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European Clean Hydrogen Alliance (ECH2A)
Round Table Clean Hydrogen in Industrial Applications (RT3)

Archetypes, Pain Points and Mitigation Options

1. Overview of the selected archetypes

#	Archetype	Comments
1	Hydrogen for industrial heat	H_2 replacing fossil fuel for high-heat applications that cannot be electrified ('hard-to-abate', e.g. steel, glass, cement, chemicals, pulp & paper, ceramics).
2	Hydrogen for multi-industrial hubs	Large-scale H_2O electrolyser on a site/hub/cluster feeding a wide range of applications.
3	Hydrogen as feedstock for the chemical industry (with carbon from various sources)	Conversion of clean H_2 and CO_2 or CO into chemical building blocks (e.g. methanol, olefins, synthetic naphtha).
4	Hydrogen for steel manufacturing (DRI and Hot Metal)	Use of H_2 for Direct Reduction of Iron Ore (DRI) and alternative iron-making processes, replacing coal/coke/fossil fuel.
5	Hydrogen for e-fuels production (e-kerosene, other e-fuels)	Separate archetype (from #3) due to application-specific pain points on the end-user side.
6	Hydrogen as feedstock for refining	Replacement of grey hydrogen.
7	Hydrogen as feedstock for ammonia	Replacement of grey hydrogen.

1.1 Summary of high-level pain points and needs

Pain points common for all mentioned archetypes:
- Lack of clear terminology, as well as a comprehensive certification and verification framework for clean hydrogen.
- Growing demand for low-carbon products but resistance to pay the necessary premium to cover the additional cost.
- Current cost of renewable and low-carbon hydrogen is too high.
- Current availability of renewable and low-carbon hydrogen is low.
- Current availability of affordable and abundant renewable electricity is low.
- Current availability of hydrogen-related infrastructure is low.
- Technological risk during process scale-up to commercial size.
- Lack of prioritisation from the EC on the sectors/functions that hydrogen should be primarily destined for from now to 2030.

What do we need to enable a faster transition and to keep investments in Europe?
- Support for investments that scale-up production and demand for renewable and low-carbon hydrogen.
- Mitigation of technological and financial risk via public funding and state-aid (Opex-related).

- A stable regulatory environment that accounts for the transition that industry needs to go through.
- Visibility as to how the upcoming sustainable product policy initiative and the other circular economy provision will influence the amounts of intermediary products and final products required by the market.

1.2 Mitigation options common for all mentioned archetypes:

- Secure access to and availability of sufficient and competitively priced renewable electricity, also by combining European and international infrastructure solutions in the most efficient forms.
- Support and drive investments in appropriately sized (from local to highly interlinked, high-capacity and digitalised) electricity, and dedicated hydrogen grids.
- Create an effective toolbox of demand-side measures to drive markets for low-GHG-impact basic materials, energy-efficient processes, etc.
- Introduce a harmonised calculation methodology for e.g. LCA, GHGs, embodied emissions.
- Encourage mandatory green/sustainable public procurement targets/policies prioritising the use of secondary and low-GHG-impact materials or products.
- Support uptake of corporate renewable Power Purchase Agreements (PPA) and facilitate a European scheme for CCfD (Carbon Contract for Difference).
- Describe transition pathways for specific industrial ecosystems, offering a better bottom-up understanding of the scale, cost, long-term benefits, and conditions of the required actions to accompany the twin transition, leading to an actionable plan in favour of sustainable competitiveness.
- Ensure an appropriate regulatory framework for CCS and CCU for the deployment of related low-carbon technologies and products.
- Implement better coordination of the EU and national funding programmes, for example through a “single window” approach, and of policies (competition policy, state aid, sustainable finance) to ensure that industry can access funding to enable the transition.
- Effective and appropriate protection against risk of carbon-leakage must be ensured.

1.3 Potential of the suggested archetypes

- Reduction of large amounts of greenhouse gas emissions (several 100 million tonnes/a).
- Preservation of industrial sites and employment while transitioning to climate-neutral manufacturing.
- Preservation of the making industry in Europe, thereby ensuring a certain level of independence.
- Maintain technological leadership in Europe (vital for a resource-restricted region).

In the following all archetypes will be further elaborated on, and respective pain points will be listed. The pain points will be segmented into 5 groups:

1. Market barriers
2. Regulatory barriers
3. Funding & financial barriers
4. Technological barriers
5. Supply chain & social barriers

2. Archetypes and Pain Points in detail

2.1 Hydrogen for industrial heat

Hydrogen replacing fossil fuel for high-heat applications that cannot be electrified ('hard-to-abate', e.g. steel, glass, cement, chemicals, pulp & paper, ceramics).

Examples:
- Steel: Clean hydrogen replacing fossil fuel currently used in reheating ovens, rolling mill furnaces, forging furnaces or areas of heat treatment.
- Glass: Hybrid glass melting is a first step to reduce the fossil fuel input into glass melting by 80%. Clean hydrogen is seen as the only sustainable source to replace the remaining fossil fuel that currently is used for the 20% remaining energy.
- Chemistry: Clean hydrogen replacing fossil fuel to enable low-CO_2/CO_2-free cracking.

Pain points

Group	Pain point descriptions
1	• Clean-hydrogen-based 'high-heat' products cannot compete on cost with conventional production under current circumstances.
2	• Lack of clear terminology, as well as lack of a comprehensive certification and verification framework for clean hydrogen (and its derivatives). • Lack of EU-wide regulatory framework on the use of hydrogen as combustion gas (e.g. NOx, etc.). • Lack of acceptance of/support for low-carbon hydrogen during transition (where no better alternative is available & green hydrogen is not available in large quantities and economically unviable). • Lack of supporting measures focusing on carbon intensity reduction in industrial heat. • Lack of a 'Level Playing Field' to avoid the risk of carbon-leakage (vs. imports based upon conventional technology, but also enabling export of 'clean' technology-based goods).
3	• Lack of availability of renewable and low-carbon electricity and hydrogen at competitive prices for industrial applications, especially for EU inland regions. • Risk of highly intermittent electricity cost impacting the cost of clean hydrogen. • Need for financial support (Capex, Opex), including risk sharing mechanisms, to bridge the gap between (higher) production cost vs. market price (based on conventional processes). • Lack of financing for studies and R&D on the influence of hydrogen on hardware and operation of furnaces and burners.
4	• Lack of a stronger network between furnace builders and users (to mitigate technological risk, to speed up of development).
5	• Insufficient grid infrastructure between supply and demand at European level: e.g. electricity grid that can cope with the increasing intermittency, direct cables to e.g. off-shore wind farms, national and regional pipelines for the transport and storage of H_2, CO_2 etc.

Mitigation options

Group	Description of mitigation options
1	• Develop low-impact product requirements/standards (on carbon intensity, embedded emissions, or other appropriate climate-related approaches) to incentivise take-up of low-impact production methods.
2	• Effective and appropriate protection against risk of carbon-leakage must be introduced. • Advance internationally recognized Guarantees-of-Origin (GO) to make renewable and low-carbon hydrogen and its derivatives tradable commodities.
3	• Timely provision of funding (Capex-/Opex-programs, H2-Global, CfD, IPCEI etc.).
4	• n/a
5	• Create regulatory framework for the construction and conversion of gas networks into dedicated hydrogen networks. • Improve framework conditions for the expansion of large-scale storage (battery/heat/gas/hydrogen). • Actions for massive ramp up of renewable electricity: Consistent further development of on-shore and off-shore wind, including off-shore grid for far-shore and necessary HVDC lines (High Voltage Direct Current). • Consistently stimulate grid intelligence and digital energy solutions. • Setup of required infrastructure for import of green energy.

2.2 Hydrogen for multi-industrial hubs

Large-scale H_2O electrolyser on a site/hub/cluster that supplies various industrial off-takes. Industrial transformation: Scalability of production and transformation potential of industrial sites can be unlocked by adding CO_2-streams from other sectors and by creating clean hydrogen networks.

- Combination of uses of H2 for the decarbonation (thousands of avoided CO_2 emissions/year) of:
  - Hard-to-abate industrial sectors:
    - New applications in industrial processes: iron and steel industry, chemistry, etc.
    - Re-use of CO_2: e.g. for methanation, e-fuels, etc.
    - Substitution of fossil-based hydrogen in refining, ammonia, etc.
    - Valorisation of co-produced oxygen and co-produced hydrogen
  - Energy consumption:
    - Production of decarbonised heat (e.g. Power-to-Gas, direct injection of hydrogen into burners or turbines, methanation, etc.).
    - Re-use of waste heat (e.g. from fuel cells, etc.)
    - Production of "utilities": e.g. steam, electricity, etc.
  - Peripheral uses in mobility, in particular heavy-duty vehicles in intra-site and intra-cluster logistics (e.g. fork-lift trucks, trucks, tractors, boats, ships, freight trains, etc.)

Pain points

Group	Pain point descriptions
1	• Clean-hydrogen-based products cannot compete with conventional production under current circumstances.
2	• Lack of clear terminology, as well as a comprehensive certification and verification framework for clean hydrogen (and its derivatives).

	• Lack of measures stimulating a market for hydrogen, particularly to valorise hydrogen as by-product of other production processes. • Need for increased ambitions on GHG emission reductions to support demand for clean hydrogen.
3	• Lack of availability of renewable and low-carbon electricity and hydrogen at competitive prices for industrial applications, especially for EU inland regions. • Need for financial support (Capex, Opex), including risk sharing mechanisms, to bridge the gap between (higher) production cost vs. market price (based on conventional processes). • Uncertainty on electricity pricing for electrolysers wrt currently applied taxes and/or tariffs.
4	• Lack of new equipment for hydrogen in combined cycle power plants. • Need for development on carbon capture to further reduce its respective cost.
5	• Insufficient grid infrastructure between supply and demand at European level: e.g. electricity grid that can cope with the increasing intermittency, direct cables to e.g. off-shore wind farms, national and regional pipelines for the transport and storage of H_2, CO_2 etc.

Mitigation options

Group	Description of mitigation options
1	• Develop low-impact product requirements/standards (on carbon intensity, embedded emissions, or other appropriate climate-related approaches) to incentivise take-up of low-impact production methods.
2	• Effective and appropriate protection against risk of carbon-leakage must be introduced. • Advance internationally recognized Guarantees-of-Origin (GO) to make renewable and low-carbon hydrogen and its derivatives tradable commodities.
3	• Timely provision of funding (Capex-/Opex-programs, H2-Global, CfD, IPCEI etc.). • Timely definition of green power purchase criteria for electrolysis operation/implementation of EU Renewable Energy Directive II (RED II) methodology.
4	•
5	• Create regulatory framework for the construction and conversion of gas networks into hydrogen networks. • Improve framework conditions for the expansion of large-scale storage (battery/heat/gas/hydrogen). • Actions for massive ramp up of renewable electricity: Consistent further development of on-shore and off-shore wind, including off-shore grid for far-shore and necessary HVDC lines (High Voltage Direct Current). • Consistently stimulate grid intelligence and digital energy solutions. • Setup of required infrastructure for import of green energy.

2.3 Hydrogen as feedstock for the chemical industry (with carbon from various sources)

Conversion of clean H_2 and CO_2 or CO into building blocks (e.g. methanol, olefins, synthetic naphtha). The clean hydrogen also can stem from the valorisation of it as a co-product (e.g. chlorine electrolysis).
The carbon can come from various sources depending on project application, such as CO_2-capture from an on-site industrial stream, from biomass combustion or from chemical recycling.

- Conversion of clean hydrogen and CO_2 or CO into sustainable materials for external use and/or internal feedstock for downstream market products.
- Various carbon sources from de-fossilised feedstock are possible depending on project application.
- Industrial transformation: Scalability of production and transformation potential of industrial sites can be unlocked by adding CO_2-streams from other sectors and by creating clean hydrogen networks.
- Methanol is a basic chemical building block used for many industrial processes and products (e.g. fuels, silicones, methylamines, methyl esters, formaldehyde, olefins).

Pain points

Group	Pain point descriptions
1	• Growing demand for low-carbon products but customers are resisting to pay the necessary premium to cover the additional cost.
2	• Lack of clear terminology, as well as a comprehensive certification and verification framework for clean hydrogen (and its derivatives). • Rapid expansion of clean hydrogen capacity supporting the transition strategy timeline is hindered as long as the source of clean electricity that can be used is kept restricted. • CCU currently cannot be used as a meaningful source of recycled carbon due to the absence of a robust carbon accounting methodology for carbon recycling.
3	• Lack of availability of renewable and low-carbon electricity and hydrogen at competitive prices for industrial applications, especially for EU inland regions. • Need for financial support (Capex, Opex), including risk sharing mechanisms, to bridge the gap between (higher) production cost vs. market price (based on conventional processes). • Lack of clarity on what accounts as long-term sequestration of CO_2 in products (e.g. silicones vs. fuels).
4	• Lack of mitigation of the technological risk during process scale up to commercial size. • Need for development on carbon capture to further reduce its respective cost.
5	• Insufficient grid infrastructure between supply and demand at European level: e.g. electricity grid that can cope with the increasing intermittency, direct cables to e.g. off-shore wind farms, national and regional pipelines for the transport and storage of H_2, CO_2 etc.

Mitigation options

Group	Description of mitigation options
1	• Sustainable product requirements that would drive market for safe & sustainable chemicals in products, green public procurement criteria, guidelines and mandatory elements. • Define 'green content quota' criteria for key products such as chemicals to enable consistent sustainable public procurement. • Develop low-impact product requirements/standards (on carbon intensity, embedded emissions, or other appropriate climate-related approaches) to incentivise take-up of low-impact production methods.
2	• Implement Contracts for Difference (CfD) for electricity costs. Having access to renewable electricity at a price level that guarantees cost-competitiveness will give

	investors certainty about cost structure when calculating the business model, as electricity has the highest share in OPEX. • Effective and appropriate protection against risk of carbon-leakage must be introduced. • Advance internationally recognized Guarantees-of-Origin (GO) to make renewable and low-carbon hydrogen and its derivatives tradable commodities. • CCU needs policy development, to frame it appropriately in the wider policy approaches to climate neutrality and other interlinked environmental objectives.
3	• Innovation support that covers eligible cost for Capex and Opex (similar to EU Innovation Fund) in order to get first-generation projects going and reach economy-of-scale. • Timely provision of funding (Capex-/Opex-programs, H2-Global, CfD, IPCEI etc.). • Timely definition of green power purchase criteria for electrolysis operation/implementation of EU Renewable Energy Directive II (REDII) methodology.
4	• A roadmap on energy needs, taking into consideration energy and resource use needed, presumed transition pathways elements which are also about changing processes, etc. • Describe transition pathways for specific industrial ecosystems, offering a better bottom-up understanding of the scale, cost, long-term benefits, and conditions of the required actions to accompany the twin transition, leading to an actionable plan in favour of sustainable competitiveness. • Progressive roll-out of green hydrogen criteria: The definition of what constitutes green hydrogen needs to be flexible enough, so it doesn't kill off the first generation of low-carbon hydrogen projects that are now in the pipeline, thereby preventing the realization of large-scale GHG reductions.
5	• Create regulatory framework for the construction and conversion of gas networks into dedicated hydrogen networks. • Actions for massive ramp up of renewable electricity: Consistent further development of on-shore and off-shore wind, including off-shore grid for far-shore and necessary HVDC lines (High Voltage Direct Current). • Improve framework conditions for the expansion of large-scale storage (battery/heat/gas/hydrogen). • Consistently stimulate grid intelligence and digital energy solutions. • Setup of required infrastructure for import of green energy.

2.4 Hydrogen for steel manufacturing (DRI and Hot Metal)

Use of hydrogen for Direct Reduction of Iron ore (DRI) and alternative iron-making processes, replacing coal/coke/fossil fuel thereby eliminating greenhouse gas emissions.

Pain points

Group	Pain point descriptions
1	• Growing demand for low-CO_2, CO_2-neutral or green steel but customers are resisting to pay the necessary premium to cover the additional cost over conventional steel. • Mid- to long-term issue: Availability of DR-grade iron ore pellets (DR: Direct Reduction).

2	• Lack of clear terminology, as well as a comprehensive certification and verification framework for clean hydrogen (and its derivatives) and low-CO_2, CO_2-neutral or green steel. • Need for technology-neutral support of hydrogen projects based on the CO_2 footprint. • Lack of a policy framework to create demand/markets for low-CO_2, CO_2-neutral or green steel. • Lack of single funding instruments that cover the entire cost gap. Currently several funding schemes need to be stacked together and these still do not close the gap. This adds complexity, risk, costs, and time to the projects. • Lack of support for Opex and respective new finance instruments, e.g. via Carbon Contracts for Difference (CCfD) to compensate for the carbon (abatement) cost.
3	• Lack of availability of renewable and low-carbon electricity and hydrogen at competitive prices for industrial applications, especially for EU inland regions. • Need for financial support (Capex, Opex), including risk sharing mechanisms, to bridge the gap between (higher) production cost vs. market price (based on conventional processes). • Lack of lead investors willing to take risks.
4	• Lack of stronger networks of plant builders with stakeholders in hydrogen generation and operators/owners of plants that apply hydrogen (to mitigate technological risk, to speed up development). • Need for development on carbon capture to further reduce its respective cost.
5	• Insufficient grid infrastructure between supply and demand at European level: e.g. electricity grid that can cope with the increasing intermittency, direct cables to e.g. off-shore wind farms, national and regional pipelines for the transport and storage of H_2, CO_2 etc.

Mitigation options

Group	Description of mitigation options
1	• Set product requirements to stimulate market demand for low-CO_2, CO_2-neutral or green steel, including minimum recycled content (Sustainable Product Initiative). • Introduce a standard/certification for low-CO_2, CO_2-neutral or green steel, based on a robust and objective carbon-accounting methodology, associated with market incentives and appropriate labels for increasing market awareness and recognition. • Create lead markets for low-CO_2, CO_2-neutral or green steel through introduction of respective product requirements in public procurement. • Allow automotive manufacturers to account for low-CO2 ,or CO2-neutral or green steel in their decarbonization objectives set by the EU (regulation on passenger cars) by expanding the scope of eco-innovation credits to encompass lifecycle emission reductions. • Create a public awareness campaign for low-CO_2, CO_2-neutral or green steel, and why it will cost more. • Increase the beneficiation and pelletisation capacities to enable valorisation of low-quality/low-iron content ores and adapt to DRI use (i.e. Fluidized Bed DR and EAF (electric arc furnace) smelter) to cope with higher gangue/slag amount from such ores.
2	• Carbon-contracts for Difference (CCfD) that are technology-neutral and support the full abatement cost, including Opex. • Effective and appropriate protection against risk of carbon-leakage must be introduced.

	• Extend scope of innovation fund to cover 100% of cost gap (not 60%), align and support cumulation of different funding sources (including national and European sources, for example under CCfDs), review state aid rules of IPCEI, EEAG. • Advance internationally recognized Guarantees-of-Origin (GO) to make renewable and low-carbon hydrogen and its derivatives tradable commodities. • Timely provision of funding (Capex-/Opex-programs, H2-Global, CCfD, IPCEI etc.).
3	• Ensure internationally competitive energy prices (strengthen scope of exemptions under EEAG, support PPAs under RED). • Support import of renewable hydrogen. • Support import of green DRI from regions where conditions are more advantageous in transitional period (i.e. DRI as media to easily transport renewable energy). • Give lead investors in low-CO_2, CO_2-neutral or green steel incentives to invest in such project (e.g. tax deductions / accelerated depreciation, …). • Timely provision of funding (Capex-/Opex-programs, H2-Global, CCfD, IPCEI etc.)
4	• Progressive roll-out of green hydrogen criteria: The definition of what constitutes green hydrogen needs to be flexible enough, so it doesn't kill off the first generation of low-carbon hydrogen projects that are now in the pipeline, thereby preventing the realization of large-scale GHG reductions.
5	• Support import of low-CO_2, CO_2-neutral or green HBI (Hot Briquetted Iron) during transition period (see above) via international partnerships, which in return allow European firms to develop their technologies and European IP. • Create regulatory framework for the construction and conversion of gas networks into dedicated hydrogen networks. • Actions for massive ramp up of renewable electricity: Consistent further development of on-shore and off-shore wind, including off-shore grid for far-shore and necessary HVDC lines (High Voltage Direct Current). • Improve framework conditions for the expansion of large-scale storage (battery/heat/gas/hydrogen). • Consistently stimulate grid intelligence and digital energy solutions. • Setup of required infrastructure for import of green energy.

2.5 Hydrogen for e-fuels production (e-kerosene, other e-fuels)

Conversion of clean H_2 and CO_2 or CO into e-fuels (e.g. e-kerosene, other e-fuels, methanol).
The carbon can come from various sources depending on project application, such as CO_2-capture from an on-site industrial stream, from biomass combustion or from chemical recycling.
This is a separate archetype due to application-specific pain points on the end-user side (e.g. aviation, marine, land transportation sectors).

Pain points

Group	Pain point descriptions
1	• Clean-hydrogen-based fuels cannot compete with conventional production under current circumstances.
2	• Lack of quotas for green fuels in marine, aviation, and overland transport sectors. • Regulation should support using renewable hydrogen for biofuel production by electricity emission rules harmonized with EU RED II rules on RFNBO (Renewable Fuels of Non-Biological Origin). • Emission standards are too low for fossil fuels.

	• Lack of Carbon Contract for Difference (CCfD) for green fuel production compared to fossil fuels. • Rapid expansion of clean hydrogen capacity supporting the transition strategy timeline is hindered as long as the source of clean electricity that can be used is kept restricted. • CCU currently cannot be used as a meaningful source of recycled carbon due to the absence of a robust carbon accounting methodology for carbon recycling.
3	• Lack of availability of renewable and low-carbon electricity and hydrogen at competitive prices for industrial applications, especially for EU inland regions. • Need for financial support (Capex, Opex), including risk sharing mechanisms, to bridge the gap between (higher) production cost vs. market price (based on conventional processes).
4	• Lack of mitigation of the technological risk during process scale up to commercial size. • Need for development on carbon capture to further reduce its respective cost.
5	• Insufficient grid infrastructure between supply and demand at European level: e.g. electricity grid that can cope with the increasing intermittency, direct cables to e.g. off-shore wind farms, national and regional pipelines for the transport and storage of H_2, CO_2 etc.

Mitigation options

Group	Description of mitigation options
1	• Support sub-quotas for eFuels in RED III as well as alignment of the Energy Tax Directive with CO_2 intensity and a well-to-wheel approach in European fleet regulation.
2	• Push in IMO to set more strict standards for emissions. • Stricter regulation around GHG emissions in European seas and harbours. • Support sub-quotas for e-Fuels in RED III as well as alignment of the Energy Tax Directive with CO_2 intensity and a well-to-wheel approach in European fleet regulation. • Create long-term visibility in regulation concerning the European energy system, including renewable electricity, renewable transport fuels in all transport sectors.
3	• Timely provision of funding (Capex-/Opex-programs, H2-Global, CfD, IPCEI etc.). • Timely definition of green power purchase criteria for electrolysis operation/implementation of EU Renewable Energy Directive II (RED II) methodology.
4	• A roadmap on energy needs, taking into consideration energy and resource use needed, presumed transition pathways elements which are also about changing processes, etc. • Describe transition pathways for specific industrial ecosystems, offering a better bottom-up understanding of the scale, cost, long-term benefits, and conditions of the required actions to accompany the twin transition, leading to an actionable plan in favour of sustainable competitiveness. • Progressive roll-out of green hydrogen criteria: The definition of what constitutes green hydrogen needs to be flexible enough, so it doesn't kill off the first generation of low-carbon hydrogen projects that are now in the pipeline, thereby preventing the realization of large-scale GHG reductions.
5	• Create regulatory framework for the construction and conversion of gas networks into dedicated hydrogen networks.

	• Actions for massive ramp up of renewable electricity: Consistent further development of on-shore and off-shore wind, including off-shore grid for far-shore and necessary HVDC lines (High Voltage Direct Current). • Consistently stimulate grid intelligence and digital energy solutions. • Setup of required infrastructure for import of green energy.

2.6 Hydrogen as feedstock for refining

Refineries need to change to clean hydrogen they use in their industrial processes.
High quantities of clean hydrogen are needed (2015: 4.5 million tons of hydrogen per annum in Europe).

- The challenge is to decarbonise hydrogen production in a cost-effective manner while simultaneously preserving existing assets and securing future renewable hydrogen production.
- Most likely way forward is retrofitting of CCUS or electrolysis to existing plants and/or step-wise partial capacity installation.
- Transition to lower GHG emissions will be accelerated by combining all sources of clean hydrogen: e.g. SMR+CCUS, methane pyrolysis, hydrogen from electrolysis, waste-to-hydrogen process, biomethane+SMR, biomethane pyrolysis, potential waste product hydrogen.

Pain points

Group	Pain point descriptions
1	• Clean-hydrogen-based refinery products cannot compete with conventional production under current circumstances. • No clear value mechanisms for clean hydrogen yet.
2	• Need for technology-neutral support of hydrogen projects based on the CO_2 footprint. • Investment becomes risky and economically unfeasible if regulatory mindset is fixed onto solely 100% renewable hydrogen from the very start. • CCU currently cannot be used as a meaningful source of recycled carbon (e.g. for PtL, Power-to-Liquids) due to the absence of a robust carbon accounting methodology for carbon recycling. • Rapid expansion of clean hydrogen capacity supporting the transition strategy timeline is hindered, as long as the source of clean electricity that can be used is kept restricted. • Transport and on-shore storage of CO_2 is a challenge from a regulatory point of view.
3	• Lack of availability of renewable and low-carbon electricity and hydrogen at competitive prices for industrial applications, especially for EU inland regions. • Traditional investment principles can prohibit early-phase investments due to the fact that projects show a combination of high risk (e.g. new business case, new technology, unknown maintenance cost) and high-Capex investments. • Need for financial support (Capex, Opex), including risk sharing mechanisms, to bridge the gap between (higher) production cost vs. market price (based on conventional processes). • Rapid scale-up of electrolysis capacity and reduction of electrolyser integration costs is a challenge. • Lack of sufficient biomethane capacity and integration within the system (e.g. cost, availability, accounting).
4	• Lack of mitigation of the technological risk during process scale up to commercial size (e.g. technology performance, integration & safety related measures).

	• Need for development on carbon capture to further reduce its respective cost.
5	• Need for significant scale-up of renewable electricity generation capacity with proximity to industrial sites. • Securing long-term on-shore storage of CO_2 is a challenge due to lack of public acceptance.

Mitigation options

Group	Description of mitigation options
1	• Create clear regulation that enables added value for clean hydrogen-based products and respective competitiveness against fossil-based products.
2	• Effective and appropriate protection against risk of carbon-leakage must be introduced. • Create clear regulation that establishes the value mechanism for captured CO_2 emissions and CO_2 utilisation in future production of fuels and durable materials. • Ensure with a clear and long-term policy framework that the European ambition remains at a world's leading level wrt sustainability, renewable energy deployment and industry GHG emissions reduction.
3	• Timely provision of funding (Capex-/Opex-programs, H2-Global, CCfD, IPCEI etc.). • Ensure flexibility in investment rules for transition period business cases, allow for new business models to be considered (e.g. leasing models) and new OPEX-support models. • Timely definition of green power purchase criteria for electrolysis operation/implementation of EU Renewable Energy Directive II (RED II) methodology.
4	• Support early (2020-25) industrial piloting and development of the water electrolyser industry, to ensure its readiness for large scale-up by the end of the 20's.
5	• Actions for massive ramp up of renewable electricity: Consistent further development of on-shore and off-shore wind, including off-shore grid for far-shore and necessary HVDC lines (High Voltage Direct Current). • Support and drive investments in a highly interlinked, high-capacity and digitalised electricity, and dedicated hydrogen grids. • Develop generally applicable schemes for renewable electricity sourcing with, in particular during the transition/scale-up period, opportunities to flexibility in temporal and geographic correlation requirements between electricity generator and electrolyser. • Improve framework conditions for the expansion of large-scale storage (battery/heat/gas/hydrogen). • Setup of required infrastructure for import of renewable energy.

2.7 Hydrogen as feedstock for ammonia

Replacement of grey hydrogen.
High quantities of clean hydrogen are needed (2015: 3.8 million tons of hydrogen per annum in Europe).
Application range of ammonia is not specified (from building block for fertilisers to conversion-of-H_2-for-long-range-transport and to maritime fuel).

- Ammonia plants need to convert the hydrogen used in their processes to clean hydrogen.

- This can be done by e.g. applying CCS to existing SMRs, replacing SMRs with electrolysis, biomethane+SMR, methane/biomethane pyrolysis, waste-to-hydrogen, or receiving pure (not blended!) and clean hydrogen from somewhere else.

Pain points

Group	Pain point descriptions
1	• Clean-hydrogen-based ammonia cannot compete with conventional production under current circumstances. • Lack of a real (global) framework around carbon footprint for farming. • Lack of standardization of labelling and certification of zero and low-carbon footprint hydrogen, ammonia and its derivates.
2	• Lack of quotas for green fuels in marine sectors. • Regulation should support using renewable hydrogen for biofuel production by electricity emission rules harmonized with EU RED II rules on RFNBO (Renewable Fuels of Non-Biological Origin). • Need for technology-neutral support of hydrogen projects based on the CO_2 footprint. • State aid criteria and RED II criteria for e.g. use of additional electricity or the proof of temporal correlation (example SDE++ in the Netherlands) will need to be relaxed if the EU is to meet its 2024 and 2030 hydrogen targets. • CCU (from SMR) currently cannot be used as a meaningful source of recycled carbon due to the absence of a robust carbon accounting methodology for carbon recycling. • Lack of single funding instruments that cover the entire cost gap. Currently several funding schemes need to be stacked together and these still do not close the gap. This adds complexity, risk, costs, and time to the projects. • Lack of clear terminology, as well as a comprehensive certification and verification framework for clean hydrogen (and its derivatives).
3	• Lack of availability of renewable and low-carbon electricity and hydrogen at competitive prices for industrial applications, especially for EU inland regions. • Need for financial support (Capex, Opex), including risk sharing mechanisms, to bridge the gap between (higher) production cost vs. market price (based on conventional processes). • The public funding that is available today, at EU and MS level, both in absolute and relative terms, is not enough.
4	• Need for development on carbon capture to further reduce its respective cost.
5	• Need for significant scale-up of renewable electricity generation capacity with proximity to industrial sites. • Insufficient grid infrastructure between supply and demand at European level: e.g. electricity grid that can cope with the increasing intermittency, direct cables to e.g. off-shore wind farms, national and regional pipelines for the transport and storage of H_2, CO_2 etc.

Mitigation options

Group	Description of mitigation options
1	• Develop low-impact product requirements/standards (on carbon intensity, embedded emissions, or other appropriate climate-related approaches) to incentivise take-up of low-impact production methods. • Standardization of labelling and certification of zero and low-carbon footprint hydrogen, ammonia and its derivates will provide higher transparency. This will

	enable market creation for zero-carbon fertilizer and zero-carbon ammonia for shipping fuel. • Fertilizer market: o Create incentives and certification systems towards reducing the overall carbon footprint of crops sourced by food companies. o Give zero-carbon fertilizer an important role in CAP (Common Agricultural Policy). o Certify synthetic zero-carbon nitrogen fertilizer as a compliment to boost yields of organic farming. • Shipping market: o Create incentives and certification systems towards reducing the overall carbon footprint of sea freight. o Quota for zero-carbon shipping fuels including the full recognition of clean ammonia as zero-carbon fuel.
2	• Consider design of specific mechanisms to support the switch to clean hydrogen in the ammonia sector. Limited modifications in ammonia production and downstream infrastructure are needed to switch to clean hydrogen, thereby enabling significant reductions in GHG emissions. • Clear, coherent, and aligned policy framework for RED, ETD, EU-ETS, Taxonomy, … • Ensure at minimum a grace period on additionality, temporal correlation & geographical correlation for renewable power to be used for hydrogen production under RED and adjacent policy frameworks. • Ensure that CCS projects/blue hydrogen and green hydrogen operates under the same state aid regulations and hence avoid financial lock-in to blue hydrogen projects. • Push in IMO to set more strict standards for emissions. • Stricter regulation around GHG emissions in European seas and harbours. • Support sub-quotas for e-fuels in RED III as well as alignment of the Energy Tax Directive with CO_2 intensity. • Effective and appropriate protection against risk of carbon-leakage must be introduced. • Advance internationally recognized Guarantees-of-Origin (GO) to make renewable and low-carbon hydrogen and its derivatives tradable commodities.
3	• Support mechanisms such as (reverse auction-based) Carbon Contracts for Difference (CCfD) type. • Enable low-cost financing instruments and mitigating actions that reduce regulatory and infrastructure-based uncertainties. • Investment support at higher levels than in current state aid regulations if this can be sufficient to mitigate market failure and hence help companies bridge the funding gap (IPCEI regulations up to 100% of Capex). • Increased funding at EU level (for ex. Increase the budget of the EU ETS Innovation Fund). • Need for financial support (Capex, Opex), including risk sharing mechanisms, to bridge the gap between (higher) production cost vs. market price (based on conventional processes). • Timely provision of funding (Capex-/Opex-programs, H2-Global, CfD, IPCEI etc.). • Timely definition of green power purchase criteria for electrolysis operation/implementation of EU Renewable Energy Directive II (RED II) methodology.
4	• Progressive roll-out of green hydrogen criteria: The definition of what constitutes green hydrogen needs to be flexible enough, so it doesn't kill off the first generation

	of low-carbon hydrogen projects that are now in the pipeline, thereby preventing the realization of large-scale GHG reductions.
5	• Holistic investments in the parallel build-out of renewable power and hydrogen production units and infrastructure. • Actions for massive ramp up of renewable electricity: Consistent further development of on-shore and off-shore wind, including off-shore grid for far-shore and necessary HVDC lines (High Voltage Direct Current). • Improve framework conditions for the expansion of large-scale storage (battery/heat/gas/hydrogen). • Setup of required infrastructure for import of renewable energy.

APPENDIX:

Comments on barriers received during the project collection for renewable and low-carbon hydrogen technologies and solutions

During ECH2A's project collection (9 April - 7 May 2021), project promoters were also asked to provide comments on barriers (respectively pain points). Listed below are the comments received for projects entered under the archetypes as defined by RT3 that weren't already mentioned by the round table in this document.

The pain points are segmented into 5 groups:

1. Market barriers
2. Regulatory barriers
3. Funding & financial barriers
4. Technological barriers
5. Supply chain & social barriers

A.1 Hydrogen for industrial heat

Group	Pain point descriptions
2	• Slow permitting process hinders implementation of projects (often due to lack of knowledge in permitting bodies around hydrogen).
4	• Burner technology and hardware is not available yet (e.g. burner >2 MW do not exist yet). • Combustion of 2 fuels is a challenge. • Lack of knowledge (and data) on effects of burning hydrogen on equipment and final product.

A.2 Hydrogen for multi-industrial hubs

Group	Pain point descriptions
4	• Combustion of 2 fuels is a challenge.
5	• Transportation of heat outside park is an issue.

A.3 Hydrogen as feedstock for the chemical industry (with carbon from various sources)

Group	Pain point descriptions
4	• Technological challenge to optimize the project by valorising the electrolyzer co-products (low temperature) off-heat and (excess) oxygen.

A.4 Hydrogen for steel manufacturing (DRI and Hot Metal)

Group	Pain point descriptions
1	• DRI plus melting unit is very innovative, but very expensive compared to conventional route.
2	• Environmental permitting process is long and painful. • Lack of regulation on emissions from hydrogen burning (needs to be created). • EU taxonomy target of 1.3 t CO_2/t steel is very tough.

	• Loss of free allowances when switching to break-through carbon-neutral technology (e.g. from blast furnace to DRI). • Need to adapt ETS regulation to hydrogen. • Need for a border tax for grey steel.
4	• Burner technology and hardware is not available yet (e.g. burner >2 MW do not exist yet). • Combustion of 2 fuels is a challenge. • Lack of knowledge (and data) on effects of burning hydrogen on equipment and final product – Funded research is needed. • Need for more R&D on impact of hydrogen on steel making process.

A.5 Hydrogen for e-fuels production (e-kerosene, other e-fuels)

Group	Pain point descriptions
1	• Synthetic fuels are significantly more expensive than fossil fuels and do not have the same support as advanced biofuels in RED II (do not have a 2 times multiplier), reducing its market value.
2	• Slow permitting process hinders implementation of projects (often due to lack of knowledge in permitting bodies around hydrogen). • Renewable fuels pay the same level of taxes as fossil fuels. • Weird regulation: feeding bio-methane into the natural gas grid is okay, but e-methane is not. • Double certification is needed for market access for SAF (sustainable airplane fuels); first for blending and then for kerosine.
3	• Issue: Bottleneck in electrolyser production capacity drives prices up and results in long lead-times (resp. supply delays).
4	• Large-size electrolysers don't exist yet. • Question marks on lifetime of catalysts used in the electrolysers. • Output of green methanol plants is a lot smaller than for conventional technology (> 1 mio t/a). • Technological challenge to optimize the project by valorising the electrolyzer co-products (low temperature) off-heat and (excess) oxygen.

A.6 Hydrogen as feedstock for refining

Group	Pain point descriptions
2	• Need for exemption from power surcharges and levies (on electrolysers).
3	• Risks of cost overruns due to construction of new technology. • Issue: Bottleneck in electrolyser production capacity drives prices up and results in long lead-times (resp. supply delays).

A.7 Hydrogen as feedstock for ammonia

Group	Pain point descriptions
2	• Lack of regulation to support the use of renewable hydrogen applied to ammonia, as in RED II.