routes

Key* policy recommendations per pathway: Different import pathways need tailor-made policy actions, and LNG infra can play a role in all paths

	Pathway 1 Upstream greenification	**Pathway 2** Downstream low-carbon H2	**Pathway 3** Upstream green H2	**Pathway 4** E-Fuels
Cost & Demand	▪ **Upstream CfD/FiT** paid to green CH4 producers; OR ▪ Downstream tradeable RLCC* obligation on industry / retailers / suppliers	▪ **Downstream tradeable renewable and low-carbon commodity obligation** on existing H2 users, with future extension to retailers for use in the gas network up to the blending limit ▪ **Upstream CfD/FiT** paid to H2 producers, designed to remove demand risk from producers ▪ **CAPEX support for infra conversion** and end user switching		▪ **Upstream CfD/FiT** paid to e-fuels producers; OR ▪ Downstream tradeable RLCC obligation on industry / retailers / suppliers
	Expansion and ongoing application of EU-ETS system (sectoral) with a carbon border adjustment (for relevant users only)			
Co-ordination	▪ Govt facilitates coordination ▪ Investor protection	▪ Development of H2 and CO2 T&S regulatory framework		▪ Govt facilitates coordination ▪ Investor protection
		Producer and infrastructure support with conditions on coordination		
Cert-ification	**Downstream certificate of (avoided) operating emissions and broader sustainability**			
		Harmonisation of international technical standards		

Role of LNG import facilities and associated policy recommendations

LNG terminals already able to import bioLNG/synLNG, and could support management of commodity quality at import

Policy clarity on roles of actors (LSO, TSO) within the H2 framework to ensure no unnecessary barriers e.g. re CO_2 capture and handling

Possibility to **convert LNG import** equipment using **CAPEX subsidy**

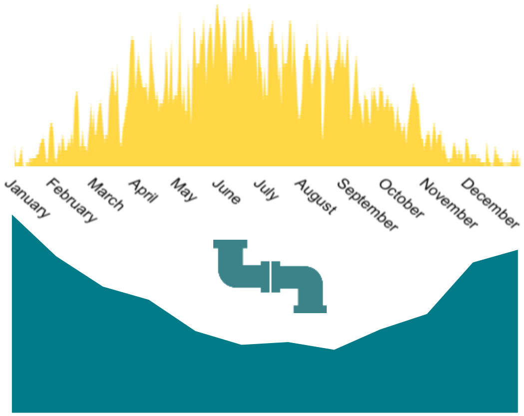
Competition between different import routes supported by ensuring **subsidies are neutral to import route**

* Further policy recommendatinos in the main body of this deck report.

Renewable & low-carbon gas will play a major role to achieve EU's climate targets alongside electrification, which is now widely recognised

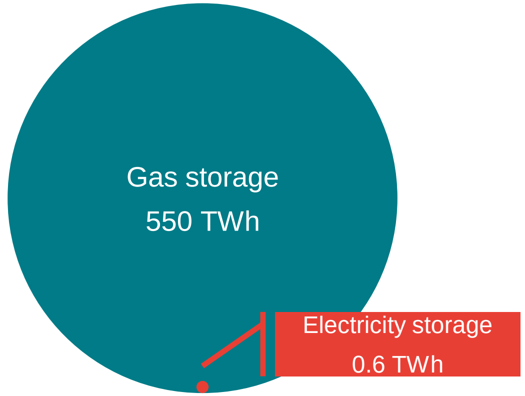
Chemical storage needed to bridge seasonal renewable supply and demand

Schematic annual profile of **PV generation**

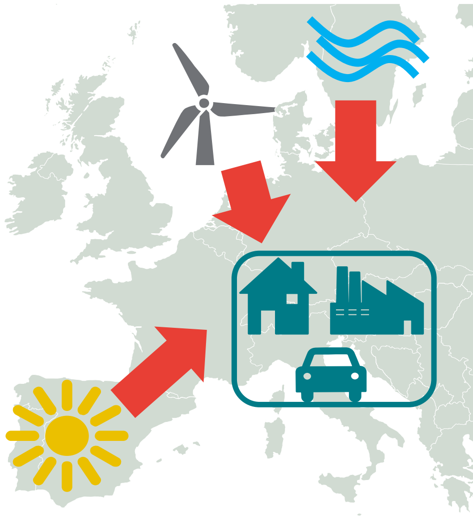


Monthly average **gas load**

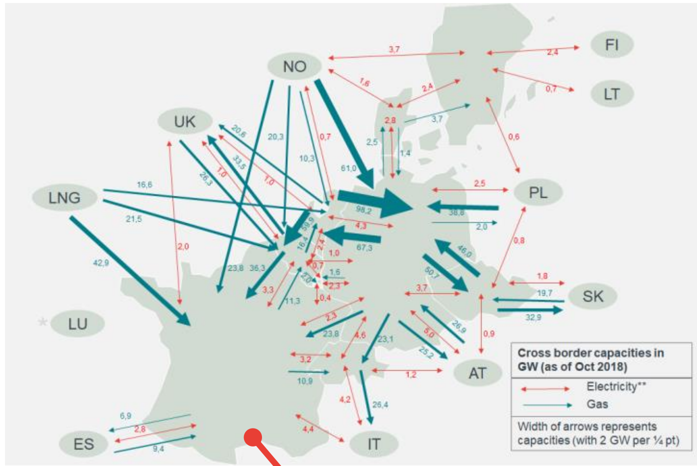
Gas storage volume is almost 1,000 times as large as electricity storage volume



Gas transport infrastructure helps to match supply and demand regionally



Cross-border transport capacities for gas exceed those of electricity by order of magnitudes



8 countries shown were analysed in the study

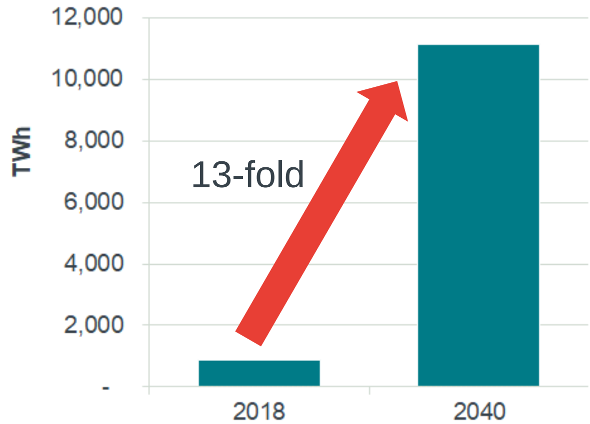
Source: Frontier Economics (2019):The value of gas infrastructure in a climate neutral Europe, *https://www.frontier-economics.com/media/3120/value-of-gas-infrastructure-report.pdf*

Significant amounts of renewable & low-carbon gas/fuels will be **imported from outside the EU**, similarly to fossil gas and fuels today

Today, more than 50% of EU's energy consumption is imported. For natural gas it is 80%

Need for RES will be substantial, creating the **challenge of finding appropriate and accepted generation locations within Europe**

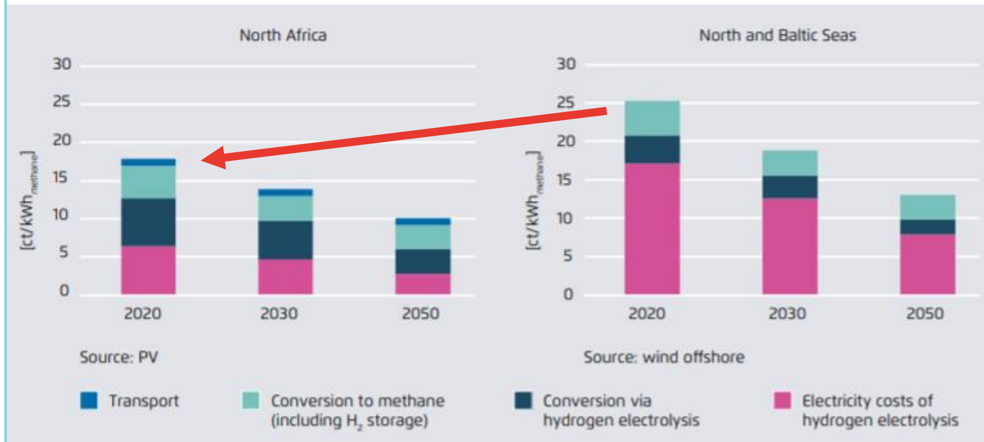
EU renewable electricity production



Despite reduced final energy demand, fulfilling total final energy consumption based on renewable electricity (or derived products such as green H2), would require EU renewable electricity production to multiply by factor 13* or more! And in many EU regions **local acceptance is already limited today…**

Import allows for substantial cost savings resulting from better (e.g. climate) conditions in other areas of the world

Example: X-region comparison of cost of synthetic methane generation

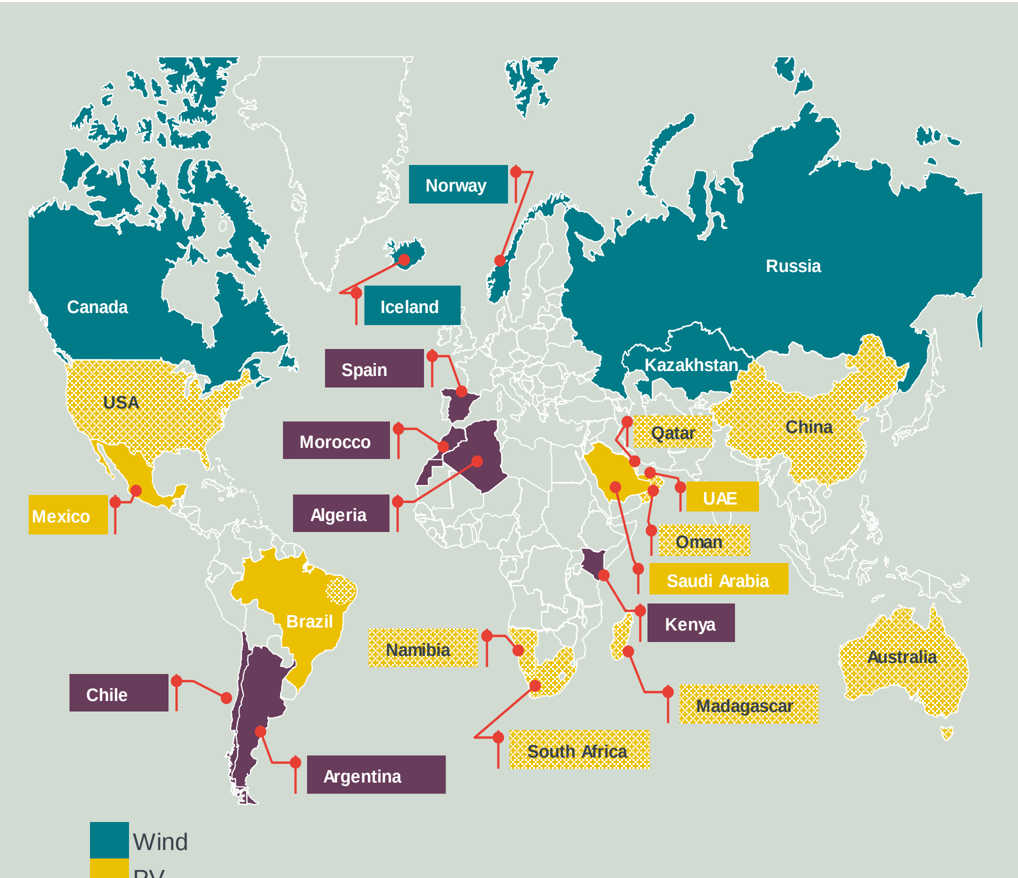


Source: Frontier Economics in: Agora Verkehrswende und Agora Energiewende (2018)

Assumptions graph on the left side: Final energy consumption develops according to IEA – World Energy Outlook 2019, Stated Policies Scenario, i.e. minus 17% by 2040 compared to 2018. All final energy demand which is not yet renewable (e.g. as biogas) is produced by renewable electricity (or products derived from that).

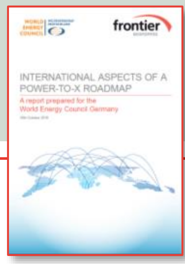
There is a large range of potential **countries to export** renewable and low-carbon gases and fuels – Example: PtX

Screening of potential PtX production countries
(Cost / natural potential / space / framework)



Cluster of potential export countries

Type	PtX Motivation and Readiness	Exam-ples
Front-runners	➢ Especially favourable in early stages of market penetration	Norway
Hidden Champions	➢ PtX could readily become a serious topic if facilitated appropriately	Chile
Giants	➢ Provide order of PtX magnitudes demanded in mature market	Australia
Hyped Potentials	➢ Potential to lead technology development; may depend on solid political facilitation	Morocco
Converters	➢ Strong motivation for PtX export technology; may require political facilitation	Saudi Arabia
Uncertain Candidates	➢ May drive PtX technology development, export uncertain	China



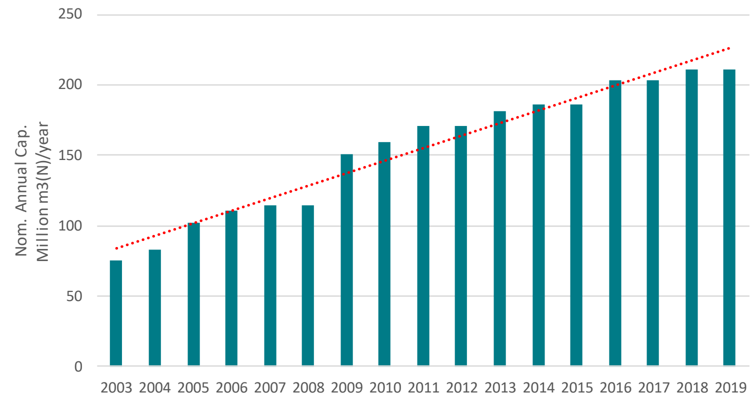
Source: Frontier Economics for World Energy Council (2019)

There are various potential **pathways** for the import of renewable and low-carbon gas and fuels – GLE defined four pathways (with sub-paths)

	0. LNG BAU	1.Upstream greenification	2. Downstream H_2"	3.Upstream H_2	4. e-fuels
Sub-paths		Bio LNG; Syn LNG	Methane reform.; Pyrolysis	Liquid H2; LOHC; Syn LNG; Ammonia	Ammonia; Methanol
Upstream production	Natural gas (CH_4)	**Bio- & synthetic methane (CH_4)**	Natural gas (CH_4)	**Production of green H_2**	**Production of green H_2**
Upstream conversion		Enrich / methanise		LOHC / methanise / N2 HB	Ammonia / methanol conversion
Export terminal and shipping	Liquid CH_4	Liquid CH_4	Liquid CH_4	**Liquid H2 (carriers)**	**Liquid NH_3 / CH_3OH**
Import terminal (EU)	Regasification of CH_4	Regasification of CH_4	Regasification of CH_4	**Regasification of liquid H_2 (carrier)**	
	OR	OR	OR	OR	
Direct liquid consumption	Consumption liquid CH_4	Consumption liquid CH_4	Consumption liquid CH_4	**Consumption liquid H_2/ methane/ N_2**	**Consumption of NH3 / CH3OH**
Further onshore processing			**CCS/CCU (e.g. SMR / pyrolysis)**		
Transmission, storage and end use	CH_4	CH_4	**H_2** (pure or blending)	**H_2** (pure or blending)	**NH_3 / CH_3OH**

LNG import facilities, having increased strongly in the EU, can play a vital role in most of these pathways & thus support EU decarbonisation

LNG import terminal capacity increased to 40 %* of EU total gas consumption



Source: Frontier Economics based on GIE, 2019

As additional decarbonisation support to the fuel switch from coal and oil to less carbon-intense natural gas that LNG already enables today

In addition to this discrete number of pathways there are various hybrid pathways, where LNG terminals can act as competitor (e.g. bio-LNG and syn-LNG as e-fuel competitor for ammonia or methanol)

LNG import infrastructure can play a vital role in most pathways

	1.Upstream greenification	2. Downstream „H_2	3.Upstream H_2	4. e-fuels
	Leveraging on expertise / skilled personal with transport of liquified gas and on location			
Shipping, import terminal, storage	Existing LNG infrastructure to import bio/syn LNG	Existing LNG infra to import LNG Possibly be active in CCSU (onsite) / CO_2 handling	Possibility to convert LNG infrastructure to facilitate some H2 carriers	Limited possibility to use/convert existing LNG infrastructure
Direct liquid consumption	Existing LNG bunkering / fuelling infra used with bio/syn LNG	Some of existing LNG bunkering / fuelling infra used for liquified H2	LNG bunkering / fuelling infra used for H2 carriers (e.g. liquid H2)	Some of existing LNG bunkering / fuelling infra used for e-fuels

* 40 % = Total LNG import terminal capacity of 210 BCM in EU (incl. UK), in relation to gas consumption of ~500 BCM.

All of these import pathways face substantial **barriers**, though, and GLE asked Frontier to analyse these & develop **policy recommendations**

To identify key barriers and develop policy recommendations, we took the following approach:

1. Longlist risks and barriers
- We listed the risks and barriers for each pathway at each stage in the value chain.

2. Identify key risks and barriers
- We highlighted the key barriers in bold and grouped them into categories
- These were the barriers, which we addressed with policy solutions in the next stage.

3. For each key barrier, list all relevant solutions
- We identified possible policy solutions.
- And described briefly each solution.

4. Evaluate solutions
- We checked relevance with regard to end user groups & pathways
- We evaluated each solution based on criteria similar to those used in the EC sector coupling study.

5. Final result: Shortlist/roadmap of policy solutions
- The shortlist is based on relevance and evaluation along the timeline.

In the main body of this presentation, focus on key barriers and policy recommendations. Further information on other steps in annex.

From a long list of barriers for each pathway we identified the following **key barriers** and grouped them into five categories

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<tr><td>Political / social</td><td>Opposition to use of biofuels and CO_2 if not from direct air capture</td><td>Opposition to import of fossil methane and, more particular, to CCU/S in EU Member States</td><td></td><td>Safety concerns around ammonia</td></tr>
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Excluded from further analysis since these barriers are not clearly addressable through policy solutions

We have identifed a long list of policies for each key barrier and evaluate them by the following **criteria**

Is the key barrier (e.g. cost or certification) considered addressed/overcome accurately?

Does intervention lead to economically efficient outcomes?

How does the policy affect gas consumers, and what amount of flexiblity does it provide to policymakers to allocate cost appropriately?

What is the expected acceptance of the policy solutions in the political sphere?

Uncompetitive costs are a key barrier common to all pathways, resulting from incomplete internalisation of carbon cost and low tech maturity

Barrier	Pathway 1 Upstream greenification	Pathway 2 Downstream low-carbon H2	Pathway 3 Upstream H2	Pathway 4 E-Fuels
Incomplete **internali-sation** of the true cost of carbon emissions	**No CO_2 pricing** in many sectors (e.g. heating, transport) to appropriately reflect the additional cost for producing, importing/transporting and storing of renewable and low-carbon gases			
	Bio LNG: Anerobic dig., thermal gasification Syn methane: Electrolysis and methanation	Investments for SMR/ATR or pyrolysis and CCUS Cost for infrastructure conversion / build (e.g. H2 network or CO_2 shipping)	Electrolysis / conversion Cost for infrastructure conversion / build (e.g. ships & import terminals to H2 carriers)	Electrolysis / conversion Cost for infrastructure conversion / build
	No extra remuneration for "green" value of renewable or low-carbon gas, or of differential impact on **flexibility** of supply (or demand)			
Techno-logical maturity of renewable/ low-carbon technolo-gies	**Low (large-scale) technological maturity** imply **learning spillovers** that hinder private investment			
	On RLCC production level			
	Thermal gasification (bio-LNG) and large-scale syn LNG immature	Conversion (ATR, pyrolysis & CCUS) immature	Large-scale electrolysis and conversion immature (apart from Haber-Bosch)	Large-scale electrolysis and conversion immature (apart from Haber-Bosch)
			Shipping / import of some H2 carriers immature	
		Large-scale H2 storage immature		

Local emissions are often not sufficiently internalised, too, but may be better addressed at local level.

Carbon pricing is the preferred long term policy, but further support mechanisms are required to enable the ramp up in the transition

Long-term: Carbon pricing with carbon leakage protection

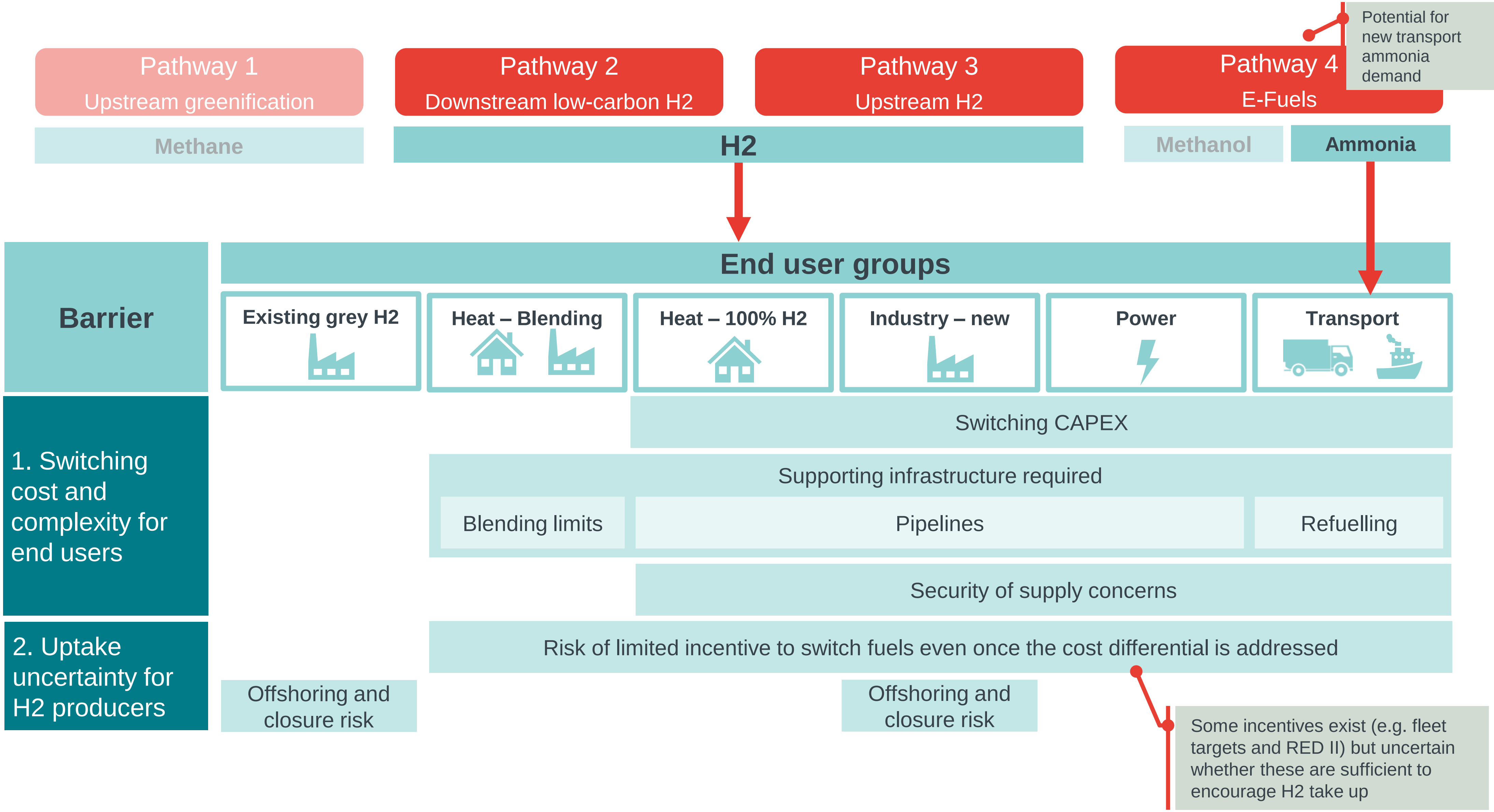
- In the long term, **carbon pricing** for all relevant sectors is the preferred option as it allows for efficient outcomes across the economy by enforcing competition between carbon abatement technologies
- **Expansion of ETS** to further sectors (e.g. heating, transport) is preferable over introducing tax, because it is leveraging an existing efficient EU level instrument and is least distortive
  - When expanding ETS to other sectors (and likewise when introducing demand obligations) it may need an **adjustment of carbon leakage protection measures**, such as an extension of the carbon leakage list or some form of carbon border adjustment mechanism. A carbon border adjustment mechanism could also help renewable and low-carbon commodities in itself, but needs cautious design e.g. with respect to burden on natural gas for blue hydrogen production.
- In addition, **changes to electricity and gas market design** should be made in order to ensure that prices fully reflect the value (cost) which more (less) **flexible** resources create (impose)

Short-term: Direct support, either downstream or upstream

In the short term some support will be needed (which in all cases may have *political issues about money leaving the EU*); there are options with upstream or downstream focus:

- **Upstream support** (**subsidy** such as **CfDs/FiP/FiT** or grants) can be effective to support immature generation as has been seen for REN electricity. Support should be allocated competitively, and in particular locationally neutral, incl. **allowing for level playing field between EU and non-EU producers**
- **EU infrastructure support** (grants or RAB) may be required for costs of new / retrofitted infrastructure e.g. LNG terminal retrofitting, pipeline conversion, new pipeline construction. Support should be allocated through an efficiently designed process.
- **Downstream**
  - One option is an **obligation scheme** for either general gas users/suppliers or specific gas (e.g. H2) users/suppliers to cover a share (“quota”) of their consumption by renewable or low-carbon commodity (or specifically e.g. H2), building on a scheme with tradeable certificates
  - **Downstream subsidies** constitute an alternative that does not burden but incentivises (low-carbon) gas use, but has no precedent and arguably provides less investor certainty over cost and demand

Switching cost/complexity for end users and uncertainty about future uptake are key **demand barriers** for the H2 pathways (2 & 3)



Different measures may be required in relation to different segments of demand

Policy type	Measure	Description
Demand creation policies	Short term: obligation on RLCC	▪ A **tradeable obligation to consume certain shares of renewable/low-carbon gas** could be imposed on existing grey H2 users. They would be likely to choose low-carbon hydrogen as the simplest alternative. ▪ **Measures to support less mature technologies** e.g. R&D and innovation funding.
Demand creation policies	Medium term: obligation on RLCC reviewed and extended	▪ A **tradeable obligation to consume renewable/low-carbon gas** could be placed on gas retailers / specific sectors for use in gas networks up to the blending limit. ▫ Initially the obligation could be **technology neutral** to allow networks / consumers to choose the most cost efficient gas (biomethane, renewable/low-carbon hydrogen) ▫ If renewable/low-carbon hydrogen maturity issues are still present, then a **specific hydrogen sub-obligation** could be used which would ramp up over time
Demand creation policies	Long term: upstream support with complementary measures	▪ Beyond existing H2 customers and limited grid blending, new H2 users face more substantial switching costs associated with converting equipment. These users will require **subsidy support for switching CAPEX** and potentially subsidy or stabilisation of the ongoing H2 price to minimise cost risks. ▪ Switching support is likely to need to be accompanied by **upstream support for producers** to mitigate demand risk. This can be addressed through support contracts that cover producers CAPEX regardless of demand (although note there is limited precedent), or a government backstop purchase agreement. ▪ Some types of end user may need stronger measures such as specific obligations and government coordination to switch, e.g. switching large sections of the methane grid to hydrogen for domestic heating.
Complementary policies	Ensure diversity of supply	▪ As H2 supply increases, **policy to support security of supply** should ensure that H2 users can be supplied from a diverse supplier portfolio. This could involve supporting imports of H2 via LNG terminals and other import facilities in addition to domestic production.
Complementary policies	CBAM	▪ In all cases, a **carbon border adjustment mechanism** (CBAM) is a desirable complement to limit offshoring risk for producers.

Certification and some standardisation forms the basis for future renewable/low-carbon commodity markets

Barrier	Pathway 1 Upstream greenification	Pathway 2 Downstream low-carbon H2	Pathway 3 Upstream H2	Pathway 4 E-Fuels
1. Certification	Lack of a common way of describing the carbon content and the sustainability of renewable/low-carbon comm. Same barrier	←	This may be especially challenging for production located outside EU	
2. Tech. standardisation			Exporting and importing infrastructure needs to be aligned further technically. Safety issues needs to be addressed further, too.	

In **RED II** already some form of "certification" addressed, but **some barriers remain**:

- Two certificates with different purposes
  - **Tradeable GoO** for all renewable energy
  - **Sustainability certificate** for biofuels, bioliquids and biomass fuels, including **GHG emissions savings** and **mass balancing**

  → Different uses refer to different form of certificates
- **Obligation** for Member States to **issue GoO only for renewable sources**, but not for low-carbon ones (this is optional)
- **"Mass balancing" approach may impede** the **blending** of renewable/low-carbon commodities into existing infrastructure (e.g. may prevent mixing of bioLNG to LNG in fueling stations)

Certificates of (avoided) operating emissions are essential for solving the cost and demand barrier, while standardisation may reduce cost

A single standardised certificate scheme proving at least carbon content is required

- For a number of policies addressing the demand and cost barrier – especially for the downstream obligations – a certificate scheme is required **which proves at least the carbon content of renewable/low-carbon commodities**. **Including sustainability aspects would be advantageous if feasible.**
- A **single scheme** or **at least interoperability** of schemes **across EU Member States and across different energy carriers** is advantageous as it offers opportunities and reduces transaction costs for market participants.
- **Conversion from one carrier to another** needs to be possible as we have multiple conversions along the value chain for some pathways (e.g. electricity to hydrogen to ammonia to hydrogen in path 3).

Establishement of technical standards on international level

- As commodities are not "new", **some form of technical standardisation** is **likely to be available already**, but e.g. new types of transports for hydrogen or direct consumption of ammonia in ships may **require additional technical standards** incl. safety regulations.
- **International technical standardisation** is demanding, but can be worth to develop as widely applied tech. standards **create security for private investors** and **reduce cost.**
- **Updating of tech. standards** is an ongoing issue espec. for rather immature technologies
- **LNG terminals** and other import infrastructure can play a role in managing gas quality standards at the point of import.

Coordination of investment along the value chain and across countries is relevant for aligning supply (outside EU) and (EU-)demand

Barrier	Pathway 1 Upstream greenification	Pathway 2 Downstream low-carbon H2	Pathway 3 Upstream H2	Pathway 4 E-Fuels
1. Coordination between exporting countries and EU (importing countries)	**High investment cost on production/conversion level** ▪ Bio LNG: Anerobic digestion, thermal gasification plants ▪ Syn methane: Electrolysis and methanation	"Old world" in terms of international coordination	**High investment cost on production/conversion level** ▪ Large-scale renewables ▪ H2 production via electrolysis ▪ Conversion for shipping (liquefaction, hydrogenisation, methanisation, ammonia)	▪ Conversion of H2 to ammonia / methanol
2. Coordination within the EU	No substantial new infrastructure required	**New large scale infrastructure investment** required, which will involve coordination challenges, including **lack of clarity over roles**, e.g. to what extent are LSOs allowed to take an active role in CCSU / CO_2 handling or TSOs in P2G production H2 T&S (repurposed pipelines / LNG terminals and new infrastructure) ▪ H2 production (SMR or pyrolysis) ▪ CCUS	H2 T&S (repurposed pipelines / LNG terminals and new infrastructure)	None for existing uses

Coordinating investment along the value chain effectively requires a range of policies - **summary**

Co-ordination with third countries

For pathways which require investment in non-EU countries (1, 3 and 4), specific policies are likely to be required

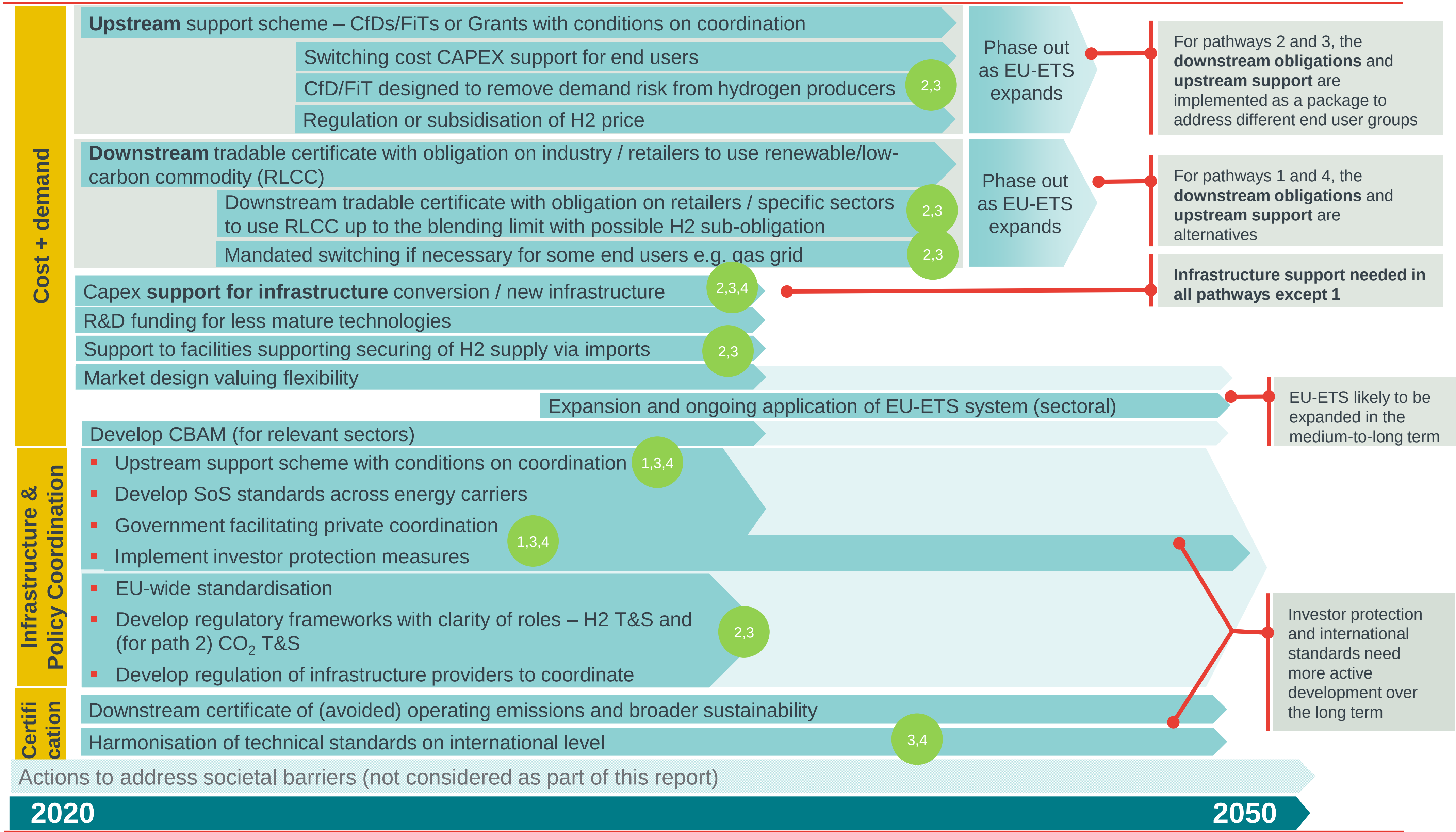
- Encouraging or enforcing **co-ordination in upstream (long-term) subsidy contracts** would be a route to reducing co-ordination risk for relevant investors and infrastructure providers. It is also arguably the point of maximum leverage
- Removing or reducing the exposure of investors to country specific risk through **investor protection measures** would also ensure risk is allocated more efficiently / costs are lower
- These measures are likely to be easier to achieve if accompanied by **diplomatic initiatives** to build trust, and align state objectives and incentives
- **EU-Guideline** recommending to **diversify supplier** countries for each RLCC and to conclude long term contracts can help ensuring long term security of supply

EU level co-ordination

For pathways which involve significant within-EU trade and transport of H2 (2 and 3), further policies are likely to be required

- Measures which help to maximise the market for international exporters, such as **transparent and harmonised technical standards as well as a coherent certification system**, will help to encourage investment by mitigating demand risk. They will also help facilitate intra-EU competition
- Measures which reassure investors that there will be efficient integration across the value chain will also help reduce the perception of risk – these include:
  - Regulation to **ensure co-operation of relevant EU infrastructure providers** (e.g. interoperability, co-ordination of required investments)
  - Developing **regulatory frameworks to ensure access to and investment in H2 and CO_2 infrastructure** including **clarity of roles** for different entities (LSO, TSO) with no unnecessary barriers

Roadmap: In the long run EU-ETS enables a low carbon society, while near term policies are needed to support RLCC take-up



Implementation of policies to address cost and demand barriers is different across the pathways, with additional measures needed in 2 + 3

Near term solutions are alternatives to each other (Pathway 1)

Near term solutions need to be implemented as a package to address different end user groups (Pathways 2 and 3)

Near term solutions are alternatives to each other (or as a package for new ammonia demand) (Pathway 4)

<table>
<tr><th></th><th></th><th>Pathway 1
Upstream greenification</th><th>Pathway 2
Downstream low-carbon H2</th><th>Pathway 3
Upstream H2</th><th>Pathway 4
E-Fuels</th></tr>
<tr><td rowspan="9">Near term</td><td rowspan="2">Upstream support (CfD / grant)</td><td>CfD/FiT paid to green CH4 producers incl. non-EU</td><td colspan="2">CfD/FiT paid to renewable/low-carbon hydrogen producers (incl. non-EU) designed to remove demand risk</td><td>CfD/FiT paid to e-fuel producers incl. non-EU</td></tr>
<tr><td></td><td colspan="2">Regulation or subsidisation of H2 price for end users</td><td></td></tr>
<tr><td>Switching /conversion cost support</td><td></td><td colspan="2">CAPEX support for infrastructure conversion (pipelines, LNG terminals, other import infrastructure) and new end user switching costs (industry, transport)</td><td>Switching cost CAPEX support for new end users (transport)</td></tr>
<tr><td rowspan="2">Downstream tradable certificate with an obligation</td><td>Tradable obligation on industry / retailers / suppliers to use RLC gas</td><td colspan="2">Tradable obligation to use RLC gas on existing grey H2 users</td><td>Tradable obligation on industry / retailers / suppliers to use RLC commodity</td></tr>
<tr><td></td><td colspan="2">Tradable RLCC obligation on retailers for blending up to limit (specific H2 obligation may be necessary if low maturity issues persist)</td><td>New ammonia transport users may require a renewable ammonia specific obligation</td></tr>
<tr><td></td><td colspan="4">Market design valuing flexibility</td></tr>
<tr><td></td><td></td><td colspan="2">Mandated switching may be required for challenging end users e.g. large sections of the gas grid</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Support to facilities securing H2 supply via imports</td><td></td></tr>
<tr><td>Innovation support</td><td colspan="4">R&D funding for less mature technologies</td></tr>
<tr><td rowspan="2">Long term</td><td>EU-ETS</td><td colspan="4">Expansion and ongoing application of EU-ETS system (sectoral)</td></tr>
<tr><td>CBAM</td><td colspan="4">Carbon border adjustment (for relevant users only)</td></tr>
</table>

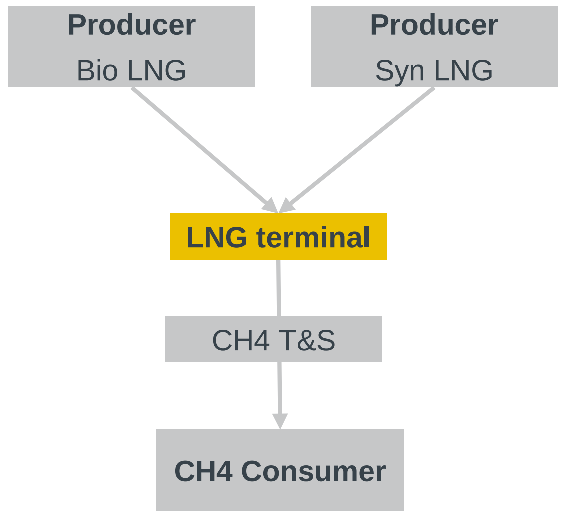
Coordination and certification policies per pathway shows that hydrogen pathways (2 & 3) require additional measures compared to 1 & 4

	Pathway 1 Upstream greenification	Pathway 2 Downstream low-carbon H2	Pathway 3 Upstream H2	Pathway 4 E-Fuels
Coordination between exporting countries and EU	Producer and infrastructure support with conditions on coordination		Producer and infrastructure support with conditions on coordination	(cont.)
	Development and ongoing ensuring of security of supply standards across energy carriers	(cont.)	(cont.)	(cont.)
	Government facilitating private coordination		Government facilitating private coordination	(cont.)
	Investor protection		Investor protection	(cont.)
Coordination within the EU		Develop and ongoing improvement of H2 T&S regulatory framework including clarity of LSO / TSO roles	(cont.)	
		Develop and ongoing improve-ment of CO_2 T&S regulatory framework		
		EU-wide standardisation	(cont.)	
		Conditions on infrastructure providers to coordinate	(cont.)	Needed for new ammonia users
Certification	Downstream certificate of (avoided) operating emissions and broader sustainability	(cont.)	(cont.)	(cont.)
	Harmonisation of technical standards on international level		Harmonisation of technical standards on international level	(cont.)

Pathway 1: Existing infrastructure is utilised, therefore the key policy solutions are producer support and establishing a certification system

B Upstream support scheme – CfDs or Grants – with conditions on coordination for the bio-LNG and syn LNG producers

R&D support for immature technologies



Investor protection

Government facilitating private coordination

A Downstream tradable certificate of (avoided) emissions with obligation on LCC

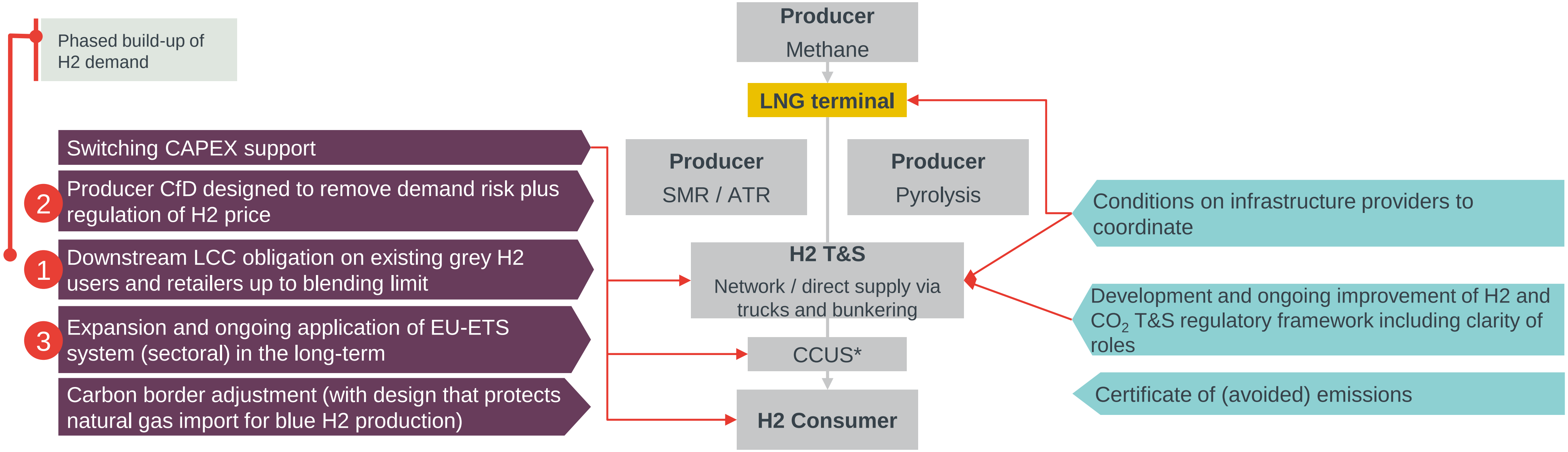
Expansion and ongoing application of EU-ETS system (sectoral) in the long-term

Carbon border adjustment

Certificate of (avoided) emissions

	Bio-LNG	Syn-LNG
Role of LNG terminals	▪ Existing LNG infrastructure is used: ▪ Import bioLNG or synLNG ▪ Bunkering / fuelling infrastructure used with bioLNG or synLNG ▪ No changes and no financial support required to equipment	
Policy implications	▪ No LNG-specific policy required to enable pathway ▪ Management of technical standards for commodity quality of bioLNG and synLNG imports could be supported by LNG terminals	

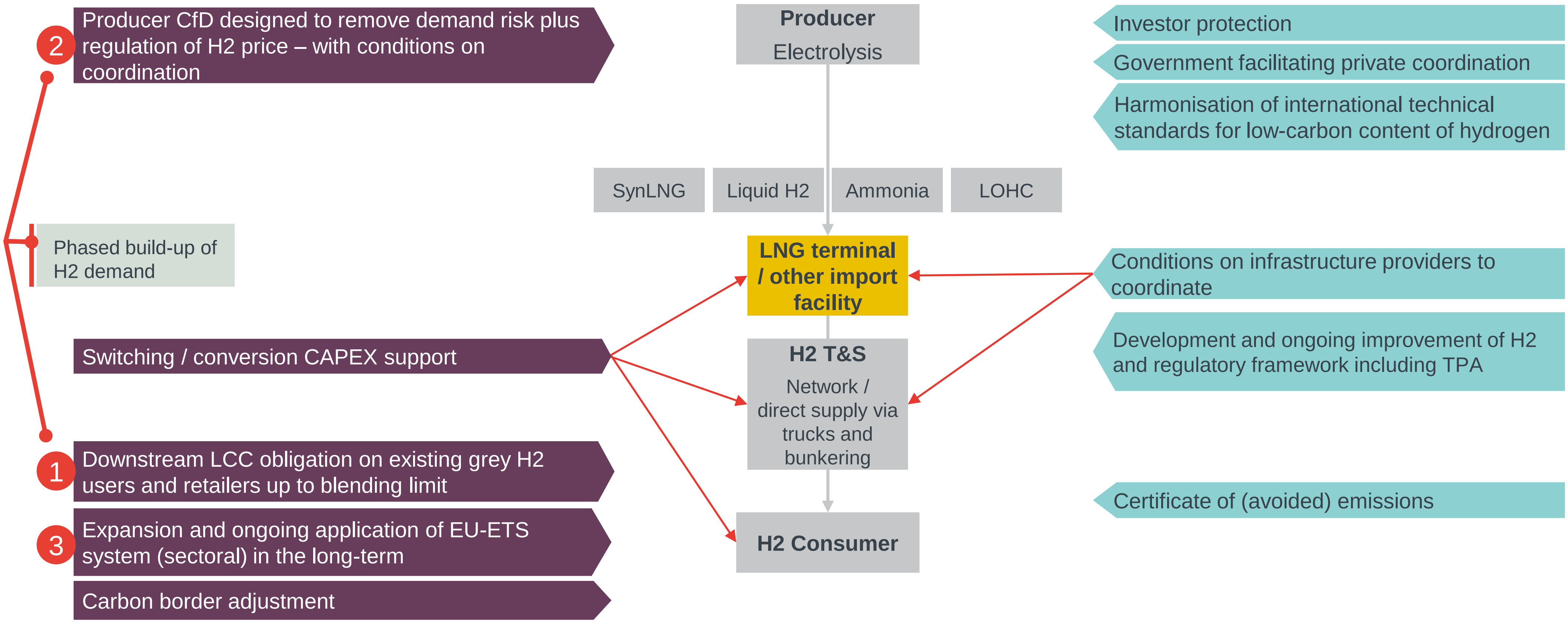
Pathway 2: A full hydrogen strategy is required, but downstream production may be easier to coordinate



	Methane reformation	Pyrolysis
Role of LNG terminals	▪ Existing LNG infrastructure is used to import LNG ▪ Some existing LNG bunkering / fuelling infrastructure used for liquified hydrogen	▪ Existing LNG infrastructure is used to import LNG ▪ Some existing LNG bunkering / fuelling infrastructure used for liquified hydrogen
	▪ LNG terminal expertise and location could be used to develop CO_2 terminals for liquid shipping to offshore injection sites	
Policy implications	▪ No LNG-specific policy necessary to enable the pathway	▪ No LNG-specific policy necessary to enable the pathway
	▪ EU policy clarity on roles of actors (LSO, TSO etc) within the hydrogen regulatory framework to ensure there are no unnecessary barriers, e.g. with respect to CO_2 capturing, transport and handling	

CCUS may face significant societal opposition. We have not addressed this barrier within this report.

Pathway 3: A full H2 strategy is required, along with policy support for upstream production and coordination across the value chain **(1/2)**



Pathway 3: A full H2 strategy is required, along with policy support for upstream production and coordination across the value chain **(2/2)**

	Liquid H2	LOHC	Syn-LNG	Ammonia
Role of LNG terminals	▪ Possibility to convert LNG infrastructure to facilitate low-carbon H2 carrier ▪ Liquid H2 ships likely to be similar to LNG ships ▪ Cyrogenic infra (e.g. storage tanks) could be adapted ▪ LNG bunkering infrastructure used for liquid H2 consumption	▪ No direct role for LNG terminal ▪ Potential role for LNG bunkering / refuelling infrastructure to be used for e-fuels	▪ Existing LNG infrastructure is used to import synLNG and for bunkering / refuelling ▪ No changes required to equipment	▪ Cryogenic facilities of LNG terminal could be used for storage ▪ Potential role for LNG bunkering / refuelling infrastructure to be used for e-fuels
Policy implications	▪ EU policy clarity on roles of actors (LSO, TSO etc) within the hydrogen regulatory framework to ensure there are no unnecessary barriers			
	▪ Government facilitating coordination / co-location of LNG terminals / other import facilities and hydrogen industrial cluster sites to provide security of supply (imports can complement domestic production) ▪ Regulation of H2 infrastructure including technical standards for commodity quality of H2 imports (could be managed/supported by LNG terminal operators) ▪ Capex conversion support (grant or RAB) to subsidise LNG infrastructure (or other import facilities) adaptation via an efficiently designed allocation process ▪ Competition between liquid H2 route and alternatives (e.g. pipelines) supported by ensuring H2 subsidies are neutral to the import route	▪ No additional LNG-specific policy necessary to enable sub-pathway		▪ Capex conversion support (grant or RAB) to subsidise LNG infrastructure (or other import facilities) adaptation via an efficiently designed allocation process

Pathway 4: Level playing field should ensure that LNG can compete with e-fuels

B
- Upstream support scheme – CfDs or Grants – with conditions on coordination
- R&D support for immature technologies

A
- Downstream tradable certificate of (avoided) emissions with obligation on LCC
- Expansion and ongoing application of EU-ETS system (sectoral) in the long-term
- Carbon border adjustment

Producer
Electrolysis

Ammonia | Methanol

Import facility

New ammonia consumers | **Existing ammonia & methanol consumers**

- Government facilitating private coordination
- Investor protection
- Harmonisation of international technical standards for low-carbon content of hydrogen
- Certificate of (avoided) emissions

	Methanol	Ammonia
Role of LNG terminals	▪ Potential role for LNG bunkering / refuelling infrastructure to be used for e-fuels	
	▪ No direct role for LNG terminals	▪ Cryogenic facilities of LNG terminal could be used for storage
Policy implications	▪ No additional LNG-specific policy necessary to enable sub-pathway	
		▪ Capex conversion support (grant or RAB) to subsidise LNG infrastructure (or other import facilities) adaptation via an efficiently designed allocation process

Details to the barriers and potential solutions – **Cost**

Cost barrier & solutions

Demand barrier & solutions

Certification barrier & solutions

Co-ordination barrier & solutions

The cost barrier can be addressed by pricing the negative external effects of CO_2 and/or by subsidising renwable/low-carbon technologies

Measure type	Solution	Description
Carbon cost internalisation	Expansion of **EU-ETS** system (sectoral)	For selected installations in the EU, a cap is set on the total amount of CO_2 emissions. The ETS regime could be extended to further installations in the EU (e.g. to the transport or private consumption sector) and could be tightened
	CO_2-Tax (in non-ETS sectors)	CO_2 emissions from fossil fuels (in non-ETS sectors) are taxed by a certain price per kg CO_2. Tax could be applied at import level or at consumption level within the EU
Upstream support	**Upstream support subsidy – CfDs** (e.g. Carbon contract for difference)	Producers of a RLCC receive a subsidy to account for the difference between their production costs/sales price and the production costs/price of the fossil reference product (e.g. natural gas or grey H2). Difference could also be referenced to CO_2 price.
	Upstream support – Grants	RLCC producers get a fixed grant per production unit (e.g. MW electrolyser) installed
	Upstream support – Loans	RLCC producers get a soft loan per production unit (e.g. MW electrolyser) installed
EU infrastructure support	**Conversion / build support –** Grant or RAB	Support for costs of new / retrofitted infrastructure e.g. LNG terminal retrofitting, pipeline conversion, new pipeline construction, storage conversion / new build
Downstream support	Downstream **certificate scheme with an obligation** on RLCC consumption	Producers sell RLCC certificates along with RLCC. For cost efficiency, these certificates can be traded de-coupled from the commodity. In addition, an obligation is placed on a party (supplier, retailer, industry) to buy (general or specific) RLCC certificates for a certain share of their commodity consumption.
	Downstream RLCC subsidies	Retailers receive a certain amount of money if they consume RLCC instead of fossil.
Market design	Market design valuing **flexibility** fully	Changes to gas and electricity market design (e.g. network tariffs and levies) in order to ensure that prices fully reflect the value (cost) which more (less) flexible resources create (impose).

Summary refers to general policies, which could be applied cross-sectorally. We do not include sector specific solutions (such as fleet targets for OEMs in the transport sector).

Carbon pricing solutions internalise the cost of carbon emissions efficiently, but may be difficult to implement short-term

Solution	Effectiveness		Efficiency		Complexity / Political feasibility		Distributional effects		Shortlist policy?
Expansion of EU-ETS system (sectoral)	0	▪ Enables internalisation of societal cost of emissions ▪ But cap / CO_2 price need to be ambitious to allow profitability of any of the 4 pathways (if no further measures to address cost issue such as subsidies)	+	▪ Cap & trade enforces competition between CO_2 avoidance techs which ensures efficient tech choice (in static and – in case of good price management – dynamic perspective)	0	▪ Building on existing system, but further sectors may require distinct design features ▪ Imaginable in the longer-term (e.g. beyond 2030)	0	▪ Integration of additional sectors with high CO_2 avoidance cost likely to increase CO_2 price for existing ETS sectors and thus increase electricity or industry product prices ▪ Possibility to re-distribute additional ETS auction revenues to customers / tax payers, though ▪ Carbon leakage risks needs to be addressed (e.g. by special treatment for exposed domestic industry or by carbon border adjustment mechanisms)	✓ (in the long-term)
CO_2-Tax (in non-ETS sectors)	0	(see above)	0	▪ Sector-specific CO_2 price entails risk of bias between CO_2 avoidance techs and inefficient choice of techs	-	▪ Could be based on already implemented systems in selected EU member states, but more likely to be on member state level than EU level ▪ Implementation complex, especially if taxes are to avoid risk of bias between CO_2 avoidance techs	0	▪ Higher carbon taxes can have similar distributional effects to higher EU-ETS prices ▪ Though sector-specific CO_2 prices allow targeted taxation with fewer unintended distributional effects	✗

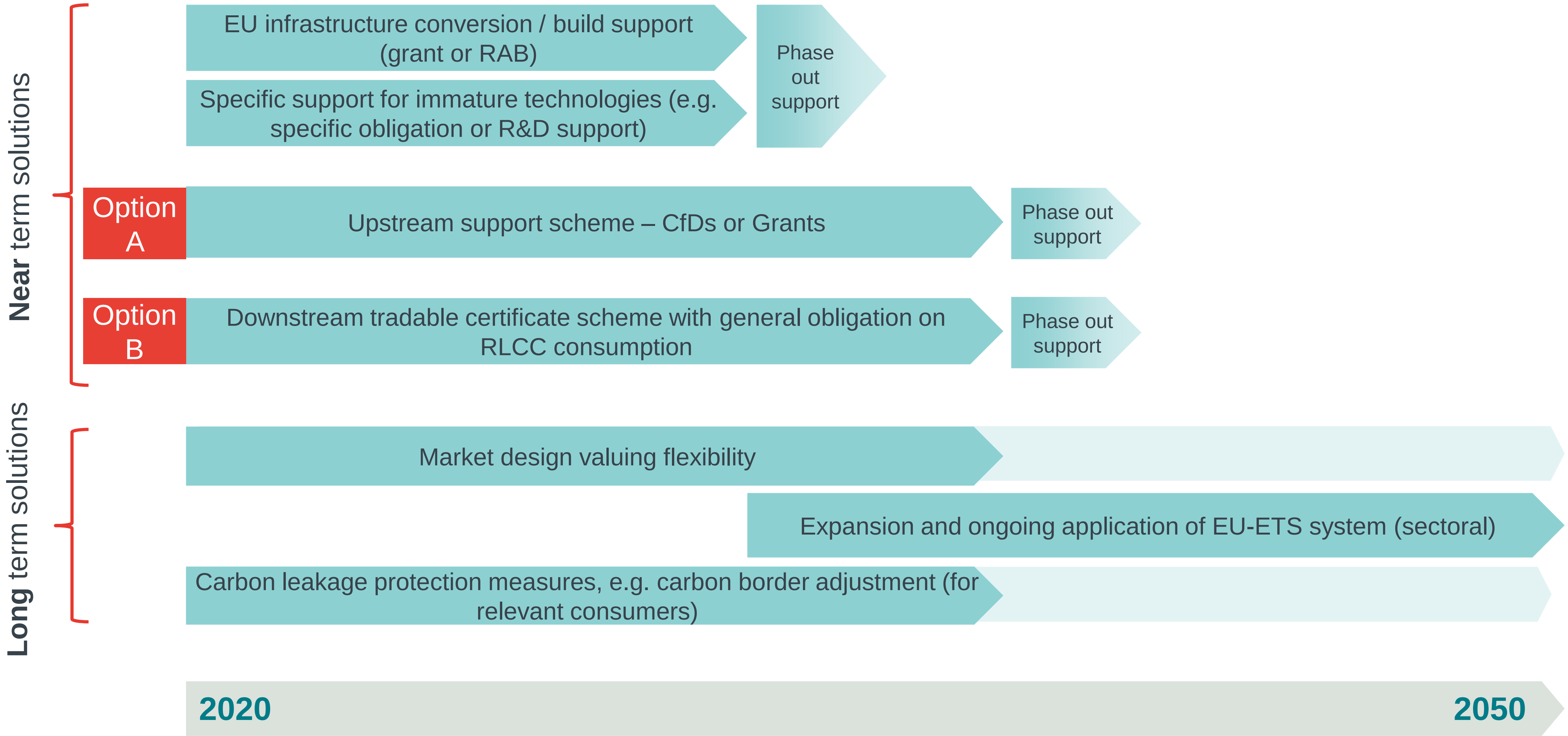
In the short-term, direct subsidies play an important role for enabling a large-scale roll-out of renewable or low-carbon technologies

<table>
<tr><th>Solution</th><th colspan="2">Effectiveness</th><th colspan="2">Efficiency</th><th colspan="2">Complexity / Political feasibility</th><th colspan="2">Distributional effects</th><th>Shortlist policy?</th></tr>
<tr><td>Upstream support scheme – subsidy in the form of a CfD</td><td>+</td><td>▪ Depends on subsidisation of the full cost difference or of OPEX</td><td rowspan="3">0</td><td rowspan="3">▪ Tech-/product-specific approach entails risk of bias between CO_2 avoidance techs and inefficient choice of techs due to different prices for CO_2</td><td rowspan="3">0</td><td rowspan="3">▪ Acceptance of support scheme might be low due to implicit financing of installations abroad</td><td rowspan="3">0</td><td rowspan="3">▪ Distributional effects depend on source of money and whether guarantee of sale of RLCC to EU
▪ Grant may be worse as funding states have to find the cash up front.
▪ Loans have fewer distributional issues as only sacrifice „soft“ interest.</td><td>✓</td></tr>
<tr><td>Upstream support scheme – Grants</td><td>0</td><td>▪ Funding of investment cost of early projects can lead to cost reductions and spillover effects, but is only effective if investment cost are the essential part of cost (and not OPEX)</td><td>✓</td></tr>
<tr><td>Upstream support scheme – Loans</td><td>-</td><td>▪ Only addresses risks linked to openness of capital markets</td><td>✗</td></tr>
<tr><td rowspan="2">EU infrastructure conversion / build support (grant or RAB)</td><td rowspan="2">+</td><td rowspan="2">▪ Subsidy directly addresses the need for new / converted infrastructure to support decarbonisation technologies</td><td rowspan="2">0</td><td rowspan="2">▪ Tech-/product-specific approach entails risk of bias between CO_2 abatement techs and inefficient choice of techs due to different prices for CO_2
▪ Support allocation process must be designed efficiently</td><td rowspan="2">0</td><td rowspan="2">▪ State aid for grants to be checked
▪ Existing RAB structures and regulation are already in place for network owners and regulated terminals
▪ Complex to design such that all gas customers do not pay for infra that is only being used by some</td><td>+</td><td>▪ Grant: Flexibility for funding the policy from taxpayers or gas users rather than specific end user groups</td><td rowspan="2">✓</td></tr>
<tr><td>0</td><td>▪ RAB: Existing gas network users pay for infrastructure that they may not be using
▪ Support for terminals must ensure level playing field between reg & non-reg terminals</td></tr>
</table>

…. while policies to indicate the "green" value and downstream obligations help to create demand…

Solution	Effectiveness		Efficiency		Complexity / Political feasibility		Distributional effects		Shortlist policy?
Downstream certificate scheme (define tradable certificates of (avoided) emissions) with an obligations on RLCC consumption	+	▪ Enforces willingness to pay for additional cost of renewable/low-carbon production such that target techs become profitable	0	▪ Tech-/product-specific approach entails risk of bias between CO_2 avoidance techs and inefficient choice of techs due to different prices for CO_2 ▪ Absence of contractual unpinning for subsidy may result in higher overall costs (compared to producer CfD)	0	▪ Generally some form of internationally tradeable certificate of (avoided) operating emissions expected to be developed ▪ Challenge to ensure additionality of supply and synchronicity of supply & demand ▪ Acceptance of obligation might be low due to implicit financing of installations abroad	0	▪ Extra cost borne by consumers of product to which the obligation refers (e.g. existing H2 consumers if quota forces them to source a share as green H2)	✓
Downstream subsidies for RLCC	0	▪ Subsidy needs to reflect additional cost of renewable/low-carbon-technologies, such that desired level of reduction difficult to meet ▪ Consumers need to favour renewable/low-carbon commodity	0	▪ Tech-/product-specific approach entails risk of bias between CO_2 avoidance techs and inefficient choice of techs due to different prices for CO_2 ▪ Absence of contractual unpinning for subsidy may result in higher overall costs (compared to producer CfD	-	▪ The use of downstream subsidies as a route to incentivise decarbonisation has few precedents to date ▪ Potential superficial advantage of directing subsidies to EU consumers, but ultimately money has to reach the investor abroad anyway	0	▪ Depends on cost reflectivity of subsidy ▪ Distributional effects between taxpayers (or whoever is funding subsidy) and consumers	✗
Market design valueing **flexibility** fully, e.g. flexibility cost-reflective electricity tariffs and levies	+	▪ Can help to improve business case for RLCC value chain, e.g. if capacity-based electricity network tariffs for end consumers reflect real system cost of electricity peak consumption and increase value of RLCC	+	▪ Improves efficiency of investment and operation decisions	0	▪ Design of cost- and flexibility reflecting system is complex, but many efforts underway in that direction already ▪ Many market design features (e.g. taxes, levies and tariffs) determined on national level	0	▪ Distributional effects on other gas/electricity network users	✓

Carbon pricing as the preferred long term policy, but further support mechanisms required to enable the ramp up in the transition



Details to the barriers and potential solutions – **Demand**

Cost barrier & solutions

Demand barrier & solutions

Certification barrier & solutions

Co-ordination barrier & solutions

Obligation-based demand policy solutions address both demand barriers, while other policies address only (1) or (2)

We have focused on hydrogen here but similar measures could be used to support e-fuels

Barriers	Solution	Description
(1) Switching cost and (2) hydrogen uptake uncertainty	Mandated conversion to renewable/low-carbon H_2	An obligation is placed on parties (specific industrial plants or sectors) to convert to using renewable or low-carbon hydrogen. The obligation ramps up over time
	Obligation on renewable or low-carbon fuel	A obligation is placed on a party to show that a percentage of the fuel they use is renewable/ low-carbon. Obligated parties can trade certificates for cost efficiency. The obligation could be placed on: end users (existing grey H2 users; industrial gas customers; transport users) or gas retailers. The obligation could specify that the obligated party must use a low carbon commodity or low carbon hydrogen specifically.
	Prohibition	Producers of high-carbon fuels are closed down over time / consumption of specific fossil fuels are prohibited.
(1) Switching cost	Conversion support – Grant	Government directly funds customer conversions (similar to EV user grant).
	Conversion support – RAB	Conversion costs and new pipelines are included in the regulated asset base of the network operator e.g. for network.
	Conversion support – Loan	Conversion costs are covered by government loans at favourable interest rates.
(2) Hydrogen uptake uncertainty	Long-term subsidy contract with government purchase agreement	Upstream producer subsidy contracts are long term to provide certainty. Government acts as a buyer of last resort if hydrogen demand falls below an agreed level.
	Subsidy contracts cover CAPEX regardless of H2 demand	Upstream producer subsidy contract payments are designed to cover producers' up front CAPEX regardless of the level of H2 demand. This removes demand risk from producers (as they have certainty that their costs will be covered).
	Regulation or subsidy of H2 price	H2 price is regulated to give users more certainty over their future costs. The regulation could take the form of volatility smoothing, or subsidies paid to end users to reduce the H2 price
	Carbon border adjustment	Carbon border tax is applied to imports to prevent offshoring (would need to be designed not to penalise import of natural gas for blue hydrogen production).
	Diversity of H2 supply	Hydrogen strategy that ensures that H2 supply is diverse e.g. imports via LNG terminals and other import facilities can complement domestic production to provide users with better security of supply.

Obligations may need to be H2-specific to address the demand uncertainty for H2 producers

Solution		Effectiveness		Efficiency		Complexity / Political feasibility		Distributional effects		Shortlist policy?
Mandated conversion		+	▪ Addresses switching barrier directly	0	▪ Not sector and technology neutral, entails the risk of choosing "wrong" sectors/technologies	-	▪ May be politically challenging to mandate industry conversion	0	▪ Conversion costs borne by end users	✗
Obligation on RLCC	Existing grey H2 users	+	▪ Creates relatively certain demand for renewable/low-carbon H2	+	▪ Technology neutral option which should incentivise take up of the most cost-effective renewable/low-carbon option	0	▪ Generally some form of internationally tradeable certificate of (avoided) operating emissions expected to be developed ▪ Challenge to ensure additionality of supply and synchronicity of supply & demand	0	▪ Extra cost borne by consumers of low carbon gas	✓
	Retailers up to blending limit	-	▪ May not incentivise take up of H2 over other cheaper renewable/low-carbon gas alternatives e.g. biomethane							✗
	Retailers / industry beyond blending limit									✗
Obligation on H2	Existing grey H2 users	+	▪ Creates relatively certain demand for renewable/low-carbon H2	0	▪ Not a technology neutral option but may be efficient in the long run if there are spillovers associated with less mature hydrogen technologies			0	▪ Extra cost borne by consumers of low carbon hydrogen	✓
	Retailers up to blending limit									✓
	Retailers / industry beyond blending limit					-	▪ May be politically challenging to oblige industry conversion without associated subsidy support			✗
Prohibition		-	▪ May not incentivise take up of H2 over other cheaper renewable/low-carbon alternatives	+	▪ Technology neutral option which should incentivise take up of the most cost-effective renwable/low-carbon option	+	▪ Precedent exists with coal phase outs / bans on diesel cars	0	▪ May impact some consumers negatively if they are forced to switch without compensation	✗

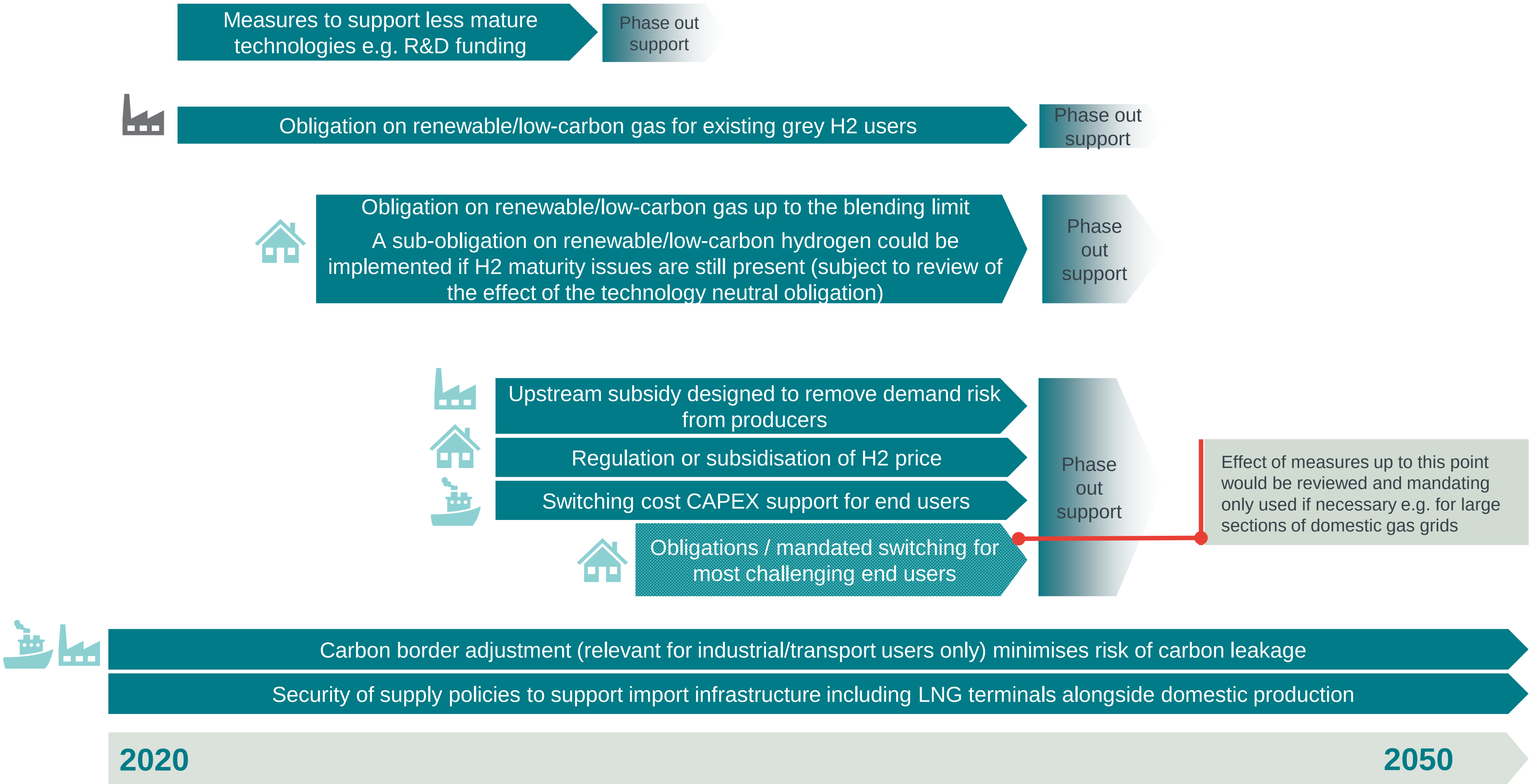
Capex support can address the cost of switching, but is likely insufficient to incentivise H2 take-up without complementary policies

Solution	Effectiveness		Efficiency		Complexity / Political feasibility		Distributional effects		Shortlist policy?
Conversion support: Grant (industrial and transport end users)	+	▪ Addresses switching cost barrier directly ▪ May be insufficient to incentivise takeup without complementary policies	0	▪ Not sector neutral ▪ Grant allocation process must be efficiently designed	0	▪ Potential state aid problems ▪ Risk of unintended consequences depends on inclusiveness for all renewable/low-carbon technologies	+	▪ Flexibility for funding the policy from taxpayers or gas users rather than specific end user groups	✓ (With complementary policies)
Conversion support: RAB (infrastructure e.g. pipelines)	+		0	▪ Efficiency incentives can be included in the regulatory framework	0	▪ Existing RAB structures and regulation are already in place for network owners ▪ Complex to design such that all gas customers do not pay for H2 infrastructure that is only being used by some	0	▪ Existing gas network users pay for H2 infrastructure that they may not be using	✓ (With complementary policies)
Conversion support: Loan (industrial and transport end users)	-	▪ No incentive to take up loans if there is no increased profit associated with adopting renewable/low-carbon fuels ▪ Could be useful alongside measures that make high-carbon fuels more expensive than renewable/low-carbon	+	▪ Loan allocation process must be efficiently designed	0	▪ Potential state aid problems ▪ Risk of unintended consequences depends on inclusiveness for all renewable/low-carbon technologies	+	▪ Conversion costs borne by end users, but overall costs comparably low	✗

Long term subsidy contracts provide additional demand and price certainty

Solution	Effectiveness		Efficiency		Complexity / Political feasibility		Distributional effects		Shortlist policy?
Long-term subsidy contracts with government purchase agreement	+	▪ Provides long term demand certainty for producers / price certainty for users ▪ Does not address switching costs	+	▪ H_2 demand mainly policy driven so government bears demand risk ▪ Government only faces high costs from backstop purchases if H_2 demand is low ▪ Long-term contracts efficient for both parties for high sunk investment	0	▪ Terms of government buyout could be complex to design (e.g. determining the threshold at which the govt buys) ▪ Lack of precedent	0	▪ Flexibility for funding the policy from taxpayers or gas users rather than specific end user groups	✓
Producer subsidy contracts cover CAPEX regardless of H2 demand	+	▪ Provides long term demand certainty for producers / price certainty for users ▪ Does not address switching costs	+	▪ H_2 demand mainly policy-driven so government bears demand risk ▪ Importing country pays producer CAPEX even if H_2 demand is high	0	▪ Lack of precedent ▪ Does not require ongoing government involvement	0	▪ Could involve high upfront costs for the importing country ▪ Flexibility for funding the policy from taxpayers or gas users rather than specific end user groups	✓
Regulation or subsidisation of H2 price	0	▪ Addresses switching complexity through providing price certainty for users ▪ Does not address switching costs or ongoing price difference between hydrogen and high-carbon alternatives	0	▪ Regulation may be needed less over time if a liquid H_2 market develops	-	▪ Choosing appropriate index for H_2 price is challenging when no H_2 market exists ▪ Design of allocation of risk that cost > price is complex and has distributional challenges	0	▪ Prevents producers charging excessively high prices ▪ Passes (some) of the cost risk to (customers or tax payers) in importing country	✓
Carbon border adjustment	0	▪ Reduces offshoring risk ▪ Only relevant for industrial users ▪ Does not incentivise H_2 take up specifically	+	▪ Creates a level playing field for domestic industry and imports (as long as there is an effective EU carbon tax system in place)	0	▪ Policy may have negative international trade implications ▪ Designing exemptions may be complex	0	▪ Increase costs to customers of industrial products	✓ (for relevant users)
Diversity of H2 supply support policy	0	▪ Reduces SoS risk ▪ Does not incentivise H_2 take up specifically	+	▪ Competition between imports and domestic production supports efficient outcomes	0	▪ May be political inclination to support domestic production	0	▪ No distributional effects	✓

In the near term, obligations can encourage H2 takeup for existing grey H2 users and limited blending…



…while in the longer term, new H2 users are likely to require subsidy support to switch

Details to the barriers and potential solutions – **Certification**

Cost barrier & solutions

Demand barrier & solutions

Certification barrier & solutions

Co-ordination barrier & solutions

The certification barrier can be addressed by developing (international) certification regimes and technical gas standards

Barrier	Solution	Description
Certifi-cation	Certificate of (avoided) operating emissions	Development of a standardised certification regime for indicating the carbon content of (renewable/low-carbon) commodities. Interoperability of certificates at least across EU Member States and conversion from one carrier to another needs to be ensured.
	Certificate of (avoided) operating emissions and broader sustainability	Development of a standardised certification regime for indicating the carbon content as well as the sustainability of renewable/low-carbon commodities. Sustainability refers e.g. to aspects like water scarcity and origin of feedstock. This broader certificate may also (but don’t have to) include lifecycle emissions. Interoperability of certificates at least across EU Member States and conversion from one carrier to another needs to be ensured.
Standar-disation	Harmonisation of technical standards on international level	Harmonise renewable/low-carbon commodity qualities etc. in order to create an importing infrastructure, which can be used for imports from different countries. Develop consistent safety regulations.

Certificates combining operating emissions and sustainability may be preferable, but realisation is demanding

Solution	Effectiveness	Efficiency	Complexity / Political feasibility	Distributional effects	Shortlist policy?
Certificate of (avoided) operating emissions	0 ▪ Carbon content is traceable, but the certificate of (avoided) operating emissions does not address the sustainability aspect	0 ▪ In a global market, a single scheme offers opportunities and reduces transaction costs for market participants (and will probably outweigh negative effects from not taking individual aspects into account) ▪ In case of tradeable certificates of (avoided) operating emissions enable matching of renewable/low-carbon commodity supply & demand without direct physical connection ▪ However, additionality of supply and synchronicity of supply & demand need to be addressed ▪ A life cycle approach would be advantageous	0 ▪ Generally some form of the certificate of (avoided) operating emissions expected to be developed, but international governance and verification will be difficult ▪ Difficulties increases if sustainability aspect is also taken into account (i.e. in case of certificates of (avoided) operating emissions and broader sustainability) ▪ Life-cycle certification would add another administrative complexity.	+ ▪ No substantial effect (as long as without obligation)	✓ (If certificates of (avoided) operating emissions and broader sustainability are not politically feasible.)
Certificate of (avoided) operating emissions and broader sustainability	+ ▪ If properly defined, the carbon content and the sustainability is traceable	+	-	+ ▪ Incentives for exporting countries to produce sustainably positive, but may lead to distributional effects between exporting countries ▪ No substantial effect otherwise (as long as without obligation)	✓
Harmonisation of technical standards on international level	+ ▪ Widely applied standards create security for private investors and reduce cost	+ ▪ Individual aspects could be taken into account after the direct import infrastructure	0 ▪ International standards demanding, but there are already standards for the RLCC available, which can provide a starting point	+ ▪ Standards may effect certain consumers negatively, but this could be addressed nationally	✓

Details to the barriers and potential solutions – **Coordination**

Cost barrier & solutions

Demand barrier & solutions

Certification barrier & solutions

Co-ordination barrier & solutions

The EU and the single member states can facilitate the development of the pathways by facilitating coordination/action of private actors

Barrier	Solution	Description
Coordination between exporting countries and EU	Multilateral climate change agreements	Include renewable/low-carbon commodities in multilateral climate change agreements and renewable policies
	Development of security of supply standards across energy carriers	Guideline on EU level, which recommends to diversify supplier countries for each renewable/ low-carbon commodity and to conclude long term contracts for ensuring long term security of supply
	Government facilitating private coordination	▪ Diplomatic support ▪ Establish cooperation with (potential) energy exporting countries (such as the (multilateral) Energy Charter, the Africa-EU Energy Partnership and the (German) Energy Partnerships) ▪ Trade framework with 3rd countries on export restrictions ▪ Review of tariff/non-tariff import restrictions
	Investor protection	International investors in production facilities receive an EU/national guarantee for the funding or operate under a clear international framework for dispute resolution
	Upstream support scheme with conditions on coordination	A condition of any upstream subsidy is coordinating with other parts of the value chain (e.g. aligning timing of construction/investment or to implementing some climate policies)

Policies addressing coordination issues on EU level deal with standardisation and regulation of hydrogen and CO_2 networks

Barrier	Solution	Description
Coordination within the EU	EU-wide standardisation	▪ Visibility on gas quality for gas producers ▪ Setting standards for blending
	Regulation of infrastructure providers to coordinate with/without fines/subsidies	Covers inter alia coordination of investment plants or the duty to inform each other on process ▪ Across the value chain ▪ Across EU member countries Could be combined with fines or subsidy/grant payments to infrastructure owners or industry
	Regulatory framework – hydrogen T&S	Clear regulatory framework for hydrogen infrastructure which sets out clarity of roles for different entities in the value chain (LSO, TSO) and does not create unnecessary barriers. This could encompass e.g. ▪ Question of permission to provide H2 transport or generation services for TSOs and LSOs ▪ Third party access to infrastructure ▪ Charging structure ▪ Taxes and levies
	Regulatory framework – CO_2 T&S	Clear regulatory framework on CO_2 regime which sets out clarity of roles for different entities in the value chain, which could encompass e.g. ▪ Question of permission to provide CO_2 handling services for LSOs ▪ Third party access to infrastructure ▪ Charging structure ▪ Leakage liability

Governments can facilitate private investment in exporting countries by extending existing policies to renewable/low-carbon commodities

Solution	Effectiveness		Efficiency		Complexity / Political feasibility		Distributional effects		Shortlist policy?
Multilateral climate change agreements	0	▪ Inclusion may increase awareness, but often further actions on national level required to implement international agreements	+	▪ Multilateral agreement may have a major signalling effect	-	▪ Multilateral agreements difficult to achieve ▪ Risk of unintended consequences high because of many opposing interests	+	▪ No direct distributional effects	✗
Development of security of supply standards across energy carriers	0	▪ Simple recommendation does not ensure reaching security of supply, but inherent value	+	▪ Measures of the guideline may lead to efficient outcomes, e.g. long-term contracts would be efficient for both parties for high sunk investment	+	▪ Introduction of an guideline is not to be expected as controversial	+	▪ No direct distributional effects from the guideline	✓
Government facilitating private coordination	0	▪ Government can facilitate coordination, but just addresses initial hurdles	+	▪ Existing diplomatic relationships can be used ▪ But risk that individual governments choose countries countries they have relationships with and so exclude key potential exporters	0	▪ Similar issues like multilateral agreements, but to a lesser extent due to more specific agreements and lower number of countries involved	+	▪ No distributional effects	✓
Investor protection	+	▪ Addresses country risk	+	▪ Politically desired investment in third countries are efficiently supported	+	▪ Already existing instrument	+	▪ Depends on whether this has financial consequen-ces for importing country govts	Long term: ✓
Upstream support scheme with conditions on coordination	+	▪ Can ensure adherence to co-ordination requiremetns (e.g. investment timing)	+	▪ Conditions can prevent inefficiencies across the value chain	0	▪ Acceptance of support scheme might be low due to implicit financing of installations abroad, but conditions may slightly increase acceptance on EU member state side ▪ However, overall complexity increases and feasibility depends on type of conditions.	+	▪ Conditions on coordination probably only have a minor impact on distributional effects, but may depends on type of condition	✓

A hydrogen economy requires a regulatory framework for hydrogen and CO_2 similar to that of natural gas today

Solution		Effectiveness		Efficiency		Complexity / Political feasibility		Distributional effects	Shortlist policy?
EU-wide standardisation	+	▪ Similar technical standards and transparency standards facilitate coordination between EU member states and implementation of an interoperable (hydrogen) infrastructure	0	▪ Reasonable technical standards can decrease overall cost if similar settings ▪ National regulation may be reasonable in case of specific characteristics (e.g. different types of end users prevalent)	0	▪ Certain technical standards already available, but need to develop them further	0	▪ Depends on extent to which national characteristics lead to different provisions	✓
Regulation of infra-structure providers to coordinate with/without fines/subsidies	+	▪ Level of fines/subsidies may be crucial for final implementation	+	▪ Obligations reasonable for important aspects	+	▪ Depends on clarity of important steps/aspects to coordinate on	+	▪ None from coordination, but maybe if joint decisions need to be made	✓
Regulatory framework including clarity of roles – hydrogen T&S	+	▪ Depends on regulatory framework and required scope	+	▪ Depends on regulatory framework and required scope ▪ Articulating roles of different entities (LSO, TSO) clearly will support efficient use of existing infrastructure	0	▪ Risk allocation likely to be complex, but precedents exist	0	▪ "Who pays" leads to distributional effects, e.g. first hydrogen users may need to pay more first or hydrogen users may need to pay for „old" natural gas grid	✓
Regulatory framework including clarity of roles – CO_2 T&S	+	▪ Depends on regulatory framework and required scope	+	▪ Depends on regulatory framework and required scope ▪ Articulating roles of different entities (LSO, TSO) clearly will support efficient use of existing infrastructure	0	▪ Risk allocation likely to be complex, but precedents exist	0	▪ "Who pays" leads to distributional effects. ▪ Funding can be socialised across various groups (gas users, taxpayers)	✓

Coordinating investment along the value chain effectively requires a range of policies - **roadmap**