Department for
Energy Security
& Net Zero

Hy4Heat Evaluation

Annex C: Hydrogen investment trends and patents

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Department for
Energy Security
& Net Zero

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Investment trends in hydrogen technologies

This annex presents findings from an analysis of investment in companies or projects relating to hydrogen. One of the aims of Hy4Heat is to stimulate industry to invest in parallel programmes of R&D relating to the development of hydrogen for heat technologies and/or their safe implementation in the gas network. The review provides a time series analysis of the extent of investment in hydrogen technology R&D.

In addition, this analysis extended to identifying firms participating in Hy4Heat, and the investment / financial outcomes achieved by these firms.

The sources used for this data analysis are:

- **Pitchbook**. Pitchbook is an online platform that provides close to real time information on UK high growth companies, with a focus on financial data. The data from these sources can be used to acquire information relating to the fundraising efforts of organisations, including the number, location and size of private equity deals secured, and the valuation of firms. This includes a description of the primary activities of organisations raising finance. Organisations and deals relating to hydrogen have been identified and the data analysed, alongside a review of the data for firms involved in the Hy4Heat programme. For equity deals and finance raised, Pitchbook is a strong and robust data source. However, it does not provide information for smaller value deals or have a complete coverage of smaller firms. It also does not include information about firms which self-finance (use their own resources to fund expansions).
- **Innovate UK data**. Innovate UK provides data about publicly funded grants awarded to firms from Innovate UK in the UK. This includes information about the size of grants, the level of collaboration, the year of the award and a description of the innovation project being funded. The description of the funded projects has been reviewed to discover if the research project included hydrogen-based research, and the number, date and value of these projects has been analysed.

Private investment in Hydrogen

This section draws on data from Pitchbook. To identify investment in organisations relating to hydrogen, the following two search terms outlined below were used. These terms were selected to try to remove investment in companies investing in hydrogen technologies focused on vehicles and in healthcare products, or other hydrogen investments which are unrelated to the Hy4Heat programme.

Two main search terms were used.

First, a broader set of terms to capture investment in wider hydrogen technologies that play a role in the wider hydrogen economy, but not specifically tailored to the types of appliances in focus for Hy4Heat. Including; "*Hydrogen OR hydrogen fuel OR hydrogen fuel cell OR fuel cell technology OR fuel cell systems) NOT (Automotive OR Autonomous cars OR HealthTech*)" – The results are presented as a standalone analysis of wider investment in hydrogen, to show the scale of investment in hydrogen technologies, not just in companies which are working to develop hydrogen heating or safety technologies. This allows a comparison to be made between investment in hydrogen technologies and investment in hydrogen for heat technologies.

Secondly, a more tailored set of terms to the topics of relevance to Hy4Heat. This set of terms replicated the search criteria used for the analysis of patents in the PATSTAT database:

"*hydrogen and fire; hydrogen and cooking; hydrogen and heat; H2 and heat; hydrogen and odour; hydrogen and purity; hydrogen and boiler; hydrogen and sensor; hydrogen and safety; hydrogen and meter; hydrogen and network; hydrogen and CHP; hydrogen and combined heat and power; hydrogen and cookers; hydrogen and oven; hydrogen and stove; hydrogen and hob; hydrogen and thermostat (presented together)*".

In addition to the main search terms used, the following inclusion criteria was applied:

- All financial deals except for public grants awarded.
- Information from between 2010 and September 2021.[1]
- No geographic restrictions

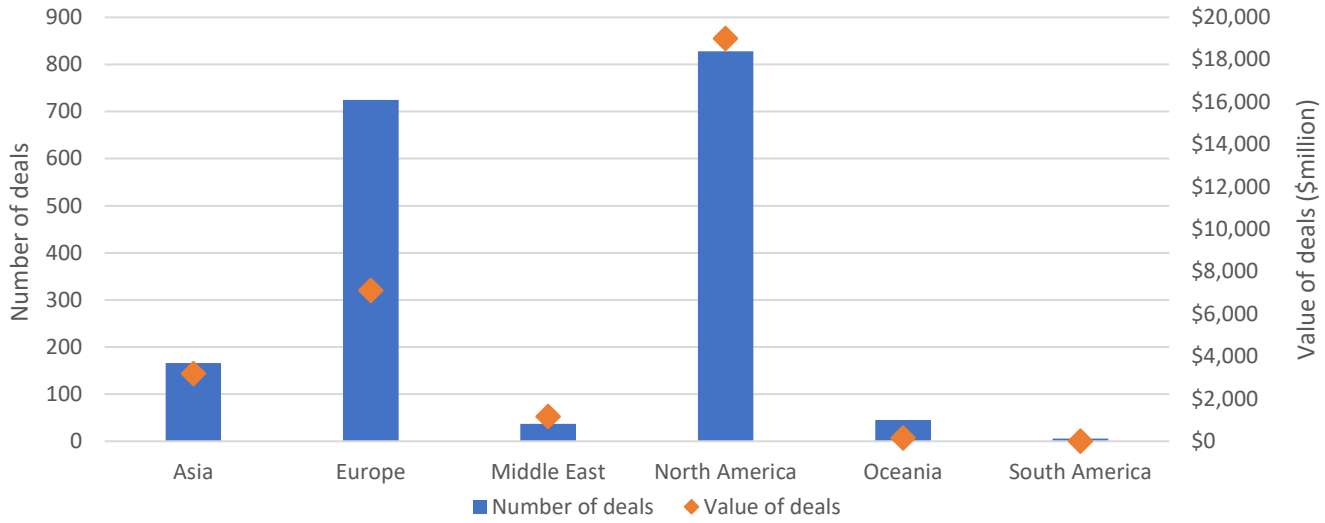
Results: wider global hydrogen investment

Analysis of the wider trends in global hydrogen investment, not specifically related to the Hy4Heat project, was conducted to better contextualise where Hy4Heat sits within global investments into innovative hydrogen investment.[2] Since 2010, there have been over 1,800 investment deals relating to hydrogen. These deals were valued at $31 billion (where valuation details were available).

Figure 1 below shows the number and value of deals by world region related to hydrogen. The majority of deals (46 percent) occur in North America, followed by Europe (40 percent) which are the two dominant regions. In total 1,553 of the 1,807 completed deals (86 percent) occurred in either North America or Europe.

[1] We have included 2021, even though not a complete year, due to the large number of financial transactions highlighted by the search terms in 2021.
[2] NOTE: The data presented here does not necessarily present a complete picture of a nation's commitment to and funding of hydrogen for heating research. This is because it does not capture all public investment in hydrogen for heating research, and it does not capture all private research and development spending on hydrogen for heating projects.

Figure 1 Number and value of investment deals by global region

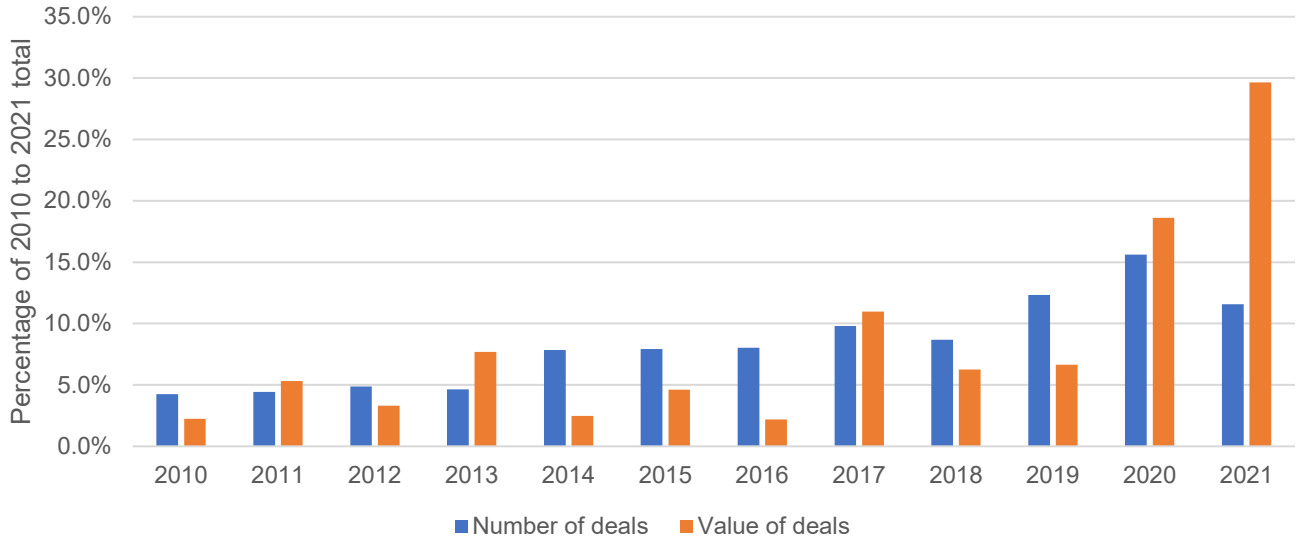


Source: Pitchbook, September 2021

North America not only dominates in terms of deals but also in the value of those deals. 62 percent of the total value of deals are in North America, followed by Europe (23 percent) and Asia (10 percent). Europe has a relatively low proportion of total value compared to its share of deals (23 percent compared to 40 percent), suggesting the average value of deals in Europe is lower than elsewhere in the world.

The patterns over time have been explored in more detail in Figure 2 below. This shows that, in general, there was an increasing trend in the number of deals completed from 2010 onwards. The pattern for the total value of deals completed each year is inconsistent – there was a large spike in value in 2013 (31 percent of the total value of investments between 2010 and 2020). However, other than this spike in value the percentage of total deal value each year was generally higher in the latter half of the decade (average of 11 percent per year of the total value of investment from 2015 onwards) than the earlier half of the decade (an average of four percent, excluding 2013).

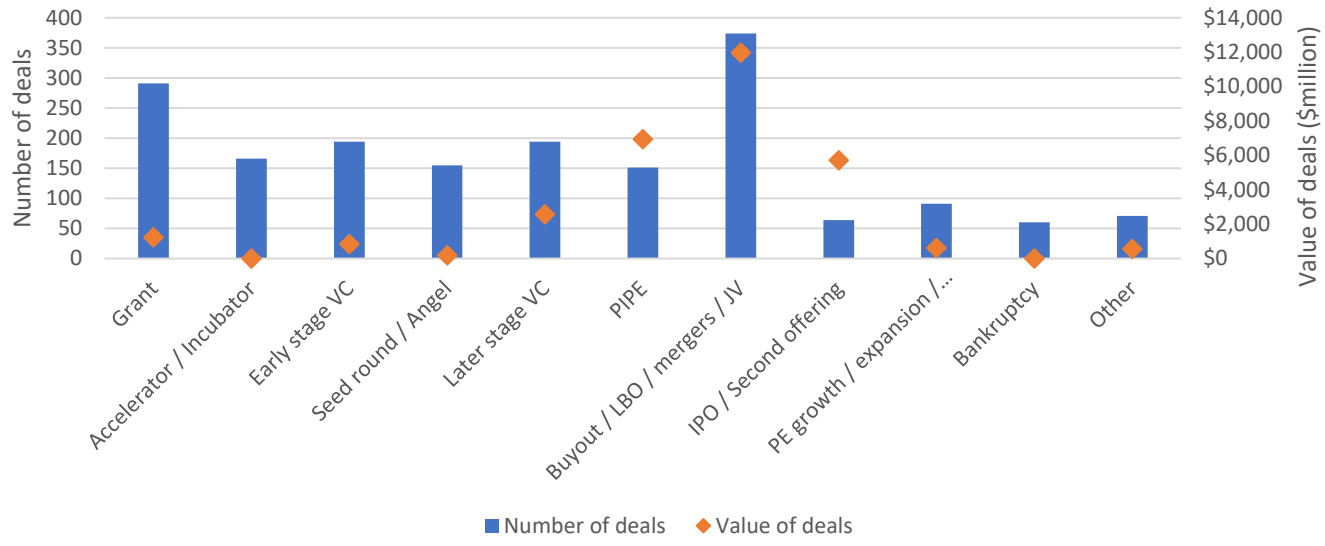
Figure 2 Proportion of the number of deals and value of deals by year



Source: Pitchbook, September 2021

The majority of completed deals were early stage investments as may be expected – 806 deals (45 percent of all deals) were for grants, accelerator / incubator, angel investment / seed stage or early stage venture capital (See Annex A for a Glossary of Investment Terms). However, as would also be expected, the majority of the monetary value of deals is in public investment and buyouts (77 percent of the total value of deals is IPOs, Joint Ventures, Mergers, Buyouts and Private Investment in Public Equity, PIPE).

Figure 3 Number and value of deals by deal type[3]



Source: Pitchbook, September 2021

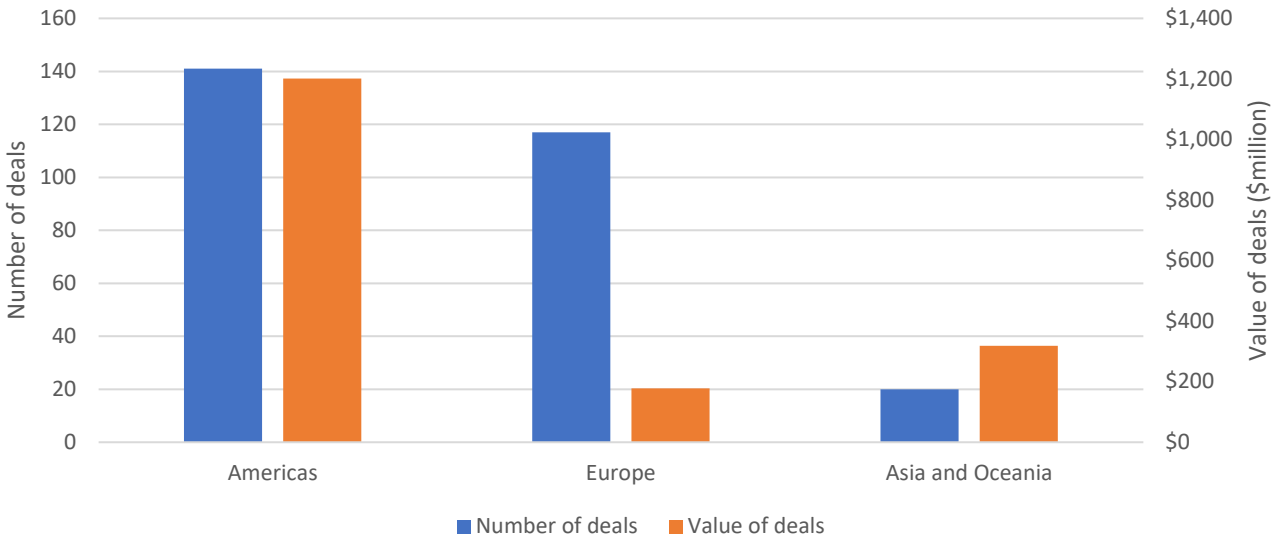
[3] Definitions of deal types included in appendix.

Hydrogen for Heat specific investments

A total of 281 deals were identified worldwide which related to the search terms specifically tailored to the Hy4Heat programme. These deals were estimated to be worth $1.7 billion (where valuation details were available).

Deals were concluded in only four global regions – the Americas, Europe, Asia and Oceania. The number and value of deals is presented in the figure below. This shows that the majority of deals and the value of deals is for companies based in the Americas (50 percent of deals, and 71 percent of deal value). 117 deals were completed in Europe, with a value of $178 million. This indicates that the average value of deals is higher in the Americas than in Europe.

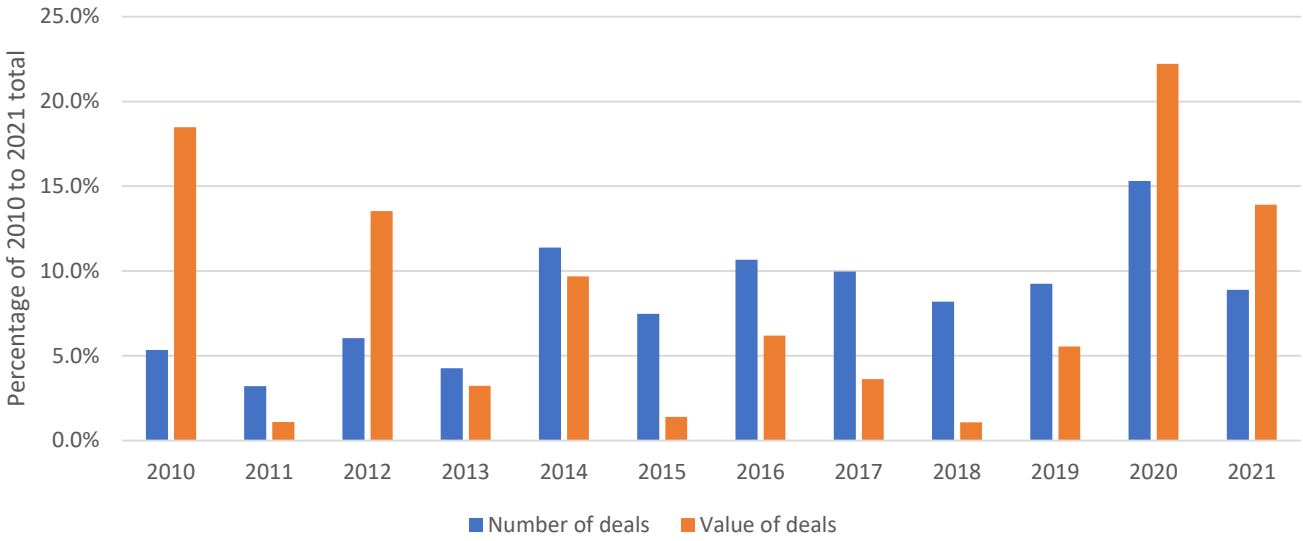
Figure 4 Number and value of deals by global region for Hydrogen for Heat specific deals



Source: Pitchbook, September 2021

When analysing the number of deals per year, there is a striking difference between the pattern of the number of deals and the value of deals between years. The number of deals per year remains relatively constant (between three and eleven percent of the total number of deals between 2010 and 2021), with no upward or downward trajectory (although a slightly higher proportion in more recent years). However, the majority of the total value of deals was achieved in 2010 and 2020 (19 percent in 2010 and 22 percent in 2020). So far, the deals completed in 2021 represent nine percent of the total for the entire period – indicating (alongside the 2020 value) that investments in the area may be increasing.

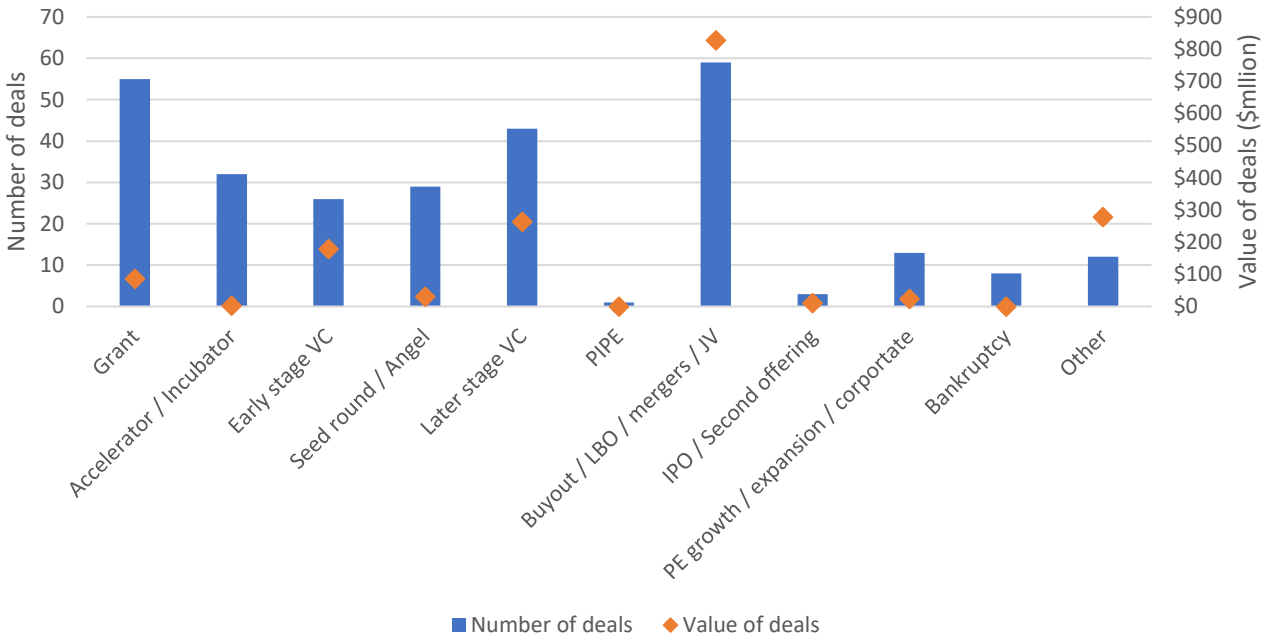
Figure 5 Number and value of deals by year for Hydrogen for Heat specific deals



Source: Pitchbook, September 2021

The type of deal was also explored. This showed that the majority of deals completed were for early stage investments (142 deals, 51 percent) - for grants, accelerator / incubation, angel investment / seed stage or early stage venture capital. However, as would also be expected, the category of financial deal with the largest monetary value is in buyouts and mergers and acquisitions (around 24 percent of the total value of deals is buyouts).

Figure 6 Number and value of deals by deal type for Hydrogen for Heat specific deals[4]



Source: Pitchbook, September 2021

[4] Definitions of deal types included in appendix.

European trends

Wider hydrogen investment

The analysis below focusses on deals within EU, EEA countries and the UK between 2010 and 2019. It excludes twenty deals which were categorised as outside Europe (all from Russia). Within the UK, EU and EEA, a total of 705 deals were completed with a total value of $7.1 billion. The highest number of deals were made in the UK (26 percent), followed by Germany (15 percent) and France (15 percent). European deals are highly concentrated within these three countries. Looking at the total size of deals, the UK still tops this list (29 percent), followed by Germany (27 percent) and Norway (18 percent). The size per deal is much higher in Germany and Norway ($47.3 million and $49.7 million) than in other European Countries.

Table 1 Deals by European Country

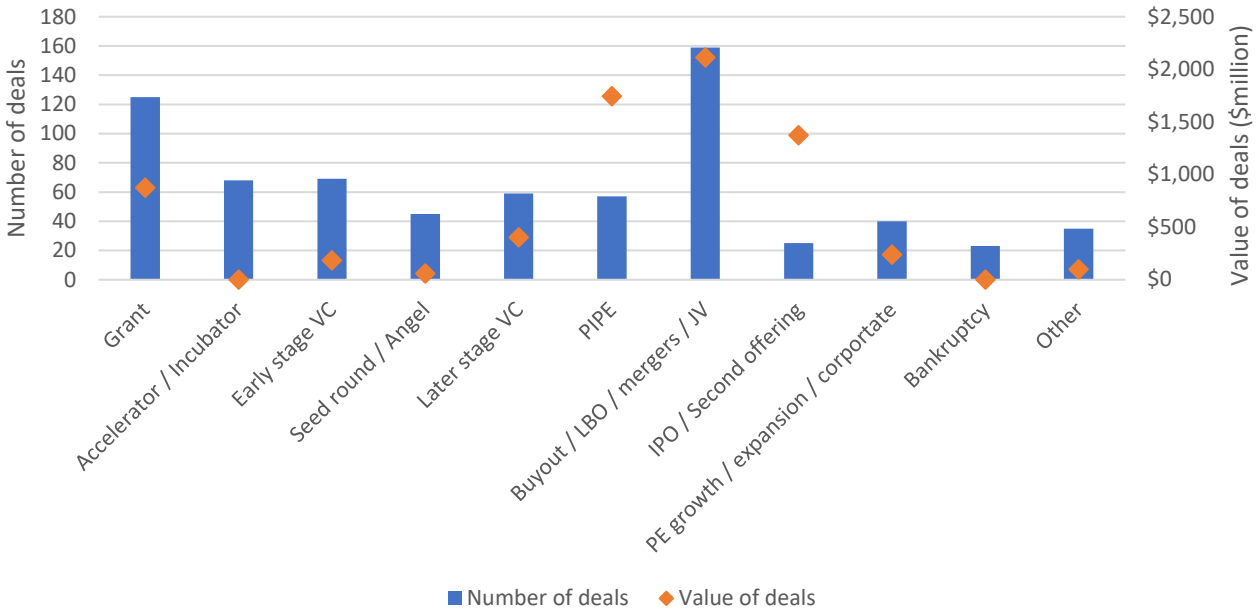
Country	Number of deals	Total deal size ($million)	Size per deal ($million)[5]
UK	185	2,081	14.8
Germany	108	1,894	47.3
France	104	750	11.4
Switzerland	48	66	2.0
Norway	46	1,291	49.7
Denmark	44	320	11.0
Netherlands	40	123	6.8
Spain	30	151	11.6
Sweden	27	31	1.7
Other EEA and EU countries	73	387	8.6

Source: Pitchbook, September 2021

As with the global pattern, the majority of completed deals were early stage investments, as may be expected – 307 deals (44 percent of all deals) were for grants, accelerator / incubation, angel investment / seed stage or early stage venture capital. The majority of the total value of deals (74 percent) is in public investment and buyouts.

[5] Only including deals which have a value assigned.

Figure 7 Number and value of European deals by deal type[6]



Source: Pitchbook, September 2021

Hydrogen for heat specific investments

There were 111 deals completed in Europe between 2010 and 2021, with a value of $177 million. The largest proportion of these deals were concluded in the UK and Germany (23 percent and 22 percent respectively). However, the value of deals completed in the UK were much lower value than those completed in Germany. The total value of the deals in the UK was forty million dollars (22 percent), whereas German deals represented $57 million (32 percent).

Table 2 Deals by European Country for Hydrogen for Heat specific deals

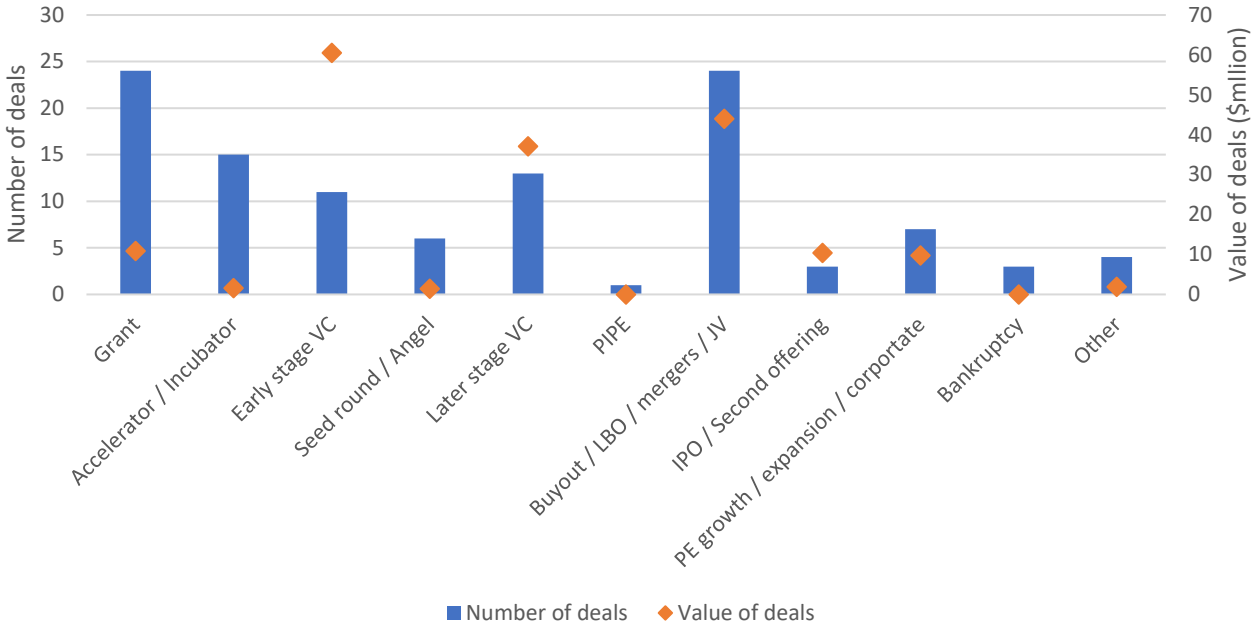
Country	Number of deals	Total deal size ($million)	Size per deal ($million)
United Kingdom	26	7.42	2.5
Germany	24	73.2	5.2
Denmark	15	44.1	1.0
Netherlands	11	0	0.8
Other countries	35	66.6	3.0

Source: Pitchbook, September 2021

[6] Definitions of deal types included in appendix.

The analysis of the types of deals in Europe presented differences to the global pattern. Within Europe, around half of deals were for early stage investments (grant, accelerator / incubation, angel investment / seed stage or early stage venture capital), but these represented 42 percent of the total value of deals.

Figure 8 Number and value of European deals by deal type for Hydrogen for Heat specific deals[7]



Source: Pitchbook, September 2021

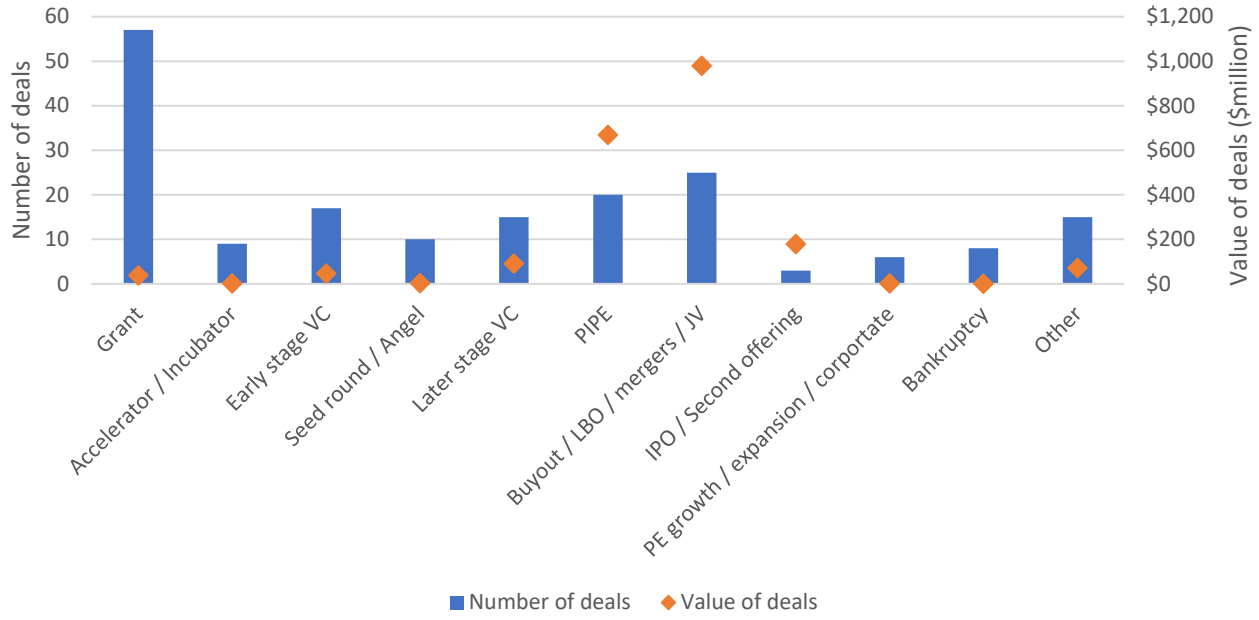
UK trends

Wider Hydrogen finance

There have been 185 deals in the UK since 2010, with a total stated value of $2.1 billion. The figure below shows that, much like the global trend, the largest number of deals is for early stage funding, with half of all deals being for grants, accelerator / incubation, seed / angel investment or early stage VC. The pattern for the value of deals also follows the global trend.

[7] Definitions of deal types included in appendix.

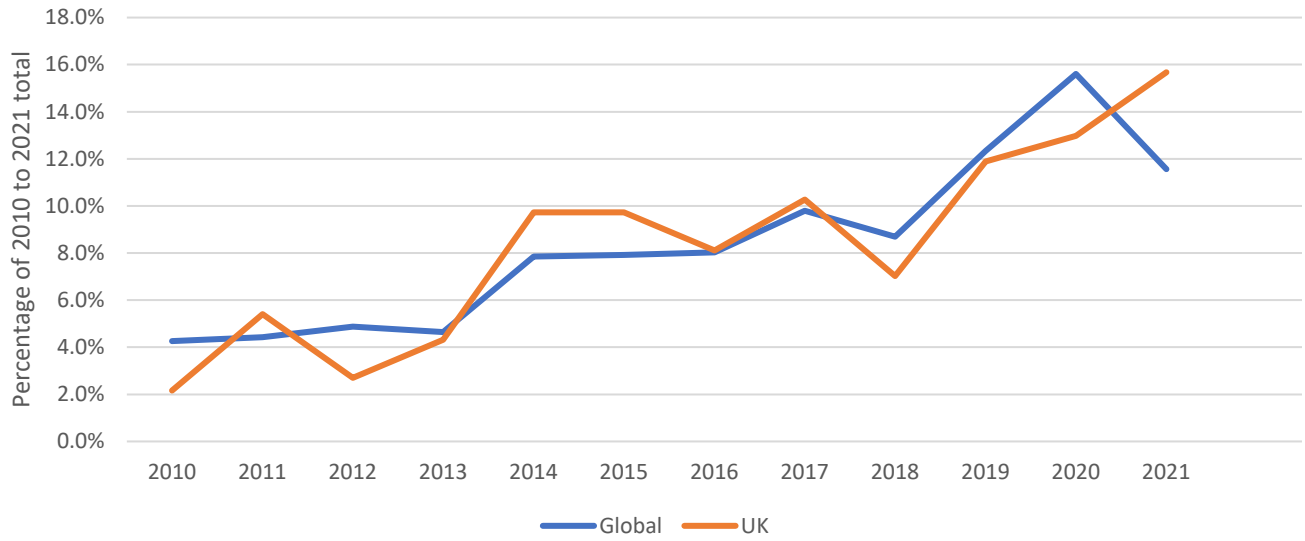
Figure 9 Number and value of deals in the UK by deal type[8]



Source: Pitchbook, September 2021

The figure below shows the percentage of total deals occurring in a given year globally and in the UK over the period 2010-2021. Globally, the highest number of deals occurred in 2020 (16 percent). Conversely only four percent of deals made between 2010-2021 occurred in 2010. In the UK the highest number of deals occurred in 2021 (so far), with 16 percent of all deals over the period.

Figure 10 Percentage of total deals occurring in a given year, global and UK, 2010-2020



Source: Pitchbook, September 2021

[8] Definitions of deal types included in appendix.

Investment in Hy4Heat specific technologies: UK trends

There were 26 deals completed in the UK between 2010 and 2021, with a total value of $40 million. These eleven deals included:

- Six grants (valued at $0.9 million)
- Five early stage VC deals / seed funding (valued at $32.7 million)
- Four later stage VC deals (valued at $3.2 million)
- Three Corporate (Other) deals (valued at $1.8 million)
- Three accelerator / incubator deals (valued at $1.4 million)
- Two bankruptcy deals (no value)
- Three buyout / merger deals (no values presented)

Businesses involved in the delivery of Hy4Heat

The profile of the businesses directly involved with the Hy4Heat programme have also been explored. There are 31 businesses involved in the delivery of the programme, and of these, Pitchbook held records for 20 companies. This shows the majority of companies involved in the programme have information available on Pitchbook. However, half of these firms (10 firms) have incomplete information in Pitchbook (no valuations, financial deals made). A further ten companies have information, due to ownership status (being privately owned) or insufficient activity.

A summary of the key financial activity of the participants shows that since the programme began:

- participating businesses had merged with or acquired three other businesses;
- two companies had been acquired / bought out;
- one company had secured Venture Capital funding; and
- one participating business had secured additional grant funding.

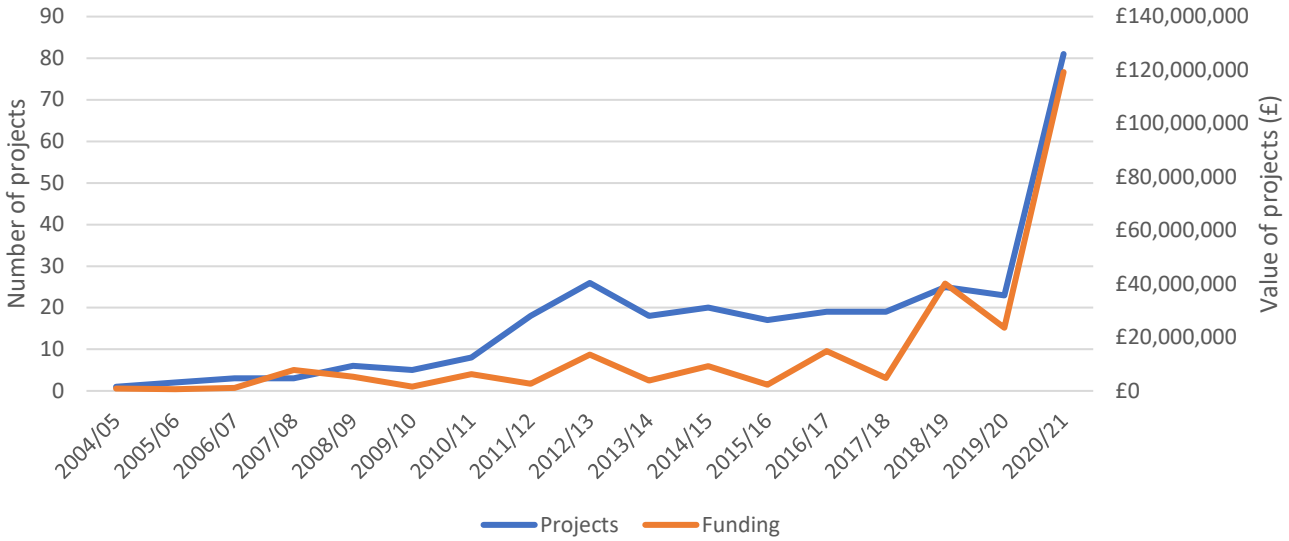
Public grant funding of hydrogen research

Innovate UK holds records of grants awarded by Innovate UK from 2004 onwards. They have awarded grants relating to research and development involving hydrogen (based on an assessment of the project title and description) in every financial year from 2004/05 onwards. A total of 298 projects have been funded (including hydrogen fuel cells and batteries), with a total grant funded value of £259 million (an average value of £869,600 per project). The value of projects ranges from £5,000 to £27 million.

The figure below shows the number of projects and value of grant funding awarded by Innovate UK to projects relating to hydrogen Research and Development. The number and value of projects generally increased over time, with the highest number of projects awarded (14) in 2020/21. The value of grant funding for hydrogen projects was also highest in 2020/21 with £119 million awarded, nearly half of the total awarded since 2004 (46 percent).

In total, 467 private companies have received funding from Innovate UK to undertake research relating to hydrogen.

Figure 11 Number and value of Innovate UK funded projects relating to hydrogen Research and Development



Source: Innovate UK database, September 2021

Patent Trends

Baseline analysis of global patents on hydrogen heating technologies 2010 to 2019

The findings in the section above are based on investment trends in firms developing hydrogen technologies. This does not capture all R&D relating to hydrogen for heat technology R&D as much of it can be self-financed through an organisation's own internal R&D budget. Analysis of patent data provides another indicator of trends in hydrogen technology development, which countries are most active in this space and the types of technologies being developed. Patent descriptions are not necessarily a reliable indicator of what types of technology will actually be commercialised, because some patents are more an expression of ideas and concepts which are being developed, but may not prove to be technically or commercially viable. Nevertheless, analysis of patent data forms a complementary strand to this baseline review as it can identify broader global trends in the international hydrogen R&D landscape, and cover examples of technologies in development in countries which a search of publications in English language may not uncover e.g. China. This is discussed in the section below.

Baseline Analysis

As part of the scoping stage of the evaluation, a baseline analysis of hydrogen appliance patents was carried out in summer 2019. This searched for global trends on patenting hydrogen heating technologies was carried out through analysis of the European Patent's Office PATSTAT Global Database. PATSTAT Global[9] contains bibliographical data relating to more than 100 million patent documents from leading industrialised and developing countries. This was based on a keyword search of the titles of patents filed globally, since 2010 to 2019. The search terms used were:

> Hydrogen odour; Hydrogen odor; Hydrogen purity; Industrial hydrogen heat; Hydrogen heat; Hydrogen boiler; H2 Heat; Hydrogen meter; Hydrogen gas boiler; Heat hydrogen; Hydrogen cooker; Hydrogen cooking; Hydrogen safety; Hydrogen sensors; Hydrogen heater; Hydrogen fire; Hydrogen network; Hydrogen hob; Hydrogen stove; Hydrogen oven; Hydrogen Gas fire; Hydrogen thermostat; Hydrogen burner; Hydrogen CHP

Each term was searched for individually in PASTAT. This search returned 496 unique filed patents. An Excel database was developed with details of each patent, including their unique ID identifier, country of origin, date, name of person or company which filed the patent and their abstracts. This section provides a summary of analysis of the return, including;

- Breakdowns by number of patents filed by country of origin
- Results of a narrower search tailored the types of appliances developed by Hy4Heat
- A table with illustrative examples of a selection of relevant patents, including a description of the technology based upon the patent abstracts.

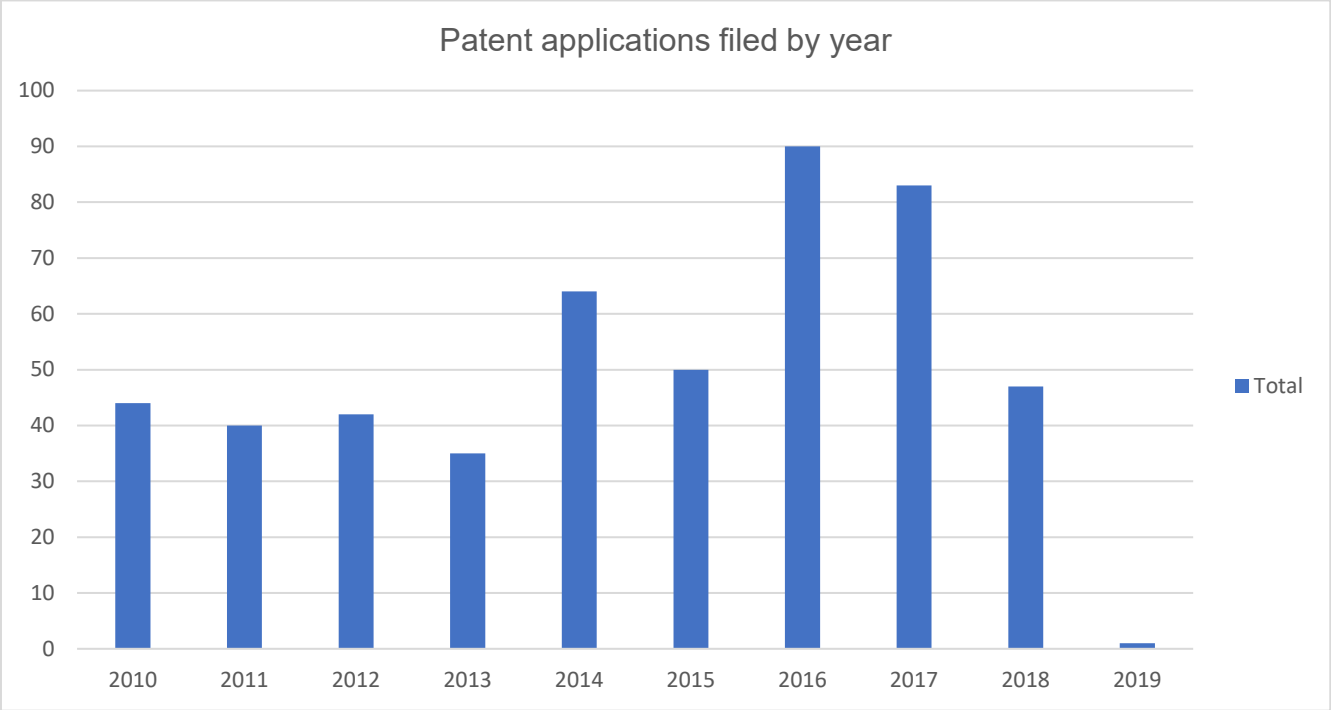
[9] https://www.epo.org/searching-for-patents/business/patstat.html

The table and the figure below provide a split by number of patents filed by country of origin and by filing year. However, in some cases, the country of origin was not stated. In which case, the table lists the legal authority where the patent is registered.

Table 3 Hydrogen heating patents by country and filing authority

Country	**Patents**
China	291
Korea	60
United States	39
Japan	38
Taiwan	7
Germany	5
Canada	3
Russian Federation	3
United Kingdom	2
Ukraine	1
Poland	1
Malaysia	1
World Intellectual Property Organization (WIPO)	33
European Patent Office	12
Total	**496**
Europe Total incl. EPO	**21**

Figure 12 patent applications filed by year up 2019



While this gives an indicative overview of the extent of hydrogen for heat technologies that are being developed in other countries, it cannot be considered exhaustive, since relevant technologies are not always clearly identifiable from patent application titles and abstracts, especially if these were filed in Chinese, Korean, or Japanese language. The timeline data is based on the dates in which patents were filed, rather than the date which the patent was approved and granted. In the UK a patent application is published within 18 months. It may take several years for a patent to be granted, so presenting the data based on publication date gives a timelier overview of recent activity.

To identify patents with potentially higher relevance to Hy4Heat the search was narrowed to the following keywords which more directly relate to the subject areas of Hy4Heat Work Packages. This search was extended to cover not only the patent titles but also a key word search of terms in their abstracts. Keywords used were:

> Hydrogen heat; Hydrogen odour; Hydrogen odor; Hydrogen boiler; Hydrogen gas boiler; Hydrogen cook; Hydrogen hob; Hydrogen stove; Hydrogen oven;

This search produced 183 returns. The majority relate to the broader term ‘hydrogen heat’; of which most describe using hydrogen for industrial appliances such as vacuum furnaces. Vacuum furnaces are used in various industry sectors such as electronics, medical, crystal growth, energy and artificial gems. The table below provides a breakdown of results by the main type of technology or appliance in focus.

Keyword	**Number of Results**
%hydrogen heat%	161
%hydrogen boiler%	7
%hydrogen gas boiler%	1

%hydrogen cook%	2
%hydrogen oven%	1
%hydrogen stove%	9
%hydrogen hob%	0
%hydrogen odour%	0
%hydrogen odor%	2
Total	**183**

There is a large concentration of patents in the area of hydrogen production & usage in industrial settings. Most originate from China, followed by Korea, the US, and Japan. There are some limited relevant patents on hydrogen boilers & hydrogen cooking, which appear to be applicable in domestic settings, again most commonly from China and Japan.

From this list, a further screening was carried by reading all of the patent abstracts and manually extracting a selection of six illustrative examples which appear most relevant to topics covered in Hy4Heat. A draft list was selected by the project team at Technopolis and then sent to hydrogen subject matter experts at Hinicio to comment on; a) their relevance to appliances developed under Hy4Heat and b) whether the technology appears likely to be technically feasible/practical to develop, or more just ‘an idea’. This stage of the review was based on subjective judgement (by an expert on hydrogen) through reading the description of the technology in the patent abstract.

This selection of six illustrative patents is listed in the table below. Including; their title, country of origin, date, name of individual/firm who filed the patent and the patent abstract. These six patents suggest that different types of hydrogen boiler and cooker appliances (mostly for use in commercial or industrial settings) are being developed in China and Japan.

The projects listed below give a summary of technologies that have been patented in relation to hydrogen appliances that were considered most relevant to Hy4Heat. As discussed in the introduction to this section, patents are not necessarily a reliable indicator that these technologies will actually be commercialised, because some patents are more an expression of concepts, but have not yet been proven to be technically or commercially viable. Nevertheless, analysis of patent data forms a complementary strand to this baseline review as it can identify broader global trends in the international hydrogen R&D landscape.

Table 4 Examples of international hydrogen heating technology patents

Application title	Inventor	Applicant/ Company	Abstract	Country/ Year
L-shaped water-tube hydrogen boiler structure	LIPING GU; YUFENG PAN; JIANTAO SUN; ZHONGQUAN TIAN	JIANGSU TAIHU BOILER CO LTD	The invention provides an L-shaped water-tube hydrogen boiler structure. By the L-shaped water-tube hydrogen boiler structure, hydrogen can be smoothly combusted in the boiler without any explosion risk, and can be used as a clean energy source to achieve energy saving and environmental protection effects in the field of boilers. The L-shaped water-tube hydrogen boiler structure comprises a steam drum, a high temperature superheater, a low temperature superheater, a convection section, an economizer, a hearth and a chimney, and is characterized in that the whole boiler has an L-shaped structure; the hearth is positioned in a lower transverse cavity of the L-shaped structure; a combustor is connected to an inlet of the hearth; the high temperature superheater, the low temperature superheater, the convection section, the economizer and the chimney are sequentially arranged in a vertical cavity body above the hearth from bottom to top; the steam drum is arranged above the vertical cavity body; an explosion door is reserved at a flue position connected with the high temperature superheater above the hearth; and inspection doors are uniformly distributed on the vertical cavity body.	China 2012
Energy-saving hydrogen burning boiler	CAI RONGCHENG	JIANGSU LEE & MAN CHEMICAL LTD	The utility model discloses an energy-saving hydrogen burning boiler, which comprises a hydrogen boiler, a chimney and an economizer, and is characterized in that a heat pipe type heat exchanger is arranged between the economizer and the chimney. Compared with the prior art, the energy-saving hydrogen burning furnace has the advantages that the heat pipe type heat exchanger is arranged at an inlet of the chimney, steam is produced by utilizing heat of discharged smoke to be supplied to	China 2012

			other devices, and the purposes of energy saving and improvement on heat efficiency of the boiler are achieved.	
HYDROGEN COOKER	ISHIKAWA YASUO	Filed under inventor name	PROBLEM TO BE SOLVED: To provide a safe hydrogen cooker stably ejecting flames without causing backfire. SOLUTION: Hydrogen is supplied to a gas burner 8 from a hydrogen cylinder 1 in which hydrogen is pressurized and stored, through a backfire-preventing water tank 3 and a flame-coloring-agent tank 4 for coloring flames. The nozzle diameter of the gas burner 8 is formed in 0.6-1.6 mm, and a metal mesh 11 is arranged so that the flames can be seen on the gas burner 8, thus preventing a cook from getting burnt while preventing the occurrence of backfire.	Japan 2010
HYDROGEN COOKING METHOD, HYDROGEN COOKING SYSTEM, MANUFACTURING METHOD OF HYDROGEN WATER, MANUFACTURING DEVICE OF HYDROGEN WATER, AND HYDROGEN COOKING DEVICE	ISHIKAWA YASUO; HIRATA ATSUSHI + Applicant(s):	TI KK	PROBLEM TO BE SOLVED: To provide a hydrogen cooking system with hydrogen gas burning, which is safe and prevents backfire. SOLUTION: Hydrogen gas is fed from a hydrogen gas cylinder 64 to a micronano bubble generation member 69 disposed at the bottom of a tank 68 for drinking water of a manufacturing device 61 of hydrogen water, through a first line l. The hydrogen gas passed through the drinking water is fed into a combustion cylinder 75 of a hydrogen cooking device 62 through a second line l. Hydrogen cooking with backfire effectively prevented can be thus achieved, while a hydrogen water beverage is manufactured in parallel.	Japan 2013
Environmental-friendly and energy-saving oxy-hydrogen oven	XIONG KAIFU	KUNSHAN FULING ENERGY UTILIZATION CO LTD	The invention provides an oven, and particularly relates to an environmental-friendly and energy-saving oxy-hydrogen oven. The oven comprises an oven body, wherein a water electrolysis device is arranged in the oven body; the water electrolysis device is connected with the oven mouth of the oven body through a gas pipeline. Compared with the prior art, the oxy-hydrogen oven	China 2014

			provided by the invention has the characteristics that the oven is reasonable in design and simple in structure, and is safe and efficient, energy-saving and environmental-friendly.	
Water energy oxyhydrogen stove	ZHOU DEHONG	DALIAN ANKE RUISI ENERGY TECHNOLOGY CO LTD	The utility model discloses a water energy oxyhydrogen stove and belongs to the field of energy saving and environmentally friendly technologies. The water energy oxyhydrogen stove comprises a pressure control instrument; the pressure control instrument is connected with a electrolyzer; the electrolyzer is connected with an electronically controlled unit; the electrolyzer is communicated with a gas cooling bottle; the electrolyzer is communicated with a water replenishing pump; a water tank is communicated with a pipeline I; the pipeline I is provided with a magnetic valve; the pipeline I is communicated with the water replenishing pump and the gas cooling bottle through a tee joint; the magnetic valve is connected with the electronically controlled unit; the water replenishing pump is connected with the electronically controlled unit; a pipeline II is communicated with a pressure reducing valve I; the pressure reducing valve I is communicated with a flow meter I; the flow meter I is communicated with a proportional valve II; the proportional valve II is communicated with one gas inlet pipe of a one-way mixer; the proportional valve II is connected with the electronically controlled unit; the gas cooling bottle is communicated with a pressure reducing valve II; the pressure reducing valve II is communicated with a flow meter II; the flow meter II is communicated with a proportional valve I; the proportional valve I is communicated with the other gas inlet pipe of the one-way mixer; the flow meter II is connected with the electronically controlled unit; the proportional valve I is connected with the electronically controlled unit.	China 2014

Update on of global patents on hydrogen heating technologies for 2019 to 2021

To update the baseline a search for global trends on patenting hydrogen heating technologies was carried out through analysis of the European Patent's Office PATSTAT Global Database PATSTAT Global. The update was based on a keyword search of the titles of patents filed globally, since between 2019 (which was only covered by 1 single patent in the previous analysis) and Spring 2021.

The search terms used were the same as previously used. This search returned 102 unique filed patents. An Excel database is provided separately with details of each patent, including their unique ID identifier, country of origin, date, name of person or company which filed the patent and their abstracts. This section provides a summary of analysis of the return, including;

- Breakdowns by number of patents filed by country of origin
- Results of a narrower search tailored the types of appliances developed by Hy4Heat
- A table with illustrative examples of a selection of relevant patents, including a description of the technology based upon the patent abstracts.

The table and the figure below provide a split by number of patents filed by country of origin and by filing year compared to the baseline. However, in some cases, the country of origin was not stated. In which case, the table lists the legal authority where the patent is registered.

Table 5 Hydrogen heating patents by country and filing authority (sorted by 2019-2021)

Country	**Patents 2010-2019**	**Patents 2019-2021**
China	291	76
United States	39	9
Korea	60	7
World Intellectual Property Organization (WIPO)	33	6
European Patent Office	12	2
Russian Federation	3	1
Czech Republic	0	1
Japan	38	0
Taiwan	7	0
Germany	5	0
Canada	3	0
United Kingdom	2	0
Ukraine	1	0
Poland	1	0
Malaysia	1	0
Total	**496**	**102**

Figure 13 patent applications filed by year up to 2021

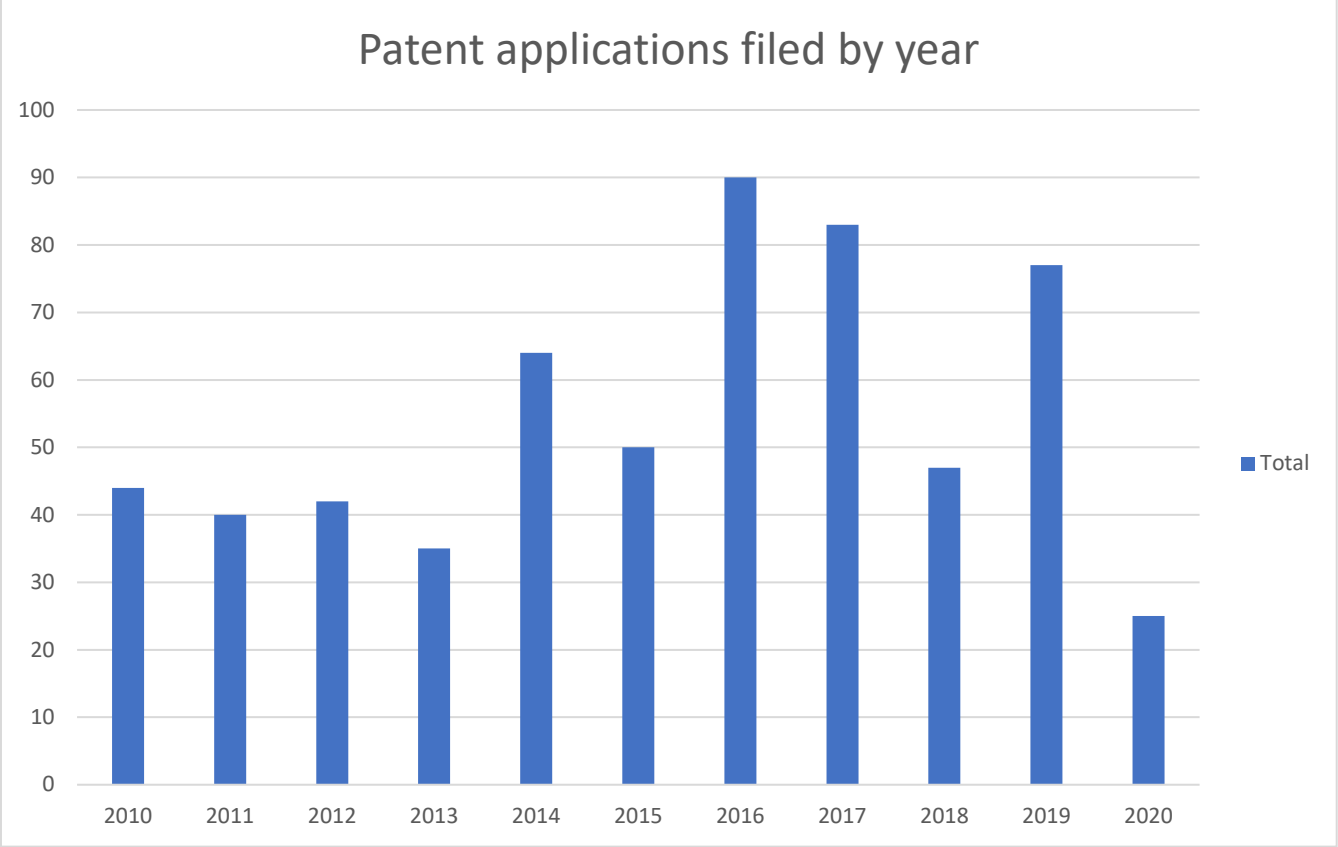


Figure 13 shows that the number of patents filed in 2019 remains higher than in the early 2010s, following the trend from 2014 of a growing trend in patents for specialised hydrogen infrastructure linked devices. The patents for 2020 are likely still not all filed, and the figure is therefore lower than the previous years.

The patents were checked against the names of the companies participating in Hy4Heat and no direct link could be identified. However, patents are often filed by persons instead of companies so it might be still possible that some were filed by companies participating in Hy4Heat. In addition, further search was conducted for the term hydrogen and the firms involved in Hy4Heat i.e.:

- Baxi
- Worcester Bosch
- Valor
- Enertek International
- Pietro Fiorentini
- Clean Burner Systems
- Legend Fires
- Worgas Burners Limited
- Birmingham Burner (Walsall) Limited.

- Teddington
- Continental
- Solid Power
- Powrmatic
- Falcon (a member of the AFE Group)
- Riello

However, no Hy4Heat related patents could be identified. To ensure that no patents were missed a broad search which checked for all patents (disregarding the company name) with '%hydrogen%' in their title which were filed in the UK between 2019 and 2021 was conducted. A total of 122 patents were filed in the UK in this time period with hydrogen in their title but none of them had a direct relation to Hy4Heat. This is likely due to the long timeframes until patent applications are processed, for example the UK IPO states that *"The IPO will publish your patent application shortly after 18 months from your filing date (or priority date if there is one), as long as you have met the formal requirements, filed Form 9A together with the appropriate fees and not asked us to withdraw your application."*

To further analyse the recent market development the 102 patents identified through the patent title search were manually checked for their relevance to Hy4Heat. Most of the heat related patents, however, relate to hydrogen power generation rather than boilers. Some others might have some ancillary benefits such as hydrogen sensors and meters. Nevertheless, beside the three following Chinese patents there were no patents with a clear direct relevance to Hy4Heat.

Table 6 Examples of international hydrogen heating technology patents 2019 - 2021

Application title	Abstract	Country
Fuel gas, tail gas and steam modifier hydrogen boiler	The invention discloses a fuel gas, tail gas and steam modifier hydrogen boiler. The hydrogen boiler is arranged on the bottom of a combustion chamber, the middle of the upper surface of fuel combustion stack is provided with a one-connected double-ring modifier used for decomposing and modifying the tail gas and the steam to generate hydrogen, the lower surface and the upper surface of the modifier are provided with net column-shaped hollow particle infrared combustion cavities with infrared radiation functions, the tail gas and the steam generated by starting boiler is introduced into the modifier, high-temperature thermal chemical reaction is carried out to generate hydrogen, the two combustion cavities are directly introduced, overlapped combustion is carried out to form a chain reaction for cyclic work of a ring, and the burning is more and more vigorous. According to the technical scheme, the hydrogen boiler can be designed as a steam boiler, the steam boiler is driven to be started by the primary energy to generate hydrogen to be directly supplied to the self-service, and the consumption of primary energy is reduced. The hydrogen boiler can also be driven by the primary energy source to be started, and then the hydrogen boiler is a	China

	hydrogen production tool used for hydrogen production transfer and use.	
Water decomposition hydrogen boiler	The invention discloses a water decomposition hydrogen boiler. By adopting the thermal decomposition of water, a hydrogen production function and a heating function are integrated. An annular-cylindershaped two-grade steam drainer, which is connected to boiler steam, is arranged in the upper part of the hearth of the boiler. A high temperature combustion-supporting material reaction combustion stack is arranged in the lower part of the hearth. A coil-shaped steam thermal decomposition hydrogen generator is arranged in the combustion stack. One end of the hydrogen generator is connected to the steam drainer so as to introduce steam into the hydrogen generator, and the other end is used to provide heating steam and discharge hydrogen.	China
Gas content detection device in novel hydrogen heater	The utility model discloses a gas content detection device in a novel hydrogen heater. Device comprising a device body, a supporting device is arranged at the lower end of the device body; a protective cover is arranged on one side of the device body; a mounting box is mounted at the upper end of the device body; a driving device is arranged on one side of the mounting box; a cavity is formed in the mounting box; an air outlet is formed in the upper end of the device body; the air outlet penetrates through the side wall of the lower end of the cavity and extends into the cavity, one end of their outlet is connected with a connecting pipe through a flange plate flange, one end of the connecting pipe penetrates through the top of the cavity, the flange plate is rotationally sleeved with a first gear, and three second gears are meshed with the periphery of the first gear at equal intervals. According to the device, the gas detector is adjusted, the length is convenient to adjust, the gas detector can rotate, the leakage position of the gas outlet can be comprehensively detected, the concentration can be detected, harm is avoided, operation is easy, the structure is simple, and the device is protected.	China

Appendix 1: Definition of Investment terms

The table below presents definitions of the investment terms used in this Annex.

Category	Term	Definition
Grant	Grant	Funding awarded to a recipient or organisation, from a Government or public body, for a specific activity.
Accelerators / incubators	Accelerators / incubators	Accelerators / incubators are defined as where a company joins a temporary program that provides funding, office space, technological development and/or mentorship. This is often in exchange for equity in the company.
Early stage VC	Early Stage VC	Early stage venture capital is an investment from a venture capitalist group during the early stages of the company's development, often in return for a percentage of ownership of the business. This is usually Series A to Series B financing.
Seed round / angel	Angel investment	Angel investment is when investment is made by an individual in a company from their personal funds and not using funds raised from other people.
	Seed investment	Seed investment is defined as any investor type provides the initial financing for a new enterprise that is in the earliest stages of developing.
Later stage VC	Later stage VC	A later stage round of financing by a venture capital firm into a company. Later stage is usually Series B to Series Z+ rounds.
PIPE	Private Investment in Public Equity (PIPE)	When a private investor (such as a private equity firm) makes a non-control equity investment in a publicly-traded enterprise through the acquisition of securities issued directly by the company
Buyout / LBO / mergers / JV	Merger/Acquisition	When an operating company acquires a control position in another company or will retain control of the combined business post-transaction. This may be achieved through cash or stock.
	Buyout / leveraged buyout (LBO)	The purchase of at least a controlling percentage of a company's capital stock
	Joint Venture	A group of business collaborate on a business project and share of the income.
IPO / second offering	Initial Public Offering (IPO)	Initial Public Offering (IPO) is defined as investments open for the general public or retail investors after the

		company has complied with the registration requirements of new securities.
	Second Offering	The issuance of new stock for public sale from a company that has already made its IPO.
PE growth / expansion / corporate	Corporate	When an operating company acquires a non-control stake in another company.
	PE Growth / Expansion	When a private equity firm makes a non-control, equity investment in a company. Cash is received by the company and not the selling shareholders
Bankruptcy	Bankruptcy	A bankruptcy proceeding in which a company stops all operations and goes completely out of business. Includes companies going out of business, where an administrator is appointed to reorganise the business, and where a trustee is appointed to liquidate (sell) the company's assets and the money is used to pay off debt.
Other	Capitalization	The founders, owners or upper management of a company using their own money to provide funding.
	Debt	This category includes many types of private debt, but most commonly involves non-bank institutions making loans to companies or buying loans on the secondary market.
	Convertible debt	Debt that can be converted to equity when certain conditions are met, like a specific valuation or date.
	Equity / product crowdfunding	The process of raising small amounts of capital from many people to fund a venture.
	Share repurchase	A company buying back its own shares from the marketplace.

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