commentary

European Academies' Science Advisory Council

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Hydrogen and synthetic fuels

Summary

As European countries continue to adapt their economic, social and industry policies to minimise the impacts of the COVID-19 pandemic, key elements of the Green Deal offer new jobs and business opportunities to help with the recovery while addressing climate change at the same time. In particular, the European Union (EU) hydrogen and energy system integration strategies clearly highlight the potential benefits of and urgent need for investment to accelerate the deployment of renewable electricity generation on which decarbonisation of the EU economy, including the future production of renewable hydrogen and synthetic fuels in the EU, will depend.

In this Commentary, EASAC (the European Academies' Science Advisory Council), which is the independent voice of the National Academies of Science of the EU Member States, Norway, Switzerland and the UK, draws upon its previous work on energy and decarbonisation policies to comment and advise, through 15 key points for policy-makers, on the implementation of the EU hydrogen strategy.

Now is the right time to begin a phased approach to the sustainable development, production and use of renewable hydrogen. Strong governance of the emerging renewable hydrogen sector and the removal of market barriers in the EU is needed, with good coordination between EU and Member State strategies and rules. Targeted investments in decentralised electrolysers should focus on further cost reductions and feeding renewable hydrogen into sustainable local markets and networks. For the foreseeable future, hydrogen should be used primarily for decarbonising those applications that are difficult to electrify.

The EU should build a strong leadership role in global hydrogen markets, by developing international partnerships with third countries to include not only collaboration on research and technology development but also the trading of hydrogen production technologies, renewable hydrogen and synthetic fuels. Further studies and demand-driven initiatives, including research, should be initiated soon at EU and national levels to address the emerging and long-term needs for hydrogen infrastructure, standards and certification.

EASAC calls on the EU to establish science-based long-term energy and climate policies that will remove market barriers and build investor confidence in the production and use of renewable hydrogen.

EASAC welcomes the publication of the European Commission's Hydrogen Strategy (EU, 2020a), which reflects much of the related science-based policy advice published by EASAC and others over the past few years (EASAC, 2017a, 2018, 2020a; IEA, 2019; FCH, 2019).

It is timely that this EU hydrogen strategy has been launched together with a new EU strategy for energy system integration (EU, 2020b) as part of the EU Green Deal, and notable that both strategies recognise the urgent need to accelerate decarbonisation with the aim of limiting climate warming in accordance with the Paris Agreement (UN, 2015). The EU vision for the production and use of renewable hydrogen[1] highlights the urgent need for substantially more renewable electricity, which is also recognised in EASAC's report on the decarbonization of transport (EASAC, 2019a), but more work is needed to determine exactly how and how quickly so much renewable electricity can be delivered, including that from generation within the EU and imports.

Governance in the energy sector is crucial at this time of climate crisis, when EU Member States need support to secure economic recovery from the ongoing COVID-19 pandemic (EASAC, 2020a). It is therefore particularly welcome that, in line with the EU regulation on the governance of the energy union and climate action (EU, 2018a), the EU hydrogen strategy recognises the need for coordination with the national hydrogen strategies of the Member States, because this will maximise opportunities for the whole EU to benefit from the diversity of renewable energy resources and the evolving markets for hydrogen across the Member States (EWK, 2020). Current hydrogen markets in the EU are set to change and evolve because chemical processes including the production of ammonia must be decarbonised and refinery demands will drop as the use of fossil fuels is phased out. At the same time, new markets are expected to emerge for renewable and low-carbon hydrogen[2], notably in steel making, long-distance transport and energy systems (EASAC, 2019a). Links to the circular economy in the EU hydrogen and energy system integration strategies are also important in this respect (EASAC, 2016).

EASAC welcomes the international dimension of the new EU hydrogen strategy, which acknowledges the need for the EU to establish a leadership role and to compete in the emerging global markets for innovative energy technologies, including renewable hydrogen and hydrogen-derived synthetic fuels[3]. Detailed information on synthetic fuels was recently published by the Royal Society (2019). Cooperation with third countries, especially those that have large renewable energy resources, will be important for the long term as global markets emerge for renewable hydrogen and hydrogen-derived synthetic fuels. Consequently, the EU hydrogen strategy's commitment to the EU becoming a recognised international stakeholder in renewable hydrogen markets and developments should be steadily strengthened from now onwards, and will become increasingly important in the medium to long term. Like other international cooperation activities of the EU, this should be designed and managed on a partnership basis, bringing added values to all parties concerned.

The ambition of the EU hydrogen strategy, to produce up to 10 megatonnes of renewable hydrogen by 2030, is little more than the current EU demand for fossil-based hydrogen, or about 11% of the global demand of 70 megatonnes (IEA, 2019), but this nevertheless implies very ambitious trajectories for the future development and deployment of electrolysers for renewable hydrogen production, with accelerations that are well in excess of recent learning curves for granular technologies, which can be mass produced in small units to benefit from economies of scale (Wilson *et al*., 2020). However, EASAC recognises the need for an ambitious hydrogen roadmap, and that the different industries in the emerging low-carbon hydrogen supply and demand chains, especially small and medium-sized enterprises, need a common vision of the future, as a basis for building new business models. The EU strategy's longer-term objectives to deploy hydrogen at large scale and to reach all hard-to-decarbonise sectors by 2050 provides such a vision and should help to build investor confidence in new businesses and in the required innovative technologies. Like other roadmaps, it also indicates to policy-makers where adjustments to framework conditions will be needed to achieve these objectives.

The phased approach, which is proposed in the EU hydrogen strategy, is consistent with successful approaches used for other innovations over many years. Experience with such innovations has demonstrated the importance of avoiding premature and expensive lock-ins to solutions or infrastructures that are subsequently made redundant by cheaper technologies or market developments. Hence, building on recent experience

[1] EU hydrogen strategy defines 'renewable hydrogen' as hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. Renewable hydrogen may also be produced through the reforming of biogas (instead of natural gas) or biochemical conversion of biomass, if in compliance with sustainability requirements.

[2] EU hydrogen strategy defines 'low-carbon hydrogen' as encompassing fossil-based hydrogen with carbon capture and electricity-based hydrogen, with significantly reduced full life-cycle greenhouse gas emissions compared with existing hydrogen production.

[3] EU hydrogen strategy defines 'hydrogen-derived synthetic fuels' as a variety of gaseous and liquid fuels based on hydrogen and carbon. For synthetic fuels to be considered renewable, the hydrogen part of the syngas should be renewable. Synthetic fuels include, for instance, synthetic kerosene in aviation, synthetic diesel for cars, and various molecules used in the production of chemicals and fertilisers.

in the electricity sector, where distributed generation is playing an ever-increasing role, it makes sense to promote the large-scale deployment of renewable hydrogen by investing now in distributed electrolysers for local hydrogen production feeding into local market networks, together with sustained research on bringing down the costs of the most promising technologies. Hydrogen demand-driven studies of integrated power and gas networks (transmission and distribution) and market mechanisms should also be supported now, and used to guide short-, medium- and long-term policies, as well as planning and permitting procedures for future infrastructure investment and market development. These studies should be regularly updated with information on market developments and on the performance improvements and cost reductions of maturing technologies that will result from the progressive deployment of renewable hydrogen in local, regional and eventually in global markets.

Most hydrogen is produced today from fossil fuels, using processes with high levels of greenhouse gas emissions. Such processes must be replaced or adapted to deliver low-carbon hydrogen sustainably with minimal greenhouse gas emissions and affordable costs (Figure 1). The costs of producing hydrogen from fossil fuels with carbon capture and storage have been estimated to be lower than those of producing renewable hydrogen by electrolysis, but the costs of electrolysers are falling quickly and the future market prices of hydrogen will depend on future carbon pricing as well as on the costs of production technologies and infrastructure (Royal Society, 2018; IEA, 2019). EASAC therefore concurs with the message in the EU hydrogen strategy that potential investors should take into account the limited overall effectiveness (56–90%) of greenhouse gas capture from the multi-stage hydrogen production process when considering investments in fossil-based hydrogen with carbon capture and storage, and notes the analysis of the IEA which shows that such plants have carbon footprints of 30–120 grams of carbon dioxide equivalent per kilowatt-hour (gCO_2e/kWh) (IEA, 2019) compared with less than 10 gCO_2e/kWh for renewable hydrogen produced using wind-generated electricity. Similar conclusions have recently been drawn by Babacan *et al*. (2020).

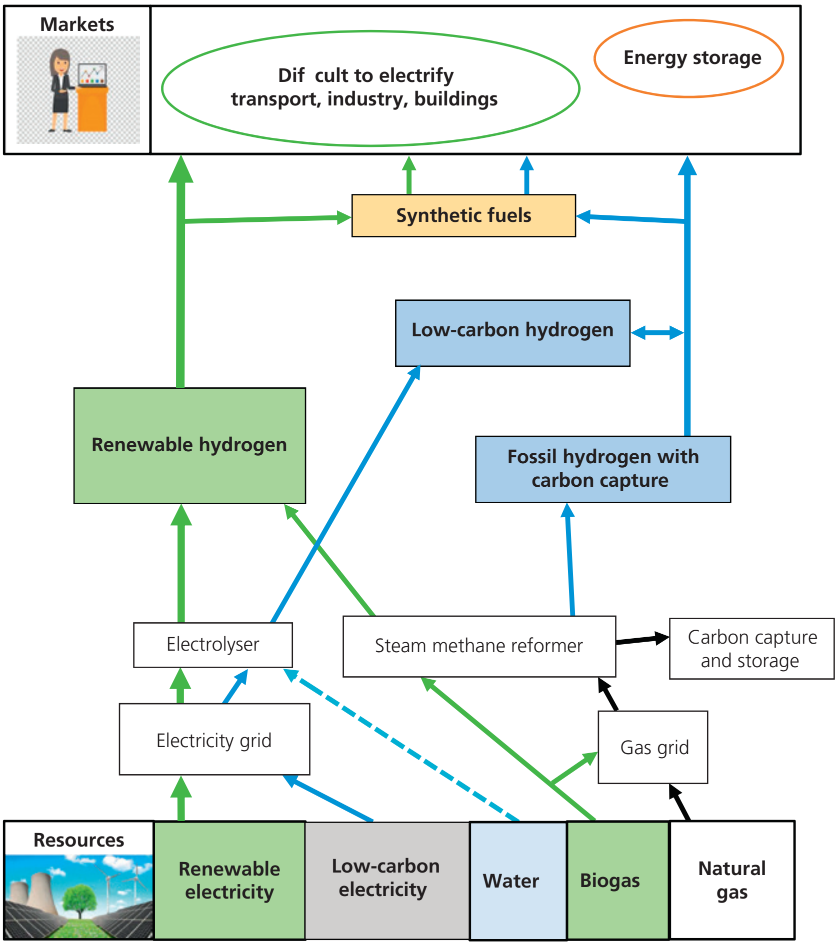

Figure 1 Overview of the emerging hydrogen economy, based on terminology used in EU hydrogen strategy. Production pathways for renewable hydrogen are shown in green; fossil hydrogen with carbon capture and low-carbon hydrogen are in dark blue.

Many barriers to the long-term development of hydrogen markets remain, and it will be important for these to be removed as the new hydrogen strategy is implemented. Standards and transparent regulatory and certification frameworks are needed, but it is particularly urgent to remove the subsidies, taxes, levies and other incentives, which continue to distort energy markets by directly and indirectly supporting the use of fossil fuels. The establishment of the Clean Hydrogen Alliance, which is foreseen in the EU hydrogen strategy, should be complemented by inputs from independent expert groups and coordinated to assist not only with the development of a pipeline of investment projects, but also with the identification of market barriers and the development of measures for removing them.

In terms of incentives for future hydrogen markets, EASAC notes that the EU hydrogen strategy recognises the need to address carbon pricing as part of the decarbonisation process, and EASAC looks forward to proposals for ambitious revisions to the Emissions Trading System Directive (EU, 2018b) that are designed to achieve this in the near future. In addition, the EU regulatory framework for energy and climate will need to be regularly updated in the coming years to accommodate the changing environmental and economic impacts of energy use, as energy supplies are decarbonised.

EASAC recognised in its report on the decarbonisation of transport (EASAC, 2019a) the potential for the use of hydrogen (e.g. with fuel cells) in those parts of the transport sector that are difficult to electrify, such as long-distance freight haulage by road and shipping. EASAC also highlighted in that report the long-term potential for using hydrogen-derived synthetic fuels in aviation and green ammonia in shipping, but noted the inherent inefficiency of synthetic fuel production, which leads to less energy being delivered if renewable or other low-carbon electricity is used via synthetic fuels than if that electricity is stored in a battery and used directly (e.g. for transport). Hence, the resource requirements and costs of the delivered energy are typically higher when using synthetic fuels than when using the same renewable electricity directly. This implies for the foreseeable future that the use of synthetic fuels is likely to be focused on applications that are difficult to electrify. However, in the long term, the use of synthetic fuels may evolve because they can be easily stored and transported over long distances, and some countries with large renewable energy resources may be able to supply synthetic fuels at competitive prices to those countries that lack renewable energy resources (Runge *et al.*, 2020).

There are many potential drivers for future hydrogen and synthetic fuel markets including not only fuel production, storage and distribution costs, but also the delivery of resilient energy systems, consumer choice (in spite of higher mobility costs, some drivers may prefer to use 'traditional' vehicles with liquid fuels or fuel cell vehicles) and prices. Renewable hydrogen can be produced more cheaply in some countries than in others because of the big variations in the availability of renewable energy and in the costs of investment capital (interest rates). The future competitiveness of hydrogen and synthetic fuels is also likely to be affected by carbon prices, by the implementation of the new EU taxonomy regulation with its criteria for environmentally sustainable economic activities and its disclosure obligations that aim to promote market transparency (EU, 2020e), and by the rules of the planned Carbon Border Adjustment Mechanism (EU, 2020f), which the European Commission is scheduled to propose in 2021 to reduce the risks of carbon leakage.

In the light of its own work on the sustainability of forest biomass for energy production (EASAC, 2017b, 2018, 2019b), EASAC warmly welcomes the message in the EU hydrogen strategy about the need for sustainability requirements where forest biomass is used to produce renewable hydrogen, and the reference to the statement in the EU Biodiversity Strategy (EU, 2020c) that the use of whole trees for energy production should be minimised.

The important role that hydrogen and hydrogen-derived synthetic fuels can be expected to play in the medium to long term in relation to the management of electricity grids was highlighted in EASAC's report on electricity storage (EASAC, 2017a). As grid electricity is increasingly decarbonised by replacing fossil-fuelled power generation with wind and solar generators, more storage (centralised and distributed) will be needed to facilitate grid flexibility management, and both renewable hydrogen and hydrogen-derived synthetic fuels are likely to be used in the medium to long term for electricity storage. In the long term, EASAC has also identified that there may be a role for hydrogen and hydrogen-derived synthetic fuels as energy carriers for transporting renewable energy over very long distances, such as across oceans.

EASAC is currently working on the decarbonisation of buildings and will not finalise its advice for policy-makers on the future use of hydrogen in buildings until its report is published in 2021 (EASAC, 2020b). However, it is already clear that some hydrogen may be used in the short term in the building sector, because the owners of existing gas boilers could in the near future be supplied by their local gas distribution network with up to 10–20% of low-carbon hydrogen blended with natural gas (Hydeploy, 2020). At the same time, as building heating demands are substantially reduced through renovation (EU, 2020d), natural gas is phased out, and existing boilers reach the end of their working life, gas boilers are likely to be increasingly replaced, where feasible, with district heating systems in urban areas (HRE, 2020) or electric heat pumps, both of which are likely to be cheaper to run than gas boilers fuelled by hydrogen. The building sector will therefore become increasingly 'coupled' to the industry and transport sectors as they all compete for renewable electricity to deliver their decarbonisation objectives.

EASAC will continue to offer independent scientific advice for policy-making on issues related to the decarbonisation of the EU economy, and fully supports the commitment in the EU Green Deal strategies to urgent actions and investments to increase the EU's supplies of renewable electricity, which will be needed to underpin the entire decarbonisation process.

Key points for policy-makers

1. **Urgently increase the generation of renewable electricity**, which should be used directly where possible, and is essential for large-scale renewable hydrogen production.
2. **Remove subsidies, taxes, levies and other incentives for fossil fuels**, which continue to distort energy markets and limit the potential growth of markets for renewable hydrogen and synthetic fuels.
3. **Include independent experts** beyond the Clean Hydrogen Alliance in the work to identify and develop measures for removing market barriers.
4. **Strengthen carbon pricing** by revising the Emissions Trading System Directive to stimulate markets for renewable hydrogen and hydrogen-derived synthetic fuels.
5. **Introduce new regulations** (besides the Emissions Trading System) to accelerate change from fossil to renewable hydrogen in chemical and other industries, including steel production.
6. **Build investor confidence** by supporting stakeholders working together in local hydrogen networks (Member States, industry, civil society, and science community).
7. **Promote sustainable development of hydrogen markets**, beginning with local or regional networks close to renewable electricity supplies, hydrogen production plants and hydrogen consumption centres.
8. **Establish strong links for coordination of governance structures** between EU, national, regional and local levels.
9. **Secure supplies of renewable hydrogen from outside the EU** (in addition to EU production) by establishing international partnerships and trade cooperation with interested third countries as well as with EU neighbours.
10. **Promote investments** in renewable hydrogen and hydrogen-derived synthetic fuels, with a focus on minimizing the energy invested, as well as accounting for the overall life-cycle costs per unit of greenhouse gas emission reduction.
11. **Encourage investment in renewable hydrogen** by promoting the EU taxonomy with its disclosure obligations for environmentally sustainable economic activities.
12. **Establish standards for hydrogen production** based on life-cycle greenhouse gas performance, and certification of low-carbon hydrogen to use with EU taxonomy for investments.
13. **Support the rapid development of electrolysers**, prioritising those with falling costs and fast market diffusion and learning curves, to accelerate hydrogen production.
14. **Prohibit the use of whole trees** for producing renewable hydrogen by using sustainability criteria that limit carbon payback times to less than 10 years.
15. **Support research, market studies and demand-driven initiatives** on hydrogen infrastructure (local, national and international) and on certification and standards.

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EASAC

EASAC – the European Academies' Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in giving advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

EASAC covers all scientific and technical disciplines, and its experts are drawn from all the countries of the European Union. It is funded by its member academies with some contributions from independent foundations and organisations such as UNESCO. The expert members of EASAC's working groups give their time free of charge. EASAC has no commercial or business sponsors.

EASAC's activities address many of the challenges highlighted by the United Nations Sustainable Development Goals, and include substantive, evidence-based studies of the scientific aspects of policy issues, as well as reviews and advice about specific policy documents. EASAC hosts workshops aimed at identifying current scientific thinking about major policy issues and at briefing policy-makers. EASAC also produces short, timely statements on topical subjects.

EASAC is the regional affiliated network in Europe of the InterAcademy Partnership (IAP), which is a global network of more than 140 national, regional and global academies of science, medicine and engineering. EASAC collaborates with academies in IAP's three other regional networks, namely the Association of Academies and Societies in Asia (AASSA), the Inter-American Network of Academies of Science (IANAS; the Americas) and the Network of African Science Academies (NASAC), on actions that support the special role of science and provide independent evidence-based advice to policy-makers as they seek solutions to address the world's most challenging problems. EASAC's work with IAP helps to bring a global perspective to the science-based advice that it produces for EU policy-makers.

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To find out more about EASAC, visit the website – www.easac.eu – or contact the EASAC secretariat at secretariat@easac.eu.

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