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Hydrogen – an explosive gas or the future of green energy?

The European Patent Office (EPO) and International Energy Agency (IEA) have co-authored a report on patenting technology related to hydrogen. Here, Tim Belcher, partner in EIP's Elements team, digests aspects of the report relating to storage and production.

Hydrogen as an energy source will have a significant role to play environmentally, economically and politically, and innovation will drive development and adoption of the technology. IP plays a key role in protecting innovators' research and attracting future investment.

Hydrogen. The simplest element and one of the most abundant on the planet, but relatively rarely found in elemental form (i.e. not in combination with other elements). It is heavily used in ammonia, fertiliser and steel production but elemental hydrogen must be generated to get useful quantities, and both production and storage are not straightforward.

The bulk of the world's hydrogen is currently generated from fossil fuels; carbon-neutral production routes are available but their higher cost has slowed adoption of so-called "green hydrogen". Hydrogen can act as an energy store/carrier (akin to a battery), and thus has the potential to reduce reliance on fossil fuels in circumstances where other green energy sources cannot be used (e.g. shipping, aviation). Water is the only by-product of such use.

Both politics and economics are shifting in favour of 'green' hydrogen. The significant increase in gas and oil prices sparked by Russia's invasion of Ukraine has shifted the energy landscape. Not only is there a need for energy security, but diversity too; the BBC recently reported that offshore wind is allegedly a potential target for sabotage and governments will be aiming to secure a variety of national energy sources. Coupled with many governments committing net-zero carbon emissions (often by around 2050), interest in hydrogen as an energy store is growing. The historically higher cost of generating green hydrogen is offset against rising energy prices, whilst governments are investing in the technology, reducing net costs in the private sector.

A recent report authored by the International Energy Agency (IEA) in collaboration with the European Patent Office (EPO) concludes that innovation in the production and storage of hydrogen is accelerating, although further investment is needed "to unlock new applications of hydrogen". Innovative companies will invest significantly in finding creative solutions which overcome the current barriers to wider adoption of green hydrogen and patents are a vital tool which should allow innovators to see a return on this investment. Indeed, the EPO report notes that "more than 80% of later-stage investment in hydrogen start-ups [went] to companies which had already filed a patent application, indicating the importance of patenting ...in this area."

Innovation and trends in low-emission hydrogen production methods

While hydrogen production currently remains almost entirely fossil fuel-based, the IEA/EPO's report shows a significant acceleration of innovation in alternative, low-emission methods seemingly motivated by climate concerns. These technologies can help produce low-emission hydrogen in various ways: from water and electricity (known as electrolysis), methane pyrolysis, from fossil fuels with minimal CO2 emissions (using carbon capture, utilisation and storage (CCUS)), and from bioenergy (for example via biomass gasification).

Hydrogen production from water can be achieved by thermochemical, photocatalytic and electrolytic methods. Electrolysis of water is currently the most efficient of these and uses electricity to split water molecules apart into hydrogen and oxygen. The declining cost of renewable or nuclear-generated electricity is increasing interest in electrolytic hydrogen production; locating electrolysers at sites with excellent renewable resource conditions (wind, sun etc.) looks likely to become a viable low-cost hydrogen generation option. Further, in some cases, the technology can be used in a reversible manner – to make hydrogen from electricity or to produce electricity from hydrogen – depending on market demand.

Three electrolytic cell formats dominate the industry:

1. Solid oxide electrolyser cells (SOECs), which operate at high temperatures (typically ~800°C). A significant portion of the energy input to the system is provided

as heat (rather than electricity) and this can reduce the overall cost of hydrogen production. Further efficiencies are found by locating such cells in sites where significant heat is generated anyway (e.g. nuclear power stations, or waste industrial heat).

2. Polymer electrolyte membrane cells (PEMs), use expensive platinum group metal catalysts but are highly efficient and can operate at higher current densities; employed at sufficient scale, they can generate hydrogen at a cost competitive with other electrolysers. PEMs also have the advantage of being comparatively simple and can be designed to accept widely varying voltage inputs, which makes them ideal for use with renewable sources of energy such as photovoltaic solar panels.
3. Alkaline electrolysis cells (AECs), which are generally cheaper than PEMs as they use cheaper, nickel-based catalysts. This technology is more mature but is less efficient and there is a reasonable consensus in the industry that development of AECs is unlikely to keep up with other electrolysis systems.

The IEA/EPO's analysis points to AECs dominating the commercial landscape, but with innovation focussed on PEMs and SOECs, suggesting an approaching change in the relative dominance of these different electrolyser systems. Innovation in the field of electrolysers is dominated by Japanese and European companies (based on number of patent filings), but investment in manufacturing capacity for electrolysers is dominated by Chinese companies (largely AECs), with European and US companies also spending on increasing capacity (SOECs and PEMs respectively).

Emerging trends and obstacles in hydrogen storage and transportation

Hydrogen is, inconveniently, quite explosive and specialist equipment is therefore needed for storage and transport. For hydrogen to be adopted as a fuel on a large scale, efficient systems will be required to port hydrogen from production site to consumption site. Prevention of leaks from storage facilities is also more difficult for hydrogen as compared to other gases (e.g. methane). Significant progress and standardisation in this area is thought to be required in order to reduce risk for investors and for progress to accelerate.

Today, most hydrogen is stored and transported as a compressed gas. In some areas, regional demand for hydrogen is high enough that overland pipelines are in place which distribute it in a compressed form. However, if green hydrogen becomes more competitive as an energy carrier, transit over greater distances will be required and compression technologies will not readily scale to the necessary extent at a viable cost point; the weight and volume of the storage apparatus is prohibitive and energy input for compression is high.

Liquefaction is an established technology for hydrogen trucks that could also facilitate the long-distance transportation of hydrogen in ships, followed by regasification upon arrival. Chemical storage, such as reversible incorporation of hydrogen into methanol, allows high storage density. However, whilst both liquefaction and chemical storage can be more readily transported, they require significant energy input to transform the hydrogen. Nevertheless, through converting hydrogen (which has very low energy density) into fuels that have similar properties to oil and gas, not only can the costs of storage and transport be reduced but it also becomes easier to use low-emission hydrogen in long-distance road, air and maritime transport, which rely heavily on liquid fossil fuels without a clear alternative in a net zero emissions future.

The IEA/EPO report gives an interesting insight into where investment has been targeted over the last twenty years. Throughout this period there have been a large number of filings related to distribution infrastructure and the storage of pure hydrogen, with the number of filings per year growing. Progress in this area looks to be focussed in the US, and most applications have been filed by large, commercial entities (rather than SMEs or universities), which may be a sign that the technology is relatively mature and innovations are incremental.

Filings relevant to liquid storage and vehicle refuelling are also increasing year on year. Established players in the hydrogen market are active here alongside, unsurprisingly, the automotive sector (and the Japanese market in particular). Most applications in this field are general, but some relate specifically to the specific use of the technology (e.g. hydrogen storage at a fuel station or in a marine vessel).

As noted above, chemical storage offers much higher density storage - for example, supercritical hydrogen at 30 °C and 500 bar only has a density of 15.0 mol/L while methanol has a density of 49.5 mol H_2/L methanol - and, in some cases, reconversion to hydrogen at point of use is not required, reducing cost. Synthetic fuels, particularly liquid hydrocarbons, have the advantage of being able to be used in existing fuel infrastructure. Development of such fuels has been largely focussed in Europe and the US and, in contrast to filings made in relation to pure hydrogen, a significant proportion of filings have been made by academic institutions "signally an enduring role of fundamental research" and relatively immature technology. However, despite such apparent advantages, patent filings related to chemical storage peaked in the early 2010s and development in this areas looks to have slowed – perhaps, the EPO speculate, because the underlying reactions have been known for a long time and so there is diminishing scope for improvement.

IP protection

At EIP, we firmly believe that patent protection for innovative hydrogen solutions is vital in encouraging investment and driving research, and we hope this will make green hydrogen a commercial reality in the near future. Irrespective of entity size or position in the hydrogen value chain and wherever in that chain you sit, EIP has the team to help your IP position. Please do not hesitate to get in touch with us.