

ENERGY

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H₂
HYDROGEN

Q2 2019 | Pulse
Hydrogen Infrastructure and Storage

FutureBridge

WHAT'S INSIDE!

What supportive policy frameworks countries are developing?

What are the innovations in the hydrogen storage space?

What are the barriers to faster adoption of hydrogen vehicles?

01

Pulse Themes

- Hydrogen Infrastructure: Roadmaps
- Vulnerability of Hydrogen Infrastructure to Disasters
- Enhanced Hydrogen Storage



02

Quarterly Review of Research / Regulatory Policy Updates

- Academic Review
- Policy Updates



03

Key Player Activities

- Established Players
- Startups



01

Emerging trends

Roadmaps steering the direction of future hydrogen development



The H2 Corridor plan is a major plan released by the Chinese government focusing on Yangtze River Delta region.

South Korea aims at reaching 1200 hydrogen fueling stations by 2040.

Hydrogen Infrastructure: Roadmaps



China's H2 Corridor

28th May 2019

China released its first cross-provincial hydrogen development plan, named "**The Hydrogen Corridor Construction and Development Plan in the Yangtze River Delta Region**" or "**H2 Corridor**" which aims at development of hydrogen fueling station and expansion of fuel-cell vehicles.

The plan aims to **set up four hydrogen highways** along: **Shenyang-Haikou, Shanghai-Chengdu, Shanghai-Chongqing and Shanghai-Kunming highways.**

Three stages of development have been outlined by the plan: short (2019-21), medium (2022-25) and long term (2026-30).



South Korea's hydrogen plans

10th May 2019

South Korean ministry aims to increase the number of hydrogen fuel-cell electric passenger cars to nearly **6,400** this year.

The target underlines Seoul's efforts to promote the use of hydrogen vehicles and is a major leap from **890 units** last year.

South Korea also aims at:

- Increasing the number of charging stations for hydrogen cars to **86 by end of 2019** and **310 by the 2022**
- **2000 hydrogen buses across the country by 2022**

DEVELOPMENTS

Emerging Trends



The roadmaps indicates interest of the countries in the Asia Pacific region for adoption of hydrogen fuelled vehicles and integrating them into the mainstream. High levels of air pollution is causing these countries to look out for cleaner alternatives.

China has announced its plans to cut by half the subsidies provided for pure battery electric cars (driving range of 400 kms and above) and move to other clean mobility alternatives such as hydrogen.

Source: FuelCellsWorks (>>), IHS Markit (>>)

Safety concerns plaguing hydrogen growth



Explosions have resulted in heightened concerns over the safety of using hydrogen to power vehicles.

This has become a significant barrier in a nascent industry which is making slow inroads into the transport sector.

Vulnerability of Hydrogen Infrastructure to Disasters

nel • Explosion at refueling station in Norway

15th June 2019

Explosion occurs at a hydrogen refueling station located in Baerum, a Norway subway, operated by Uno-X Hydrogen.

Uno-X Hydrogen is a joint venture formed by **Uno-X, Nel Hydrogen and Praxair**.

The explosion has caused Nel to shutdown operating stations, located across multiple countries, including Denmark and Norway.

Toyota and Hyundai have also halted their operations following this incident.



Explosion at hydrogen plant in California

2nd June 2019

An explosion and fire incident occurred at a hydrogen plant in **Santa Clara in California**. The chemical plant is owned by Air Products and Chemical, Inc.

This occurred due to a leakage during fueling of a hydrogen tank.

No injuries were sustained by personnel at the site.

Explosion has impacted fuel cell vehicle owners in **Northern California**, as Air Products was a major supplier for most parts. Operators such as **True Zero** have been hit by fuel shortage due to the incident.

DEVELOPMENTS

Emerging Trends



Impact on global hydrogen refueling infrastructure

The explosions in Norway and California has caused instantaneous impacts on the global hydrogen markets as industry exhibits extreme caution following such events. It has resulted in hydrogen shortage and adversity for hydrogen vehicle patrons:

- Following the explosion Air Products, as a precaution pulled all hydrogen supply vehicles off the roads to perform an inspection to verify the safety of these vehicles
- Nel shutdown its 10 operating stations, located across multiple countries, including Denmark and Norway
- Toyota and Hyundai halted their operations in Norway following this incident

Source: Gasworld (>>), SFC Chronicle (>>)

Significant interest observed in hydrogen storage R&D



Increased hydrogen storage is key to further adoption of hydrogen as a viable mainstream alternative

Enhanced Hydrogen Storage



Increased hydrogen storage in metal organic frameworks

5th April 2019

Researchers at the University of Michigan have discovered ways of increasing amount of energy-dense hydrogen which can be stored in metal organic frameworks.

Information was collected on all available MOFs, including those that were previously designed and those that remain hypothetical. High-throughput computer simulations was used to hunt through database of almost **500,000 MOFs** to find the materials with the most promising capacities.

SNU-70, UMCM-9 and PCN-610/NU-100 were identified as materials with potential to surpass earlier records.



Molecular sieves increase hydrogen storage

20th May 2019

Researchers at the Lancaster University have developed a new material, made from manganese hydride which could be used to make molecular sieves within fuel tank.

The material named **Kubas Manganese Hydride-1** operates on the principle of Kubas binding, where hydrogen is stored by distancing the hydrogen atoms within a hydrogen molecule.

The molecular sieves would enable storage of hydrogen and also work alongside fuel cells in a hydrogen powered system. The material could enable volumetric storage of 4 times as much hydrogen as existing hydrogen fuel technologies.

DEVELOPMENTS

Emerging Trends



Significant advances are being made in hydrogen storage, enabling higher energy density:

Metal Organic Frameworks: The University of Michigan research would enable packing more energy into smaller and lighter packages in the future. Increasing the quantity of hydrogen which can be stored in a MOF adsorbent results in reduced pressure requirements.

Molecular sieves within fuel tanks: The Lancaster University research would enable flexibility in vehicle design and reduced size of tanks. The sieves are expected to enable storage systems which are 5 times cheaper than 700 bar tanks. This is expected to improve the adoption of hydrogen as an energy vector.

Source: Phys.org (>>), TheEngineer (>>)

Significant interest is observed amongst major market players in entering and expansion of hydrogen refueling infrastructure in the US



In the past 3 months a lot of activity has been observed in the US with respect to expansion and allied activities of hydrogen refueling stations

Hydrogen Refueling Stations: Operations and Expansions



Energy storage and clean fuel company ITM Power has extended its hydrogen refueling agreement with Shell.

The agreement runs until 2024 and covers refueling of all types of hydrogen vehicles from cars to commercial vehicles (inclusive of buses, trains and ships)

ITM Power operates 2 hydrogen stations at Shell Cobham and Shell Beaconsfield. Shell Gatwik and Shell Derby are expected to be operational in later part of 2019. ITM Power and Shell are part of the **Clean Refinery Hydrogen for Europe (REFHYNE)** consortium.

ITM Power is very active in the hydrogen production and storage space. It is involved in the construction of a **10 MW hydrogen electrolysis** plant at the Shell Rheinland refinery in Wesseling, Germany.



Retail hydrogen station operator FirstElement Fuel received a funding of \$24m from Air Liquide and a US-based subsidiary of Mitsui Group, Hy Solution, Inc.

The funding will help the operator to expand from its current capacity of 7000 fuel cell electric vehicles to more than 28,000

California is aiming at deploying 40,000 fuel cell electric vehicles by 2022. This funding is expected to be instrumental in meeting a significant part of the fueling requirements.

FirstElement Fuel entered into a long-term supply agreement for liquid hydrogen with Air Liquide. **Air Liquide has committed \$150m** as investment to build a hydrogen production facility back in 2018.

FirstElement Fuel currently operates **19 True Zero** retail hydrogen stations with 12 more under development.

Iwatani

Iwatani Corporation of America acquired four hydrogen refueling stations in California from Messer (formerly Linde, LLC)

The four retail stations are capable of supplying up to 350kg of hydrogen/day.

The acquisition marks the entry of Iwatani into the US hydrogen refueling market and increases the company's total global hydrogen refueling station network to **30**.

Iwatani's presence was earlier limited to Japan, with a base of **26 hydrogen refueling stations**.

Source: Gasworld ([>>](#), [>>](#)), PR Newswire ([>>](#))

02

Quarterly Research Review

Low Pressure Technology Enables Improvement in Storage Stability

Hydrogen storage in clathrate hydrates (Jun 2019)

Clathrate hydrates are nanoporous inclusion compounds composed of a 3D network of polyhedral cages. The cages are made of hydrogen-bonded host water molecules and captured guest gas or liquid molecules.

- Study has identified new method for stable storage of hydrogen
- Natural gas (methane and ethane) which have lower equilibrium conditions compared to hydrogen as thermodynamic stabilizers was used
- Leads to significantly reduced synthesis pressure
- Depending on the ratio of ethane and methane in the natural gas, tuned structure I or II hydrate is formed
- Hydrates were created using both gas-phase exchange and direct evolution from ice

Clathrate hydrates formation

Institutions	The Gwangju Institute of Science and Technology, KAIST
Principle	Natural gas modulator based synthesis
Details	Formation of hydrogen clusters (up to 3 molecules) in the confined nanoporous cages of clathrate hydrates
Synthesis pressure (MPa)	3 (P-H ₂)

Note: Tuning occurs only when hydrogen is involved in hydrate formation from the beginning for both hydrate structures

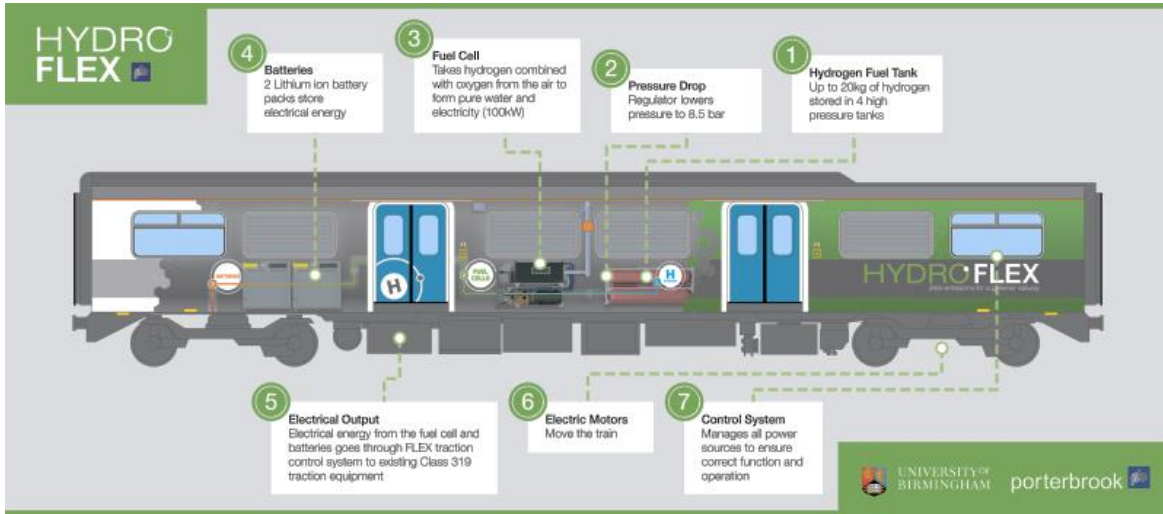
FutureBridge insight

- The environmental friendly method which makes use of water and natural gas, and operates at low pressures enables stable storage of hydrogen-natural gas compound in hydrates
- The cost of hydrogen transport can be reduced greatly if hydrogen derivatives are transported through the natural gas grid and stored at hydrogen charging stations as hydrogen + natural gas hydrates
- Clathrate hydrates do not generate chemical waste during synthesis nor decomposition and also reduces operational cost
- The results not only enables the identification of an energy-efficient gas storage material, but also point at a possible alternative energy source by the utilization of hydrogen natural gas blends

“HNGB will utilize the existing natural gas infrastructure for transportation, so it is very likely that we can commercialize this hydrate system. We are investigating the kinetic performance through a follow-up strategy to increase the volume of gas storage.” - Jae Woo Lee, Professor, KAIST

Source: ScienceDirect (>>)

Hydrogen in the Railway Network



Mainline testing of hydrogen train (Jun 2019)

- UK's first hydrogen train - HydroFLEX will be tested on the mainline railway, by rolling stock company Porterbrook and University of Birmingham
- Pilot involves the fitment of a hydrogen powerpack to an existing Class 319 train
- Enables trains to run on conventional electrified routes as well as independently

Project partners

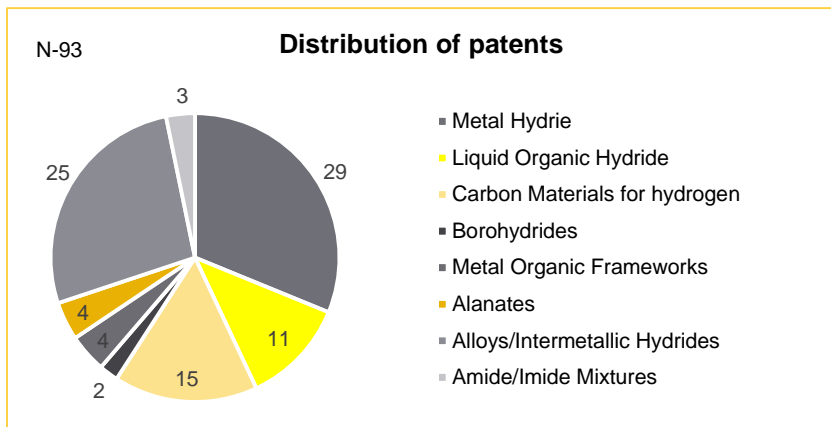


FutureBridge insight

- The pilot is expected to pave the way for mainstream adoption of hydrogen a major category in the transportation sector
- The provision to operate the train independently as well as on conventional electricity would enable a flexible train, which could operate in different parts of Britain's rail network
- The development of a zero-emission propulsion system is expected to be a critical element in enabling the decarbonization of the railway system

Source: Green Car Congress (>>>)

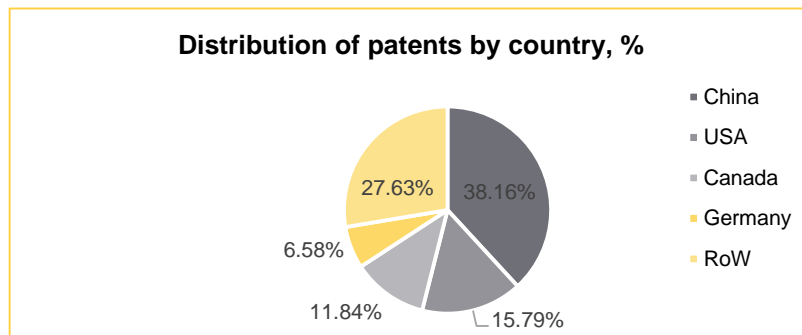
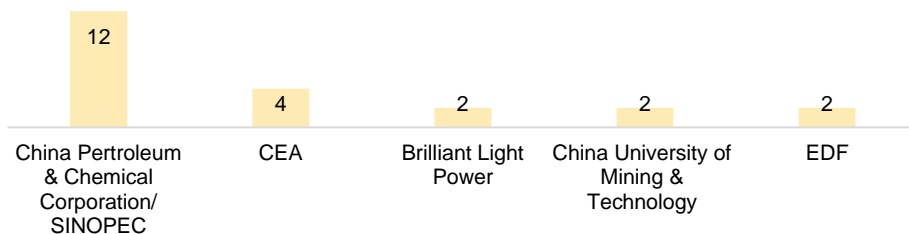
Patenting Activity – Hydrogen Storage Technologies, April – June 2019



Patenting activity – Hydrogen storage technologies (Q2 2019)

Number of patents published	93
Dominant technology segment	Metal hydride
Top patent assignees	<ul style="list-style-type: none"> China Petroleum & Chemical Corporation CEA
Patents Pending (%)	30.2
Patents Granted (%)	69.7

Top patent assignees, Q2 2019



Source: Orbit

Hydrogen Policy Developments – Global



- Japan hosted the Hydrogen Energy Ministerial meeting in 2018, where 4 key areas in which efforts were required were identified. A new roadmap for hydrogen and fuel cells was released in March 2019
- South Korea announced its hydrogen roadmap in **early 2019, whereby it aims at reaching 1200 hydrogen fuelling stations by 2040**. Prior to that the Hyundai Motor Group had released a FCEV 2030, which focuses on the development of a hydrogen society
- Australia released a national hydrogen roadmap in August 2018. It is expected that its hydrogen strategy will be released in December 2019



- The California Fuel Cell Partnership targets 1 million FCEVs and 1 000 hydrogen fuelling stations by 2030



- Hydrogen Mobility Europe through its **H2ME** initiative aims to add **47** hydrogen refueling stations by 2022 (across Scandinavia, Germany, France, UK and The Netherlands)
- France announced the €100m hydrogen deployment plan in mid 2018. The plan aims to construct 100 H2 stations (there are currently 20) and have **5,000 H2-powered light commercial vehicles and 200 H2-powered heavy vehicles** on the road by 2023

Hydrogen is today enjoying unprecedented momentum, driven by governments that both import and export energy, as well as the renewables industry, electricity and gas utilities, automakers, oil and gas companies, major technology firms and big cities. The world should not miss this unique chance to make hydrogen an important part of our clean and secure energy future.

—Dr Faith Birol, Executive Director, IEA

03

Key Player Activities

Established Players: Hyundai Motor Company – Q2 Highlights

South Korea based Hyundai Motor Company is one of the most active players in the hydrogen mobility space. It is involved in various segments of the value chain: building hydrogen refueling infrastructure, proprietary fuel systems, introducing new variants in hydrogen vehicles. It announced a long-term roadmap “FCEV Vision 2030 plan”, committing to hydrogen fuel cell development. The Group aim to reach an annual production capacity of **500,000- FCEV units by 2030**, including passenger vehicles and commercial vehicles.

Partnerships



- **MoU with Saudi Aramco** to cooperate in hydrogen and nonmetallic materials technologies (*Jun 2019*)
 - Accelerate the expansion of a hydrogen ecosystem in both South Korean and Saudi Arabian markets

Hydrogen refueling stations



- Involved in operations of **highway charging stations** e.g: **Anseong, Yeosu** in South Korea (*Apr 2019*)
- Part of special purpose company, **HyNet**, formed by the South Korean Ministry of Trade, Industry and Energy for construction of hydrogen charging infrastructure (*Mar 2019*)
 - Second largest shareholder following Korea Gas Corp

Other transportation modes



- Plans to supply **300** hydrogen buses annually from **2020** (*Jun 2019*)
- Hyundai Motor Company and H2 Energy set up a joint venture (*Apr 2019*)
 - Aimed at leading hydrogen mobility in Europe
 - Deliver **1600** fuel cell electric heavy-duty trucks from **2019-2025**
- Set to develop a **ship** powered by hydrogen fuel cells in cooperation with Gangwon province (*May 2019*)
- Involved in development of **hydrogen powered tram** by **2020** (*Jun 2019*)

Innovation deployment



- Introduced an on-site hydrogen generation, compression, storage and dispensing appliance: **SimpleFuel™** at its Motomachi Plant in Toyota City, Aichi Prefecture (*Apr 2019*)
- SimpleFuel™ uses water and electricity to produce high purity fuel cell-grade hydrogen and works on solar energy
- Following compression and pressurization it is used to power fuel cell forklifts
- SimpleFuel™ was developed by a consortium of technology innovators: PDC Machines, Ivys Energy Solutions and McPhy North America

Source: Hyundai Motor Company(>>>)

Established Players: Nel Hydrogen – Q2 Highlights

Norway based Nel Hydrogen is a global company providing solutions for the production, storage and distribution of hydrogen from renewable energy sources. Main products are hydrogen production plants for industry and energy applications, hydrogen fueling stations for the transport sector, and power-to-gas/power-to-power solutions for the renewable industry.

Partnerships



- [Working with Nikola Motors](#) to expedite the deployment of hydrogen-electric trucks by providing infrastructure (*Apr 2019*)
- [MoU](#) with Hyundai Motor Corp., Air Liquide, Nikola, Shell and Toyota on the formation of a global consortium for the development of high-capacity, high-voltage charging components for commercial hydrogen electric vehicles (*Mar 2019*)

Distribution of HRS orders, Q2 2019



Nel Hydrogen received orders from [Equilon Enterprises](#), [Hydrogen Technology & Energy Corporation \(HTEC\)](#) and [Korea Gas Technology Corporation](#) during Q2, 2019

Hydrogen station explosion: Impact on business



- A fire incident happened at a Nel hydrogen refueling station in [Kjørbo, Norway](#) on the 10th of June, 2019 which resulting in injury of three people
- Following the incident Nel halted operations at all refueling stations employing the same H2Station technology as the Kjørbo station
- 4 hydrogen stations in Germany working on Nel components were also taken off the grid
- Preliminary investigation revealed that the station's electrolyzer nor dispenser were not responsible for the incident
- An incorrectly mounted plug was found to be the root cause
- Nel will conduct an inspection and integrity testing scheme for the high-pressure storage units with similar connectors
- Following the acceptance test, the hydrogen filling station will be connected to the grid again
- Though Nel's business has been impacted adversely, BAU operations are expected to be regained gradually, once positive results are observed from the acceptance tests

Source: Nel Hydrogen (>>>)

Key Startups – Q2 Highlights



- Germany based spin-off of the University of Erlangen-Nuremberg
- Provides Liquid Organic Hydrogen Carriers (LOHC) solutions

Collaboration/Agreements



- **April 2019:** Part of the [GET H2](#) initiative in Germany which aims to use hydrogen for advancing the energy revolution
- Core elements of the initiative:
 - Construction of a power-to-gas plant with a capacity of 105 MW,
 - The transport and storage of pure hydrogen in existing infrastructures
 - Use of hydrogen



- UK based company engaged in design, integration and deployment of hydrogen fuel cell systems

Collaboration/Agreements



- **April 2019:** Developed double-deck buses in partnership **with Alexander Dennis**, UK's largest bus manufacturer
- Set to open Hydrogen and Fuel Cell Powertrain Manufacturing Installation and Fleet Support Facility in **Liverpool City Region**, which will be used to produce and install hydrogen fuel cell systems in the double-deck buses
- **May 2019:** Arcola Energy is also working with English rolling stock manufacturer for the development of hydrogen trains



- Canada based H2 infrastructure and H2 Technology Solutions provider

Funding



- **May 2019:** \$3 million funding was announced by the Natural Resources Canada and the Government of British Columbia for 2 retail hydrogen fueling stations, through its [Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative \(EVAFIDI\)](#).
- HTEC is partnering with International convenience-store chain, 7-Eleven for building the retail hydrogen refuelling stations

Source: GasWorld (>>), FuelCellsWorks (>>), NewsWire (>>)

North America

55 Madison Ave, Suite 400
Morristown, NJ 07960
USA
T: +1 212 835 1590

Europe

328-334 Graadt van Roggenweg
4th Floor, Utrecht, 3531 AH
Netherlands
T: +31 30 298 2108

United Kingdom

5 Chancery Lane
London EC4A 1BL
United Kingdom
T: +44 207 406 7548

Asia Pacific

Millennium Business Park
Sector 3, Building # 4, Mahape
Navi Mumbai 400 710
India
T: +91 22 6772 5700