Hydrogen patents for a clean energy future

A global trend analysis of innovation along hydrogen value chains

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Europäisches Patentamt
European Patent Office
Office européen des brevets

International Energy Agency

Executive summary

A successful transition to a clean energy future will be supported by rapid changes in the global economy and in people's patterns of energy consumption, all of which have the potential to sustain healthier societies, more equitable outcomes and a more resilient planet. Technology will be at the heart of many of these changes, and nowhere more so than in the scale-up of hydrogen as a clean energy carrier.

While strong policy will be needed to make low-emission hydrogen cost-competitive, it will not be possible without technology improvements across a value chain that touches nearly every part of the energy system. Innovators around the world are ramping up their efforts in areas as diverse as fossil fuel conversion, electrochemical splitting of water, graphene tanks, cryogenic storage, fuel cell motors for aircraft and the reduction of iron ore. If hydrogen is to play a major role in reducing fossil fuel emissions, its future depends on uniting a wide range of advances in different types of hardware and creating new markets for them. Compared with digital technologies such as software, hardware generally takes more time to develop and involves greater investment risk during the prototyping and market entry phases. Through patenting, inventors seek to ensure that they can recoup these investments in innovation.

Coordinating the deployment of the full hydrogen energy value chain is perhaps the most complex of all the technical challenges facing energy engineers and it is sometimes hard to discern the status of all the underpinning technology areas. Patents are strong indicators of innovation activity which can give very detailed insights into the state and direction of the science.

This study, which combines the expertise of the International Energy Agency and the European Patent Office, is the most comprehensive, global and up-to-date investigation of hydrogen-related patenting so far. Uniquely, it covers technologies for the full range of hydrogen supply, storage, distribution, transformation and end-user applications, as well as introducing new search strategies to compare incremental innovation related to established fossil fuel processes with emerging technologies motivated by the climate challenge.

Key findings

1. Global patenting in hydrogen is led by Europe and Japan, with the US losing ground in the period 2011–2020 and hydrogen-related innovation from R. Korea and P.R. China only starting to emerge at the international level.

About half of international patent families (IPFs)[1] in hydrogen technologies in the period 2011–2020 were related to hydrogen production. The other IPFs were split between end-use applications of hydrogen and technologies for the storage, distribution and transformation of hydrogen.

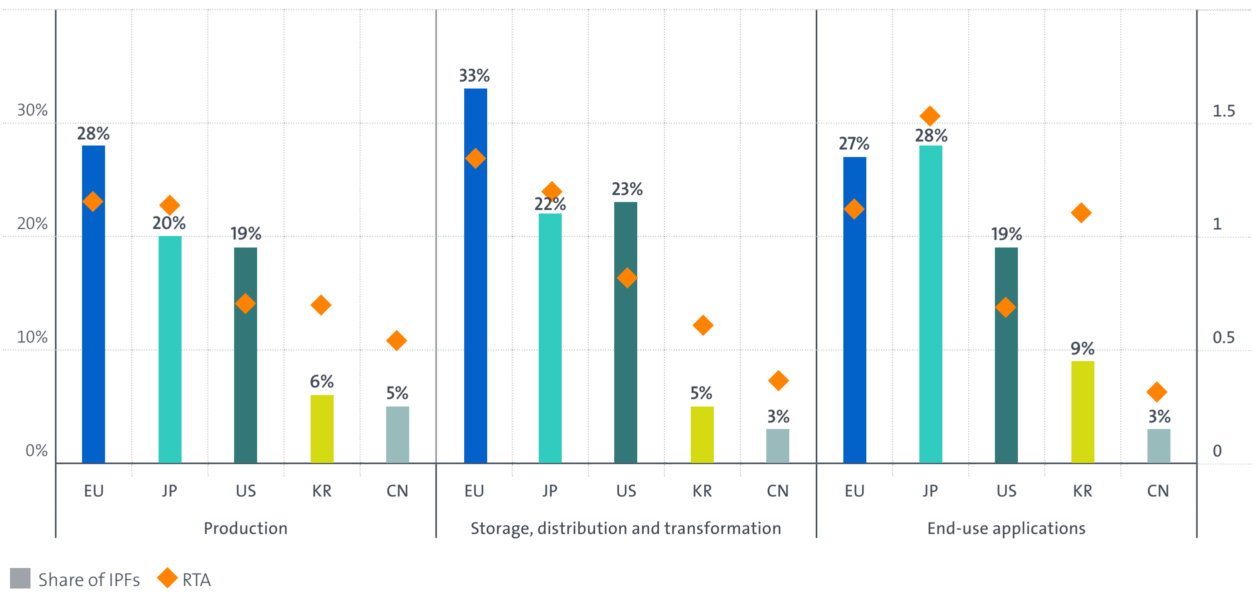
With 28% of all IPFs in the period 2011–2020 and revealed technology advantages (RTA[2]) across the three technology segments of the hydrogen value chain, EU countries are global leaders in hydrogen patenting (including 11% from Germany and 6% from France).

Japan is likewise a strong innovator in hydrogen, with 24% of all IPFs published and a revealed technology advantage in all three categories of technology. Hydrogen patenting grew even faster in Japan than in Europe during the past decade, with compound average growth rates of 6.2% and 4.5% respectively between 2011 and 2020.

The US contributed 20% of all IPF publications related to hydrogen between 2011 and 2020 and is the only major region where the number of IPFs decreased during the past decade. The number of international patent applications originating from R. Korea and P.R. China remains modest in comparison. However, it increased steadily in the period 2011–2020, with average annual growth rates of 12.2% and 15.2% respectively and a strong focus on emerging end-use applications of hydrogen in the case of R. Korea.

Figure E1

Share of international patenting and revealed technology advantage by main world regions and value chain segments (IPFs, 2011–2020)



Note: The calculations are based on the country of the IPF applicants, using fractional counting in the case of co-applications.

Source: author's calculations

1 Each IPF covers a single invention and includes patent applications filed and published at several patent offices. It is a reliable proxy for inventive activity because it provides a degree of control for patent quality by only representing inventions for which the inventor considers the value sufficient to seek protection internationally. The patent trend data presented in this report refer to numbers of IPFs.

2 The RTA index indicates a country's specialisation in terms of hydrogen innovation relative to its overall innovation capacity. It is defined as a country's share of IPFs in a particular field of technology divided by the country's share of IPFs in all fields of technology. An RTA above one reflects a country's specialisation in a given technology.

2. Innovation in established hydrogen technologies is dominated by the European chemical industry, but the new hydrogen patenting heavyweights are companies from the automotive and chemicals sectors focusing on electrolysis and fuel cell technologies.

Within each of the three main technology segments of hydrogen value chains, a distinction can be made between i) incremental improvements to well-established processes in the chemicals and refining sectors and ii) emerging technologies that could help mitigate climate change by making hydrogen a clean energy product for a much wider range of sectors. Hydrogen technologies primarily motivated by climate generated twice as many IPFs in the period 2011–2020 than established technologies. They were particularly focused on end-use applications and production methods, whereas established technologies still generate a majority of IPFs in hydrogen storage, distribution and transformation.

Top applicants in established technologies are dominated by chemical companies with an extensive background in the production and handling of hydrogen from fossil fuels. They are also diversifying into emerging technologies (such as carbon capture, utilisation and storage - CCUS) enabling the supply of low-emission hydrogen. Top applicants in emerging technologies motivated by climate are led by Japanese and Korean companies, typically from the automotive industry. Their patent portfolios are mainly focused on production by electrolysis and applications based on fuel cells but also extend to established technologies for the storage and distribution of liquid or gaseous hydrogen, an area of focus for these countries which plan to import stored hydrogen in the near future.

Universities and public research institutions generated 13% of all hydrogen-related IPFs between 2011 and 2020, with the top ten research institutions alone accounting for about 3% of all IPFs. They are dominated by Korean and European institutions and show a strong focus on climate-motivated hydrogen production methods, such as electrolysis.

Figure E2

Top international applicants in established technologies and technologies motivated by climate (IPFs, 2011–2020)

	Production		Storage, distribution and transformation		End-use applications	
	Established technologies	Motivated by climate	Established technologies	Motivated by climate	Established technologies	Motivated by climate
Top 4 – Established						
Air Liquide (FR)	174	44	94	50	18	21
Linde (DE)	155	48	87	40	9	23
Air Products (US)	61	20	30	13	2	8
BASF (DE)	34	34	23	11	2	13
Top 4 – Motivated by climate						
Toyota (JP)	12	48	114	50	2	528
Hyundai (KR)	1	16	44	14		319
Honda (JP)	7	48	48	16		200
Panasonic (JP)	5	128	2	1		6
Top 3 – Research						
CEA (FR)	10	109	21	11	1	7
IFP (FR)	48	30	4	8	1	30
CNRS (FR)	3	30	4	12	1	7

Note: IPFs have been allocated to the listed entities based on the identification of these entities as an individual or co-applicant of the related patents. Technologies related to CCUS and CO_2 avoidance in fossil fuel-based hydrogen production, as well as technologies for vehicle refuelling, are labelled in this chart as "motivated by climate". Ranking is based on the size of applicant portfolios of IPFs in established and climate-motivated hydrogen technologies. The sum of the applicants' IPFs reported in the chart may exceed the actual size of their portfolio due to some IPFs being counted as relevant to two or three different segments of the value chain.

Source: author's calculations

3. While hydrogen production remains almost entirely fossil fuel-based, patenting has already seen a major shift towards alternative, low-emission methods. This shift anticipates a boom for electrolysers, a field in which Europe has gained an edge in new manufacturing capacity.

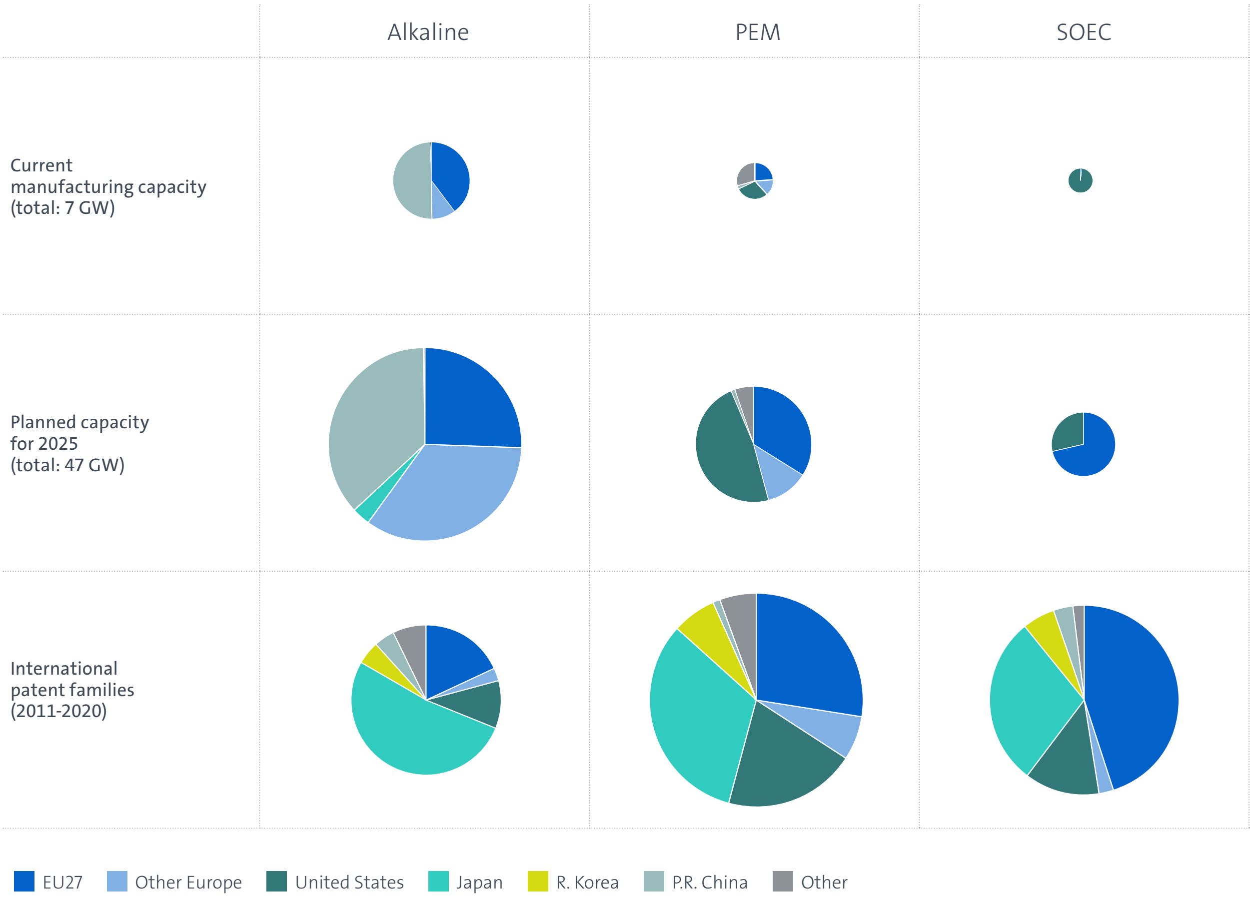
A comparative analysis of patenting trends in hydrogen production technologies over the past twenty years shows a clear shift of innovation from traditional, carbon-intensive methods to new technologies with the potential to decarbonise hydrogen production. Technologies motivated by climate concerns generated nearly 80% of IPFs related to hydrogen production in 2020. Their growth was chiefly driven by a swift rise in innovation in electrolysis.

Several categories of electrolysers are competing for the large expected market, which could rise from 1 GW to over 65 GW per year by 2030 under announced government pledges. Japan led patenting in state-of-the-art alkaline technologies and more cutting-edge PEM technologies between 2011 and 2020. However, investment in manufacturing capacity for these technologies has not yet taken off there. The EU 27 and other European countries are active in both patenting and manufacturing – notably in SOEC technologies – while also making significant contributions in terms of PEM and alkaline technologies. The US is very active in developing PEM manufacturing capacity, but less active in innovation, as indicated by patenting. P.R. China is only a small contributor to international patenting in electrolyser technologies, but is investing heavily in manufacturing capacity, with a nearly exclusive focus on cheaper alkaline technology, which has a much longer history but lower expectations for future improvements.

Published IPFs related to hydrogen production from fossil fuels have been decreasing since 2007, with emerging solutions to decarbonise fossil fuel-based hydrogen generating only limited patenting thus far. Innovation in other hydrogen production technologies motivated by climate likewise appear to lack momentum. Patenting activities in hydrogen production from biomass or waste (via gasification or pyrolysis) rose sharply between 2007 and 2011 but have decreased considerably since then. The number of IPFs related to water splitting via non-electrolytic routes has also decreased slightly since 2010. In 2020, it represented 12% of the total number of IPFs published in the field of electrolysis.

Figure E3

Origins of inventions related to electrolysers and manufacturing capacity



Note: The calculations are based on the country of the investors and IPF applicants, using fractional counting in the case of co-applications.

Source: author's calculations (based on announcements by electrolyser manufacturers)

4. Patenting activities targeting improvements in existing technologies for the storage of hydrogen and the production of ammonia and methanol grew steadily from 2001 to 2020. However, innovation in the development of hydrogen-based fuels lost momentum in the past decade.

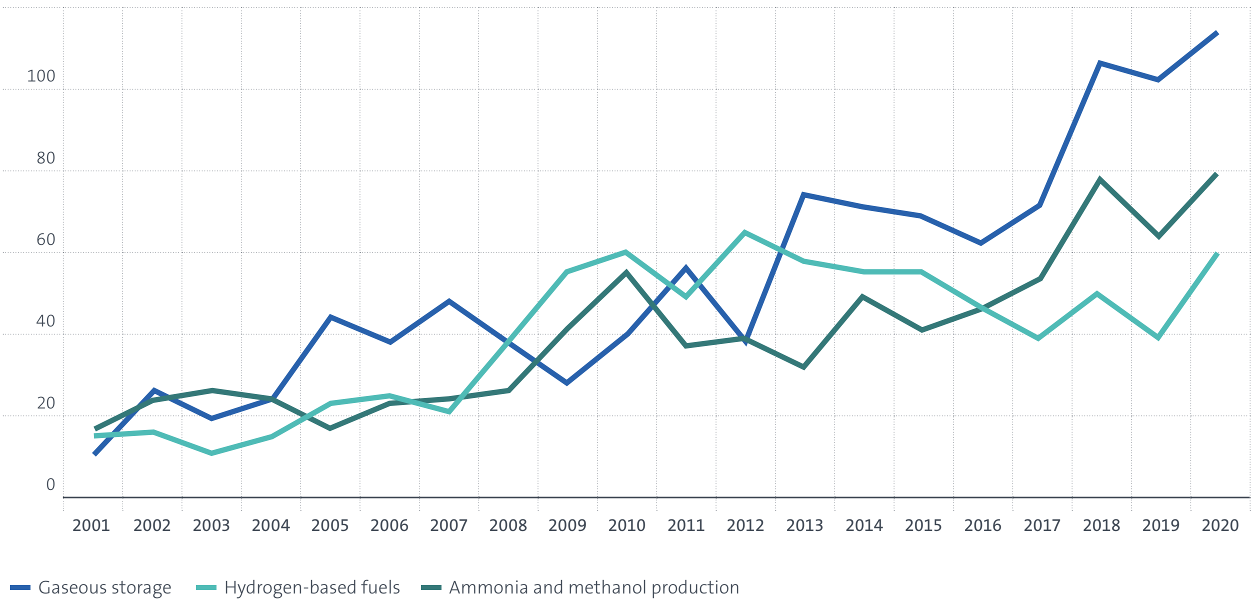
Pure hydrogen is currently transported either in gaseous form by pipelines and tube trailers or in liquefied form in cryogenic tanks. Patenting trends since 2001 show that these established technologies have attracted increasing innovation efforts over the last two decades, signalling the industry's ability to improve and interest in improving the deployment and efficiency of hydrogen distribution systems right through to vehicle refuelling. While long-established actors of the hydrogen industry are active in all technology segments of hydrogen storage and distribution, automotive companies have also become important patent applicants in some of these segments due to the importance of on-board hydrogen storage to the commercialisation of hydrogen-powered vehicles.

The number of published IPFs related to the use of hydrogen for ammonia and methanol production likewise grew between 2001 and 2020, reflecting both the efforts to reduce the significant climate impact of their production processes and the recent interest in these molecules as hydrogen-based fuels for the power and transport sectors. Like pure hydrogen storage technologies, innovation in these fields is chiefly driven by (mostly European) companies that are already specialised in the production and handling of hydrogen from fossil fuels.

Progress in other hydrogen-based fuels – for example synthetic kerosene for aviation or synthetic methane – also relies on improvements to efficiency and cost reductions, but patent data suggest that innovation in these technologies lost momentum during the past decade. US- and Europe-led efforts to develop synthetic fuels have stalled since 2011. Patenting for the competing technologies for long-distance transportation of hydrogen energy increased rapidly from 2011 to 2020, with compound average growth rates of 12.5% for liquid organic hydrocarbons (LOHC) and 7.8% for ammonia cracking. However they only represent a small number of patent families, half of which still originate from science-oriented research institutions.

Figure E4

International patenting trends in gaseous hydrogen storage, ammonia production, methanol production and alternative hydrogen-based fuels (IPFs, 2001–2020)



Source: author's calculations

5. Patenting activities for hydrogen use in the automotive sector continue to expand at much higher rates than for other end-use applications, despite some recent progress towards the use of hydrogen for steel production. However, innovation has yet to take off significantly in other industrial applications, including long-distance transportation using hydrogen-based fuels.

The strong growth of IPFs in transportation was driven by innovation in fuel cell propulsion in the automotive sector and, to a lesser extent, short-distance aviation (particularly drones). Patenting activities in these fields are largely dominated by Japanese and Korean automotive companies, and appear to generate synergies with innovation in PEM electrolysis. By contrast, innovation in internal combustion engines (ICE) and turbines using hydrogen, ammonia or methanol as a fuel has not yet been boosted by the recent policy momentum behind hydrogen, though these technologies are likely to be needed for long-distance transportation, particularly for shipping and medium-haul aviation.

IPF publications related to the use of hydrogen for iron and steel production rebounded in 2017 following several years of decrease since 2014. Nearly 40% of patenting activities in the period 2011–2020 were concentrated among a small number of steel producers and equipment suppliers. The latter are led by European companies and appear to be in a more advanced position to integrate the most advanced hydrogen technologies (such as direct reduced iron and smelting reduction) into a new generation of production equipment.

The level of patenting in other end-use applications of hydrogen in buildings and electricity generation decreased during the 2010s, denoting a lack of interest in building applications in regions other than Japan and a growing interest in batteries as an alternative solution for stationary electricity storage.

Figure E5

International patenting trends in hydrogen-based propulsion technologies, 2011–2020

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Automotive										
Fuel cells	64	72	105	98	107	187	170	171	182	234
Internal combustion engines	80	67	51	69	58	47	54	60	79	61
Aviation										
Fuel cells	16	19	34	18	22	25	30	25	23	71
Gas turbines	6	12	10	17	14	15	16	12	15	16
Shipping										
Fuel cells	3	5	15	12	8	14	10	8	16	19
Internal combustion engines	5	10	16	11	11	15	14	12	16	24

Source: author's calculations

6. Patenting underpins fundraising by start-ups developing hydrogen businesses, with more than 80% of later-stage investment in hydrogen start-ups going to companies which had already filed a patent application, indicating the importance of patenting for young firms in this area.

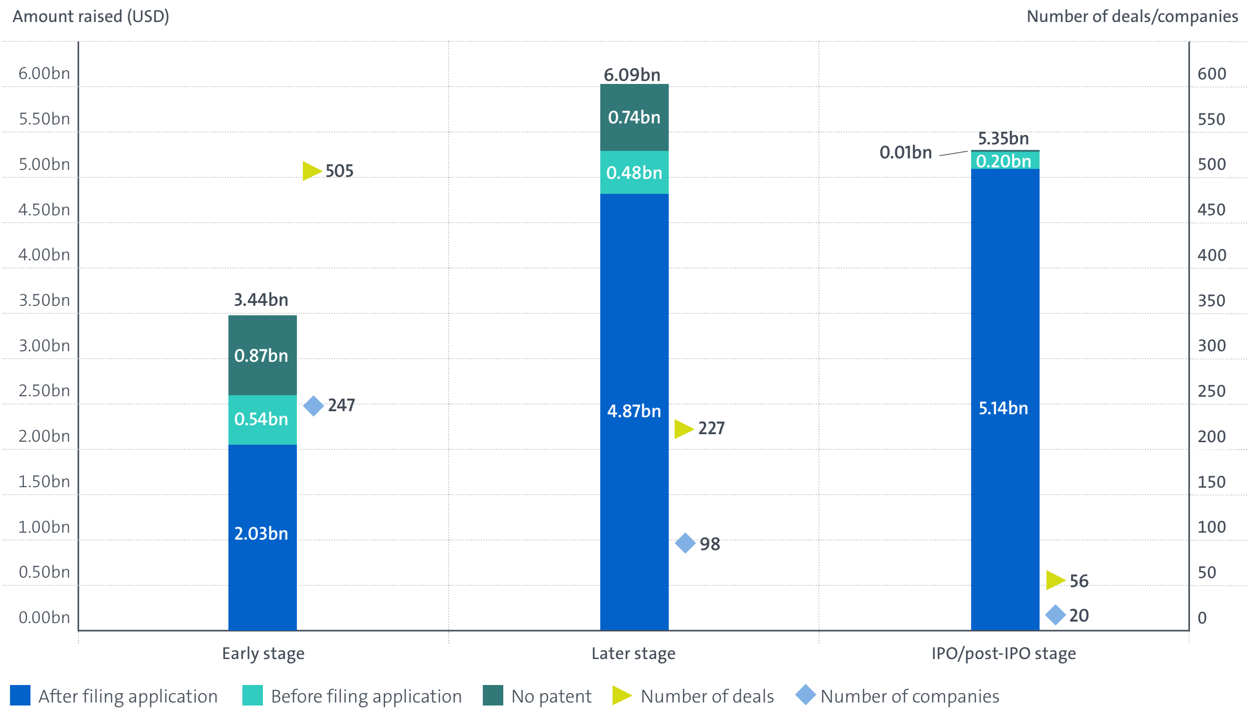
Almost 70% of the 391 start-ups which have activities related to hydrogen hold at least one patent application. Indeed, the majority of start-ups in the hydrogen sector start their journey in the laboratory and rely either on the recombination of existing technologies or on leveraging emerging technologies to address fundamental technical problems. These types of ventures require significant investments in R&D and engineering, and typically rely on patents to secure those investments.

Only 117 of the 391 start-ups filed IPFs in the scope of this study during the period 2011–2020, mostly in the EU (34%) and the US (33%), but they attracted 55% of the venture capital funding provided for early, late and IPO/post-IPO stages. A broader analysis of venture capital deals involving hydrogen start-ups with or without patent applications shows that the share of the total amount of funding raised by companies with patent applications grows consistently when moving to later funding rounds (Figure E6). More than 80% of the later-stage investment in hydrogen start-ups is received by companies which had already filed their first patent application. This percentage increases to 95% when funding acquired in the IPO/post-IPO stage is taken into consideration.

The IPFs of hydrogen start-ups mainly target technologies primarily motivated by climate, such as electrolysis and fuel cells. However, about a third of them also show patenting activities in established technologies, usually in combination with IPFs in climate-motivated technologies. This is the case in particular in hydrogen production, thus signalling attempts to reduce the carbon impact of hydrogen from gas and other fossil fuels.

Figure E6

Share of funding accruing to start-ups, by funding stage, 2000-2020



Note: Funding deals are only included for companies that were founded between 2000 and 2020. The reference date with respect to the patent filing is the earliest priority date calculated for the set of patent families assigned to the specific company. Cleantech Group, Crunchbase and Dealroom have been used as data sources for funding rounds. Early-stage funding contains the following investment types: Seed, Series A, Series B. Later-stage funding contains the following investment types: Series C-F. IPO/post-IPO stage: non-equity type transactions are not included in this stage. Reported funding at the post-IPO stage is limited to private investments in public equity types of investments, thus excluding additional public shares issues.

Source: author's calculations

7. The uneven trends in hydrogen-related patenting across technologies and regions indicate opportunities for policy action to help realise a net zero emissions future.

Despite overall positive signals from the growth of patenting activity in hydrogen technologies, there are several areas of concern. The reliance of hydrogen technologies on a complex technical value chain means that the widespread use of low-emission hydrogen will only proceed as quickly as the weakest link in the chain. The emphasis of innovators on hydrogen production is very welcome, and will lead to cost reductions over time, but cost and performance improvements are also needed in areas such as hydrogen-based fuels synthesis and end-use applications. While cost reductions in these areas are widely anticipated in analysts' economic models of the future energy system, patent data suggest that inventors are not yet incentivised to make them a reality.

The risk of a mismatch in supply and demand technologies should be taken seriously by governments. The variety of electrolyser solutions being developed in laboratories and, more recently, in commercial-scale factories has created a momentum for innovation that is supported by economic competition between companies and regions. There is a good case for governments to steer innovation towards novel manufacturing techniques, reduced reliance on some critical minerals or the use of desirable inputs such as brine or contaminated water, and the general direction is already very encouraging. However, investments into the deployment of these technologies depends on there being willing purchasers of low-emission hydrogen, which in turn depends on the existence of appropriate and competitive transformation and end-use technologies. Unless so-called "drop-in" hydrogen-based fuels are available on the market, or the technologies to switch from fossil fuel-based hydrogen are widely accessible to consumers and businesses around the globe, investment will be limited.

Governments play a key role in setting the research agenda and adopting policies that incentivise the private sector to invest in innovation. The patent data clearly shows that established players are heavyweights in hydrogen patenting and are capable of expanding into new market segments. Automotive companies and chemical companies that are active in fuel cells and electrolysis are a clear example. Sending signals about the need to transition to cleaner fuels to companies in the iron and steel, aviation and shipping sectors will stimulate technology efforts among incumbents and also catalyse new start-ups. Such signals can be based on regulation, market incentives or financial transfers, coupled with support for innovative projects. Similarly, patenting trends for the use of hydrogen to upgrade biofuels and for stationary power generation need a new impetus.

Another area to be monitored in future studies of hydrogen patenting for a clean energy future is the production of hydrogen from fossil fuels. To reduce emissions significantly, this established sector of the economy cannot continue with incremental innovations to improve efficiency. All fossil fuel-based technologies should be aligned with climate motivations if these technologies aim to have a role in a net zero energy system.

The full report is available for download at:
epo.org/trends-hydrogen
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