Seed Paper - Market Stimulation 'Green Hydrogen'

Version 1.0 (18/08/2021)

1 Objective and general information

1.1 Definition of scope

The purpose of this seed paper is the description of the status-quo (What do we have?), the target setting (What do we want?), the articulation of ideas in order to stimulate the market for 'Green Hydrogen' (What is missing or needs more attention?) and the formulation of research-questions and measures in order to capture the knowledge and opinions of different stakeholder groups (public consultation). After the public consultation this seed paper will be transferred into a position paper, which will be presented and discussed at the market stimulation workshop on the 22nd of October in Vienna. Based on the outcome, a joint strategic research and innovation agenda (SRIA) will be developed by the end of 2021. For the purpose of this document 'Green Hydrogen' also includes hydrogen in the form of liquid organic hydrogen carriers (LOHC) and 'Green Hydrogen' containing Power-to-X fuels and feedstock.

1.2 Definition market stimulation

A common understanding of market stimulation is essential in order to work out concrete measures and questions. We understand market stimulation as any support-measures proceeding from no (or few) offer and demand into a fast growing 'Green Hydrogen' market, finally substituting fossil based energy carriers and feedstock. Market stimulation for example includes providing accurate and reliable information to authorities and the public, open and fair dealing with possible drawbacks and concerns and creating hydrogen-market friendly social-framework conditions (e.g. cross border CO_2-tax, international trade rules, …)

As demarcation to the 'Green Hydrogen' Agenda topics 'Production' and 'Transport/ Infrastructure' technical questions regarding to low cost production and efficient transport are not included in market stimulation, nevertheless these aspects have a strong impact on the demand of 'Green Hydrogen'.

1.3 Definition 'Green (renewable) Hydrogen'

Renewable hydrogen ('green' or 'clean' hydrogen) is expected to play a key role in decarbonising sectors where other alternatives might not be feasible, or might be more expensive. Renewable hydrogen can be used to replace fossil-based hydrogen for industrial processes, or to start new industrial products such as green fertilisers and steel. It can also be used in the transport sector, especially in heavy-duty and long-distance trucks, buses, ships and planes.

' Terminology[1] (EC) to define forms of hydrogen:

- **'Electricity-based hydrogen'** refers to hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), regardless of the electricity source.
- **'Renewable hydrogen'** is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources.
- **'Clean hydrogen'** refers to renewable hydrogen.

[1] A hydrogen strategy for a climate-neutral Europe, European Commission, 2020.07.08, page 3-4.

- '**Fossil-based hydrogen**' refers to hydrogen produced through a variety of processes using fossil fuels as feedstock, mainly the reforming of natural gas or the gasification of coal. This represents the bulk of hydrogen produced today.
- '**Fossil-based hydrogen with carbon capture**' is a subpart of fossil-based hydrogen, but where greenhouse gases emitted as part of the hydrogen production process are captured.
- '**Low-carbon hydrogen**' encompasses fossil-based hydrogen with carbon capture and electricity-based hydrogen, with significantly reduced full life-cycle greenhouse gas emissions compared to existing hydrogen production.

The priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy. Renewable hydrogen and other renewable gases are (beside green electricity) the most compatible option with the EU's climate neutrality and zero pollution goal in the long term and the most coherent with an integrated energy system.

2 Description of status quo (What do we have?)

2.1 Motivation

Since the beginning of the industrial revolution, fossil based energy carriers fuelled the economy and created prosperity. Retrospective these energy carriers (coal, crude oil and natural gas) can be considered as low hanging fruits. The departed CO_2 accumulates in the atmosphere and is responsible for a global (and fast) increase of the average temperature. The significant contribution of mankind to global warming and the mostly negative and dramatically consequences are state of knowledge today. Beside CO_2, the use of fossil energy carriers for example releases methane, particulate matter and may also pollute maritime and freshwater resources.

2.2 Historical consideration

Hydrogen is not new to people and industry, it has a rich history as an energy carrier (coal based town gas) and feedstock in (petro-)chemical industry (ammonia syntheses, plastics production, fuel production). Minor applications are in metallurgy, as fat hardening reactant, as coolant or as a protective gas. Despite of more than 100 years hydrogen-handling experience, hydrogen is commonly best known for its oxyhydrogen-reaction and for being a historical lifting gas in airships.

2.3 Hydrogen market and production volume today

Hydrogen use today is dominated by industrial applications. The top four[2] single uses of hydrogen today (in both pure and mixed forms) are: oil refining (33%), ammonia production (27%), methanol production (11%) and steel production via the direct reduction of iron ore (3%).

Around 70 Mt of dedicated hydrogen are produced today, 76% from natural gas and almost all the rest (23%) from coal. Annual hydrogen production consumes around 205 billion m^3 of natural gas (6% of global natural gas use) and 107 Mt of coal (2% of global coal use), with coal use concentrated in the People's Republic of China. As a consequence, global hydrogen production today is responsible for 830 $MtCO_2/yr$.

2.4 Green production pathways

Water electrolysis: Hydrogen produced through the electrolysis of water with the electricity stemming from renewable sources. Water electrolysis is a mature technology and is considered to be the hydrogen production technology of choice

[2] The Future of Hydrogen, IEA, June 2019, page 89.

for the near future. Electrolysis currently accounts for 2%[3] of global hydrogen production, but there is significant scope for electrolysis to provide more low-carbon hydrogen.

Modular photo-electrolysis: This technology combines in each module a miniaturized PEM electrolyser with a high-efficiency solar cell attached to a specially designed concentrated solar photovoltaic module to leverage 100% of the sun energy – both electrical and thermal – to deliver highly competitive green hydrogen.

Thermal water-dissociation: Heat-based (e.g. concentrating solar Power, CSP) solar thermochemistry can split hydrogen from water. CSP is a relatively mature technology.

Bio-hydrogen routes: The range of bioenergy technologies is broad and the technical maturity varies substantially. The production of hydrogen requires energy, which in the case of bio-hydrogen comes either from the biomass used as raw material (steam reforming, pyrolysis, fermentation) or from solar energy absorbed by living biomass (algae, bacteria) during photosynthesis. Bio-hydrogen can also be produced from bio-methane organic waste material.

Photo-induced (non-biologic) water dissociation: Water dissociation in the presence of photo-catalysts. Photocatalytic water splitting into H_2 fuel has been a research focus for its possible key role in solving the energy crisis and environment problem. Indeed, water splitting offers in principle an ideal approach for hydrogen and oxygen production, which involves cathodic hydrogen evolution reaction and anodic oxygen evolution reaction. However, up to now they still suffer from low efficiency due to serious charge-carrier recombination.

2.5 Production costs

Today, neither renewable hydrogen nor low-carbon hydrogen, notably fossil-based hydrogen with carbon capture, are cost-competitive against fossil-based hydrogen. Estimated costs today for fossil-based hydrogen are around 1.5 €/kg[4] for the EU, highly dependent on natural gas prices. Estimated costs today for fossil-based hydrogen with carbon capture and storage are around 2 €/kg, and renewable hydrogen 2.5-5.5 €/kg.

Costs for fossil based hydrogen strongly depend on the prize of natural gas and are therefore lowest in Russia, United States and the Middle East. Costs for electricity based hydrogen mostly depend on the prize of renewable electricity. In general, the production costs depend strongly on the production region. The LCOE for solar and wind projects from different European regions, together with respective solar and wind capacity factors, enable to expect different production conditions in EU. In the best locations, hydrogen from low-cost wind and solar PV projects is expected to achieve fossil fuel parity within the next five years, specifically against hydrogen from SMR using natural gas with CCS.

3 Target setting (What do we want?)

We consider the immediate reduction of the use of fossil energy carriers (respectively their replacement by so-called 'green' energy carriers) and the feedstock-use of 'Green Hydrogen' as essential to keep up prosperity and peace. Beside bio-based (carbon-containing) energy carriers green electricity and 'Green Hydrogen' are considered to be the energy carriers and feedstock of the future.

We expect 'Green Hydrogen' to play a significant key-role in reducing worldwide CO_2-emissions. This means replacing fossil-based hydrogen in existing applications and creating new applications and markets for 'Green Hydrogen'.

Existing large volume markets for 'Green Hydrogen' are:

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[3] The Future of Hydrogen, IEA, June 2019, page 37.
[4] The Future of Hydrogen, IEA, June 2019, page 42-49.

- **Oil refining:** Used primarily to remove impurities (e.g. sulphur) from crude oil and upgrade heavier crude. Used in smaller volumes for oil sands and biofuels.
- **Ammonia production:** To date, industry produces 180 million tons of ammonia globally, with 80% used as feedstock for fertilizer and the remaining 20% for industrial chemicals production. Ammonia represents about 45% of global hydrogen offtake, making it the largest consumer of hydrogen today.
- **Methanol production:** Only some primary chemicals require large quantities of dedicated hydrogen production for use as feedstock. Beside ammonia methanol requires most of the dedicated produced hydrogen. Methanol is used for a diverse range of industrial applications, including the manufacture of formaldehyde, methyl methacrylate and various solvents.

Possible future large volume markets (additional to the mentioned existing markets) are:

- **Steel production** (direct reduction of iron ore).
- **Growing sectors in need of an independent electricity supply** (i.e. server farms)
- **High temperature heat** (excluding chemicals and steel production) industrial high-temperature heat (e.g. cement production) is a potential source of hydrogen demand growth in the future, but virtually no dedicated hydrogen is produced for this application today.
- **Clean transport fuels:** In general, hydrogen-based fuels could take advantage of existing infrastructure with limited changes in the value chain, but at the expense of efficiency losses. Possible applications range from heavy road transport to train and maritime applications over to aviation.
- **Heat in buildings:** Hydrogen as a fuel for heat in buildings, also covering the aspects of micro-CHP.
- **Energy system:** Hydrogen for power (including combined heat) generation and electricity storage and as a sector-coupling and system-integration facilitator. In addition to contribution to decarbonisation, 'Green Hydrogen' improves the flexibility of the energy system.

4 Needs assessment (What is missing or needs more attention?)

Hydrogen is already widely used in some industries, but 'Green Hydrogen' has not yet realised its potential to support clean energy transitions. What is missing and how can 'Green Hydrogen' be successful in existing and future markets?

Possible measure categories in order to promote the use of 'Green Hydrogen' are:

- Stimulate commercial demand for 'Green Hydrogen': e.g. fiscal incentives, CO_2-prize (Emissions Trading System, ETS), cross border CO_2-tax (carbon border adjustment mechanism), product CO_2-footprint, renewable energy quotas, exemption from electricity taxes and levies, strengthened emissions reduction targets, stronger CO_2 emissions standards for cars and vans, increased share of renewable energy in aviation and maritime fuels …
- International agreements and multilateral cooperation: e.g. harmonised standards, removing barriers, harmonised trading rules, globally functioning system of assessing the sustainability criteria, hydrogen guarantees of origin (HGOs), develop multilingual permit procedures …
- Financing: e.g. long-term signals to foster investor confidence, mitigate salient risks, kick-start financing, grants and loans …
- Demonstration, communication, education: e.g. showing the important contribution to the green deal, clarify safety issues, demonstrate feasibility, create (digital) networks of experts in transport and energy, increase employability in the hydrogen sector through educational programmes …

- Regulatory Framework: e.g. fasten permit procedures, regulatory framework for hydrogen infrastructure, provide trainings for relevant regulatory bodies …
- Public support for 'Green Hydrogen' technology: Funding; providing infrastructure; focused, predictable and consistent energy policy; long-term stability; optimized transport solutions, increase GHG-emission visibility through digitalization …
- System analysis and assessment on a lifecycle perspective: To avoid rebound effects and burden shifting, R&I activities should be pre-assessed vs. its potential to deliver net positive impacts in a full life cycle perspective.

5 Questions for the public consultation

The change from a fossil energy carrier based economy to an economy fueled by 'Green Hydrogen' and electricity is a revolution. As a consequence of the (required fast) change we need to overcame serious barriers to overcome, especially at the beginning. These barriers can be, amongst others, the resistance of the existing system, high start-up costs, immature products or consumer scepticism or a lack of a robust demand or the fear of sunken costs.

To support the SRIA-process, we have formulated questions in order to capture the knowledge and opinions of different stakeholder groups. The answers to the questions will be transferred in short-term, medium term and long-term research and innovation goals with accompanying actions. All questions refer to 'Green Hydrogen' and, correspondingly, to energy carriers and feedstock's containing 'Green Hydrogen'.

Question block 1: Market in general and barriers to entry

1) What are the main barriers to overcome on the way to a 'Green Hydrogen' economy?
   - Price difference to fossil based energy-carriers
   - Energy losses in the conversion, storage and transport of hydrogen
   - Government 'discrimination' of specific technologies
   - Lack of political courage for appropriate framework conditions
   - Poor public information and therefore little public interest
   - Lack/absence of a credible GO (guarantees of origin) scheme
   - Inconsistent or counterproductive funding rules
   - Obstructive regulatory and regional structures
   - Lack of common international trade rules, harmonized regulations and standards
   - Conflict of use with electrical energy
   - Other [free text-field]

2) Should the market focus on individual sectors during the ramp-up?
   - No, time is short and we have to position hydrogen as broadly as possible
   - No, a focus limits innovation

   If yes, please indicate:

   - Mobility

- Busses
- Heavy-duty transport

— Industry

- Iron industry
- Steel industry

— Chemical sector

- NH_3
- MeOH

— Energy

- Storage
- Grid stabilization
- Heat
- System integration
- High temperature-heat in industry

— Other [free text-field]

3) <u>How can we best create a level-playing field with fossil energy carriers?</u>

— No public money for fossil fuel applications

— No public money for fossil-based hydrogen

— Increasing fossil fuel prices (CO_2-pricing, …)

— Financial support for 'Green Hydrogen' and its application

— Stepwise legislation towards carbon neutrality

— Charging fossil energy carriers total costs (including external effects such as environment, health related) caused by CO2-emissions of fossil sources

— financial support for CAPEX reduction of technology via scaling up and research

— financial support for increase of renewable (cheap) green electricity production

— Other [free text-field]

4) <u>How can we best build up an open and rapidly developing 'Green Hydrogen' economy?</u>

— Cooperation beyond borders

— Fast introduction of legislation towards carbon-neutrality

— Develop measures to boost renewable energy production capacities

— Give easier access to research results for citizen and energy communities

— Create digital networks of European stakeholders for improving knowledge-exchange and cooperation

- Strategic strengthening of 'Green Hydrogen' in existing or new hydrogen strategies and policies (national and European)
- Creation of strategic demonstration projects and flagship initiatives
- Exchange of best practice examples
- Other [free text-field]

5) Is a bottom-up or top-down approach preferable in order to support 'Green Hydrogen' economy best?
   - To be fair, it needs (more) top-down legislation
   - If yes
     - The European Commission should set the legislation
     - The states should set the legislation
   - Industry knows best what it needs to reach the goals
   - Other [free text-field]

6) How do you rate the influence of top-down (concentrated energy production and supply) and bottom-up (dispersed energy production) approach on public acceptance and on the market
   - In top down systems the objectives are far away from citizens. They are taken by the public as national objectives, and sometimes as objectives of the big business
   - In bottom up system the objectives are related to personal values and goals, they support active participation of producers and consumers
   - Concentrated energy production and supply is needed first to reach price competitiveness and develop the corresponding infrastructure, dispersed energy production will follow
   - Dispersed energy production and supply for specific use cases is needed first to create public awareness and acceptance. Concentrated energy production and supply follows as market demand increases.
   - Other [free text-field]

7) Are binding quantitative 'Green Hydrogen' targets (e.g. in strategies) essential in order to stimulate the market and to foster investor confidence?
   - Yes, why and which kind of targets are required?
   - No, why?
   - Other [free text-field]

Question block 2: System, system integration and sector coupling

8) Which are the most important dimensions for system integration?
   - Infrastructure

- Market design and business models
- Regulation and policy
- Component technologies (e.g. efficiency improvement)
- Households, citizens and communities
- Other [free text-field]

9) Sector coupling[5] - which are the main barriers?
   - Technology readiness level (TRL) of components
   - Market design
   - Stability of regulatory and market conditions
   - Resource limitations
   - Intransparent cost and revenue shares
   - Other [free text-field]

10) Should we focus on concentrated or dispersed renewable energy production/hydrogen supply and utilization systems?
    - Both are necessary and should be stimulated
    - Both are necessary but we should focus more on dispersed energy production due to its systemic advantages
    - Concentrated: large units on transmission voltage levels, servicing complete electricity market system
    - Dispersed: smaller units on distribution voltage levels, structured into subsystems, involving direct participation of consumers and producers.
    - Model of hydrogen supply and utilization system: Part of infrastructure – distribution networks of 'Green Hydrogen'
    - Model of hydrogen supply and utilization system: Multi-energy hubs\ 'Green Hydrogen' valleys, structured into use cases and energy eco-systems
    - Other [free text-field]

11) The role of energy- and grid-regulatory is to provide for safe and reliable system and thus to oppose changes. How could they better support the introduction of 'Green Hydrogen' as an energy carrier?
    - There is no conflict
    - The introduction of new technologies, new players and new business models that change existing system constraints are in conflict with the role of regulators

[5] Sector coupling: The integrated approach by all sectors (electricity, gas, heat, transport, and industry), by using energy in a sector that was generated in another sector, and enabling an overall increase in efficiency.

- In order to obviate conflicts, the regulatory should introduce pilot projects regulations
- Pilot project regulations should be coordinated on European (e.g. BRIDGE) level to enable projects with partners from different countries
- Other [free test field]

Question block 3: Market support

12) Should public procurement focus on hydrogen applications (e.g. acquisition of hydrogen-vehicles)?
    - No
    - Yes, in areas and applications where hydrogen systems are most suitable
    - Other [free text-field]

13) Should development (and funding) focus on components or system-integration R&D?
    - Both research areas are as important
    - On components R&D
    - On system-integration R&D
    - Other [free text-field]

14) How can we display GHG-emissions along the supply chain at best?
    - Mandatory life cycle assessment (LCA) for all products
    - Certificates of origin for 'Green Hydrogen'
    - Develop appropriate digital applications
    - Label products with their GHG-emission footprint
    - Label products with their environmental impact
    - Introduce and display carbon-tax
    - Other [free text-field]

Question block 4: Society, public-acceptance and public-relation

15) How can we inform people at best about 'Green Hydrogen'?
    - Municipality workshops
    - Develop easy-to-understand content
    - Integrate renewable energies and hydrogen in school education
    - Make potential emissions "visible" via digitalization
    - Use social media to extent research's range
    - Continuous learning about 'Green Hydrogen' in all types of schools

- Making positive and negative environmental impacts (local resources, pollution) visible
- Making regional/local development and employment visible
- Other [free text-field]

16) How can we support citizen participation in 'Green Hydrogen' scenarios?
    - Mandatory actions forced by legislation (like vehicle exhaust emission legislation)
    - Roadshows
    - Case-study demo approaches
    - Supporting citizen energy communities
    - Supporting the start-up scene and enabling people to build companies
    - Allowing citizen participation in 'Green Hydrogen' investments
    - Other [free text-field]

17) How can we empower local energy communities at the production sites?
    - I don´t believe that specific local actions should be set. All local activities will follow automatically if the boundaries are set correctly top-down.
    - Other [free text-field]

Question block 5: Internationality, cooperation and regional aspects

18) Are the announced measures in your country strong enough to support fast ramp-up of a 'Green Hydrogen' economy?
    - Yes
    - No, better adjustment of the local and regional activities are needed
    - Announcing works, but implementation is poor
    - Except individual activities, frankly, my home country is a slow follower compared to other countries
    - Other [free text-field]

19) How can we facilitate plant permit procedures internationally better?
    - Offering multilingual permit procedures
    - Deploy a European permit help desk
    - Speed-up the acknowledgment of digital signatures
    - Create a European legal form to support renewable energies and green hydrogen
    - Develop a platform to access needed national documentations in translation
    - Permit procedures are not ta special bottleneck

— Other [free text-field]

20) How can we create internationally acknowledged vocational trainings and academic programmes to build up a hydrogen work force?

- Once, a hydrogen economy is on track, such things will develop automatically. No governmental actions are needed
- Build upon the existing partnerships of universities and create international programmes focused on renewable energies & 'Green Hydrogen'
- Develop further training programmes for employees in the gas market
- Develop further training programmes for employees in regulatory bodies
- Engage more women in energy and transport via mentoring programmes
- Other [free text-field]

21) How can we secure a resilient international hydrogen supply?

- Develop models and continue to test them on robustness and sensitivity
- Commitment to long-term hydrogen supply partnerships
- Foster efficient energy use and renewable energy supply locally to simplify the additionally needed import and distribution
- Decentralize the gas market to involve local communities better
- [free text-field]

22) What strengths do you see in your country in terms of a 'Green Hydrogen' economy?

- [free text-field]

23) Have we forgotten, referring to market stimulation 'Green Hydrogen' in general, anything important?

- [free text-field]

6 Glossary

CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
EC	European Commission
LCOE	Levelised Cost of Electricity
SRIA	Strategic Research and Innovation Agenda
SMR	Steam Methane Reforming