



사단  
법인

대한설비공학회 2025년도 하계학술발표대회 특별강연

# 천연수소의 가능성을 바라보다

2025.06.19

알펜시아리조트

유호선 전임회장



# 강연 구성



## 수소와 수소경제



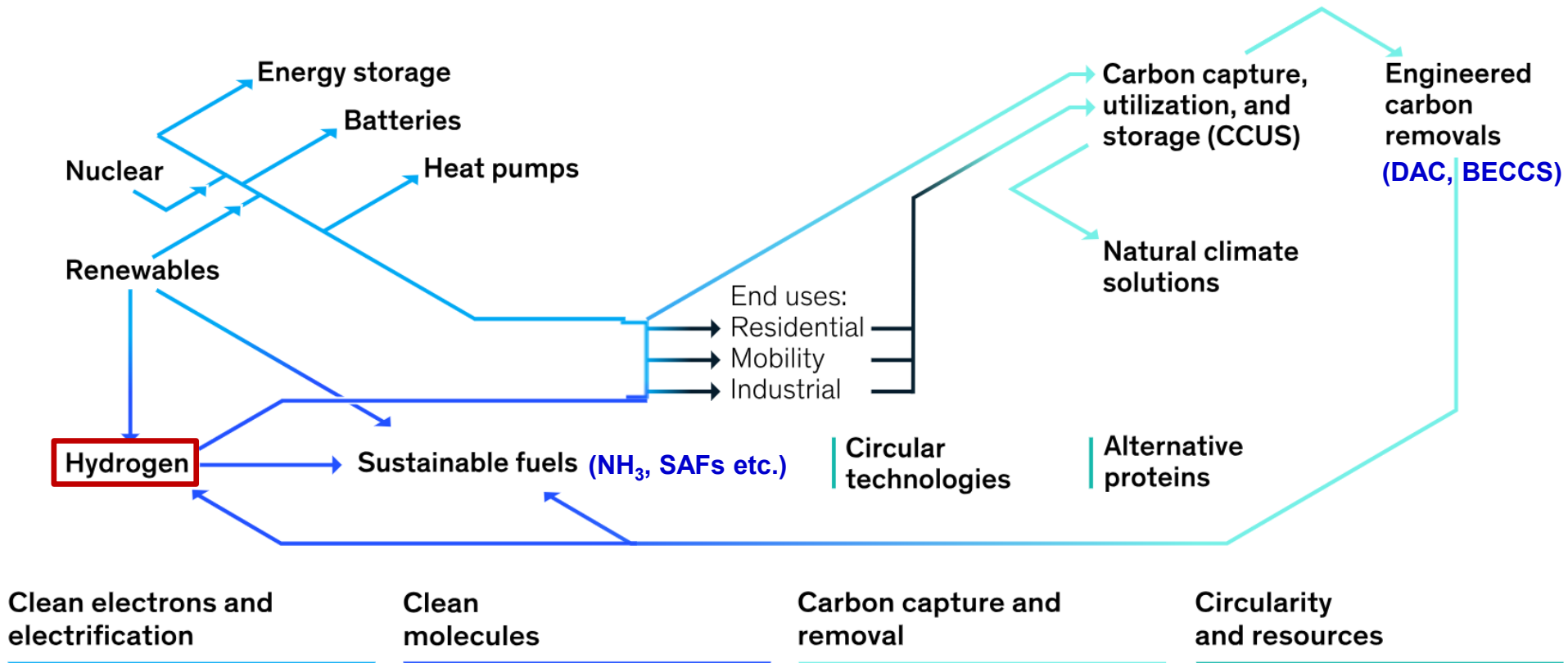
## 천연수소의 浮上



## 개발동향 및 전망

# 수소는 기후기술(Climate Tech)의 求心 역할

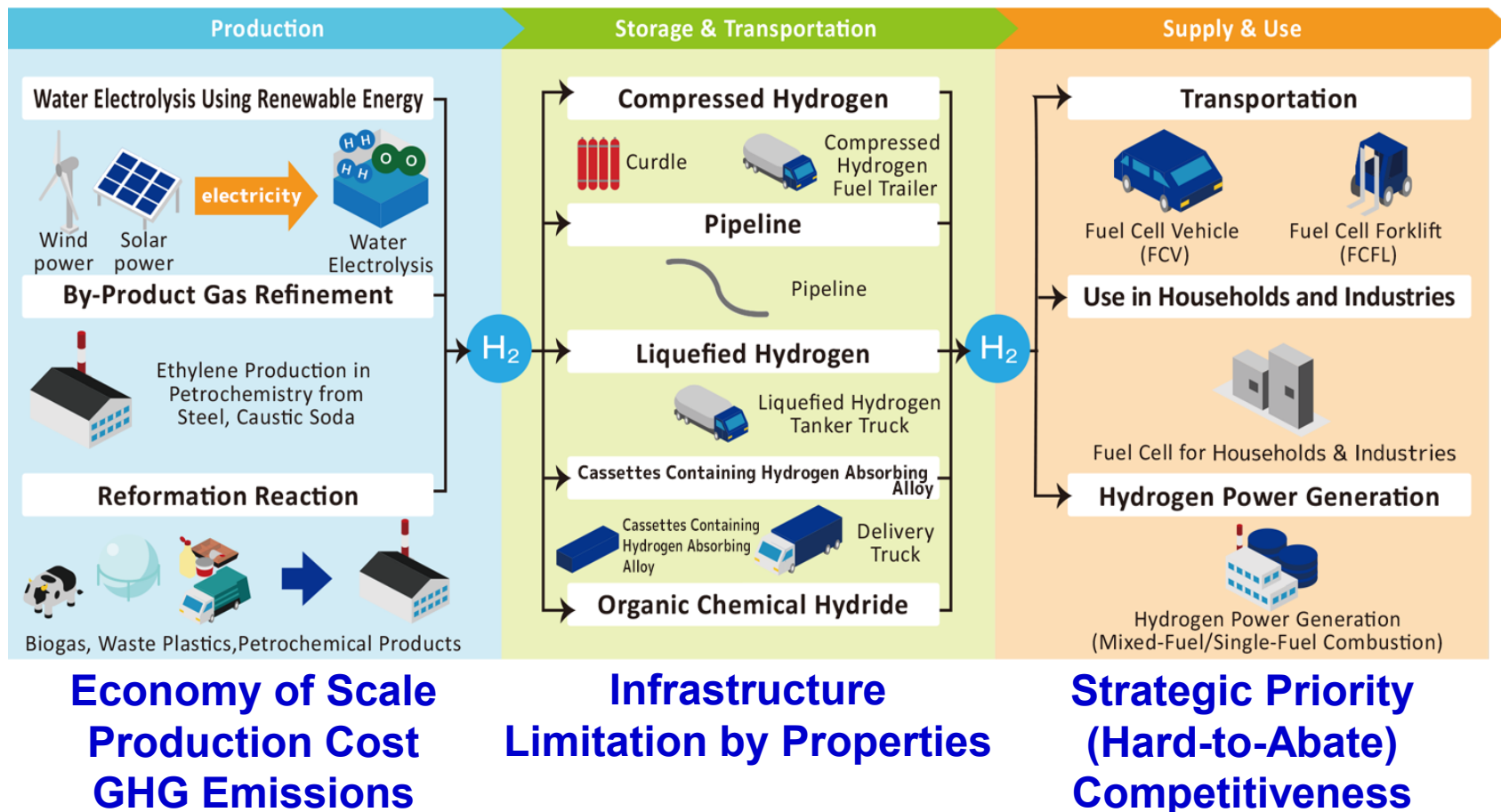
## A Network of 12 Techs is Required to Achieve Climate Goals



<https://www.mckinsey.com/capabilities/sustainability/>

our-insights/what-would-it-take-to-scale-critical-climate-technologies

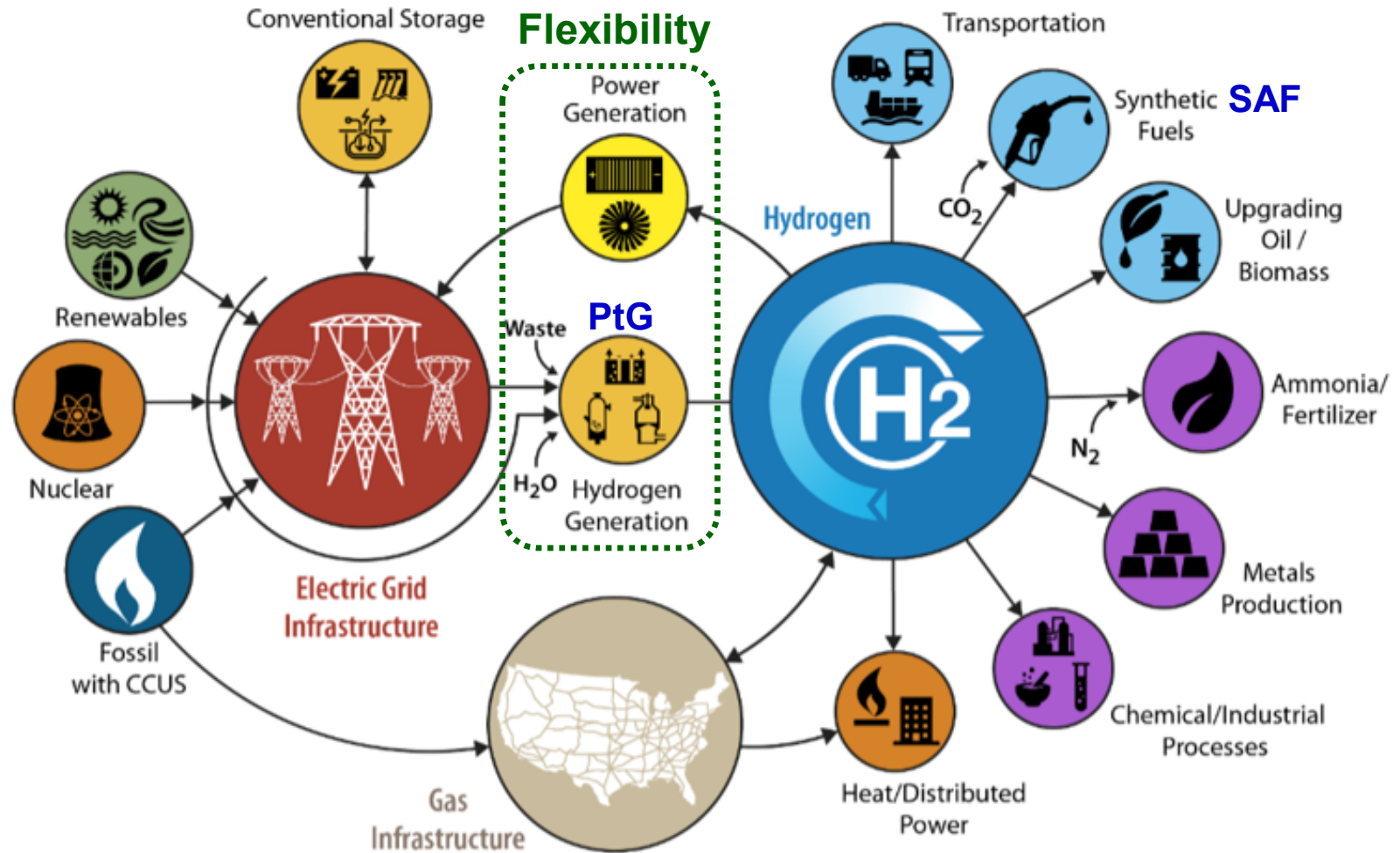
# Challenges in Hydrogen Value Chain



[https://www.env.go.jp/seisaku/list/ondanka\\_saisei/lowcarbon-h2-sc/en/demonstration-business/index.html](https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/en/demonstration-business/index.html)

Johnson, N. et al., Realistic roles for hydrogen in the future energy transition, Nature Reviews Clean Technology, 2025

# 수소경제(Hydrogen Economy)가 궁극 목표

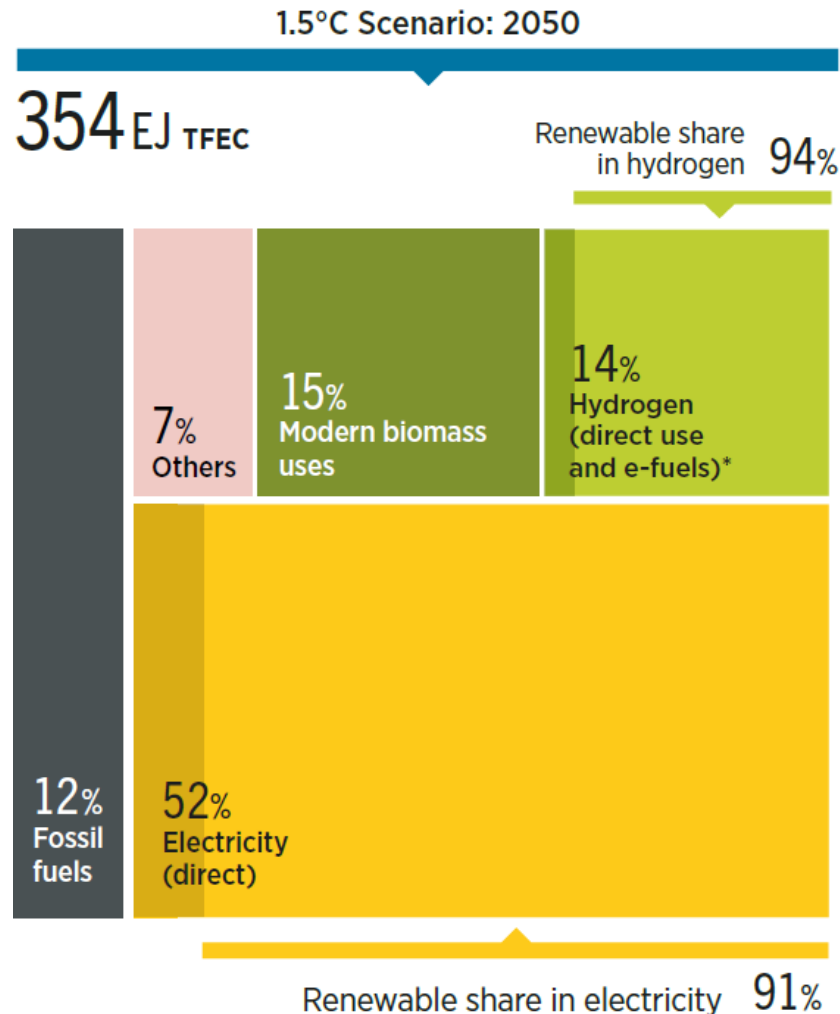
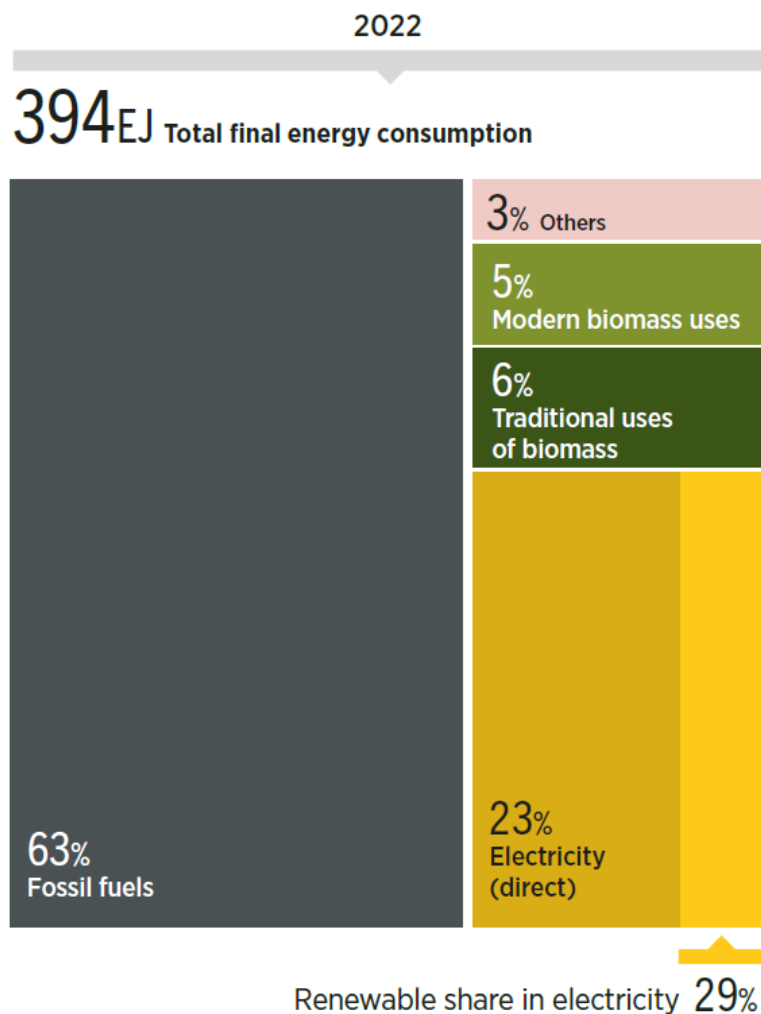


Source: U.S. Department of Energy, *Hydrogen Program Plan*, Figure 3, November 2020

Note: CCUS is carbon capture, utilization, and storage.

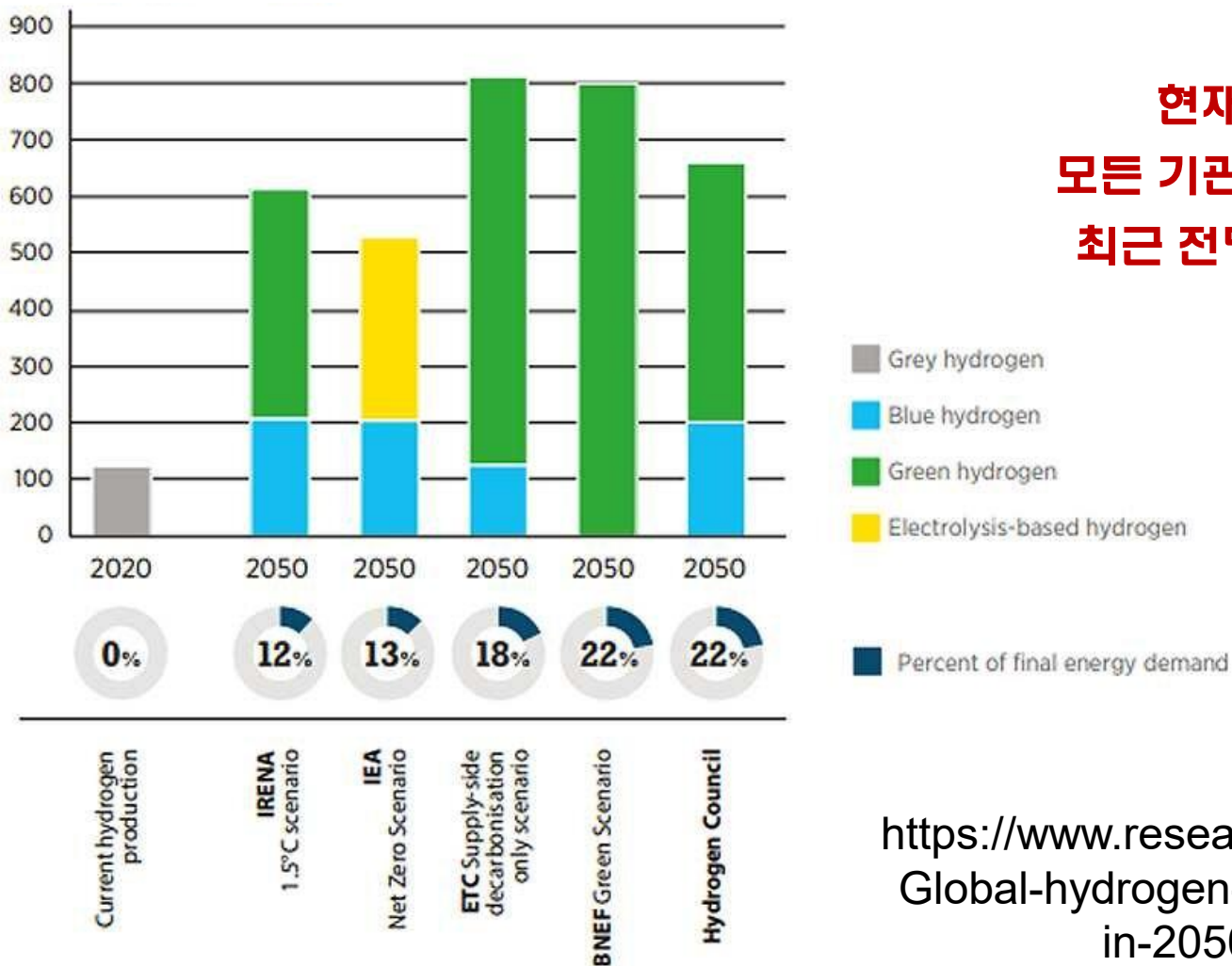
# 수소는 IRENA 2050 1.5°C 목표 달성에 기여

## Total Final Energy Consumption (TFEC) by Energy Carrier



# 수소 2050 기관별 최대 생산 시나리오 비교

## Global Hydrogen Production by Technology, Mtpa



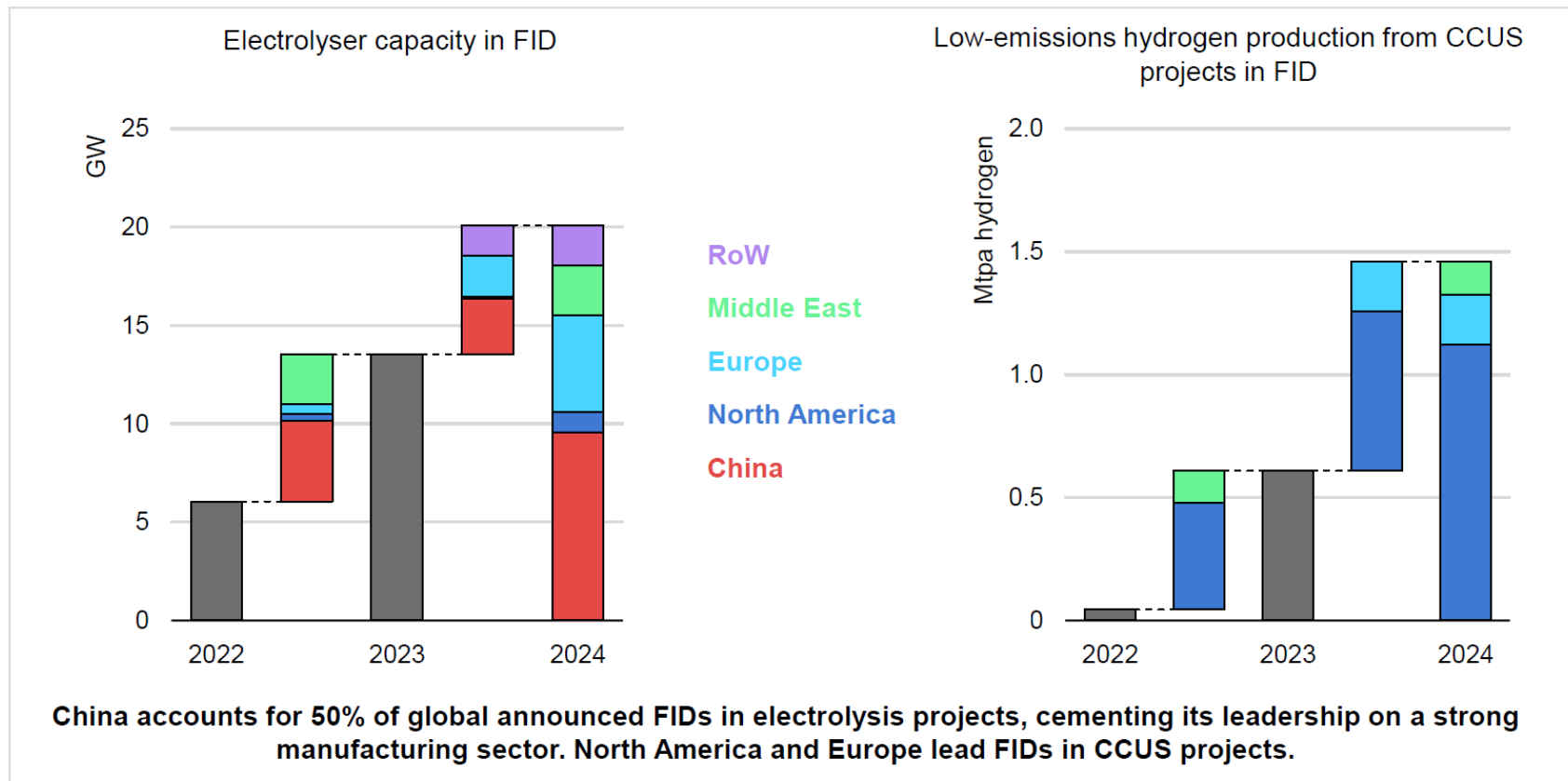
**현재 100 Mt 정도 생산**  
**모든 기관 500 Mt 이상 전망**  
**최근 전망일수록 감소 추세**

[https://www.researchgate.net/figure/Global-hydrogen-demand-forecast-in-2050\\_fig1\\_377144277](https://www.researchgate.net/figure/Global-hydrogen-demand-forecast-in-2050_fig1_377144277)



# 電解槽 제조 중국, 블루수소 생산 歐美 주도

## China and electrolyzers: the sequel to solar PV and EVs?



IEA 2024. CC BY 4.0.

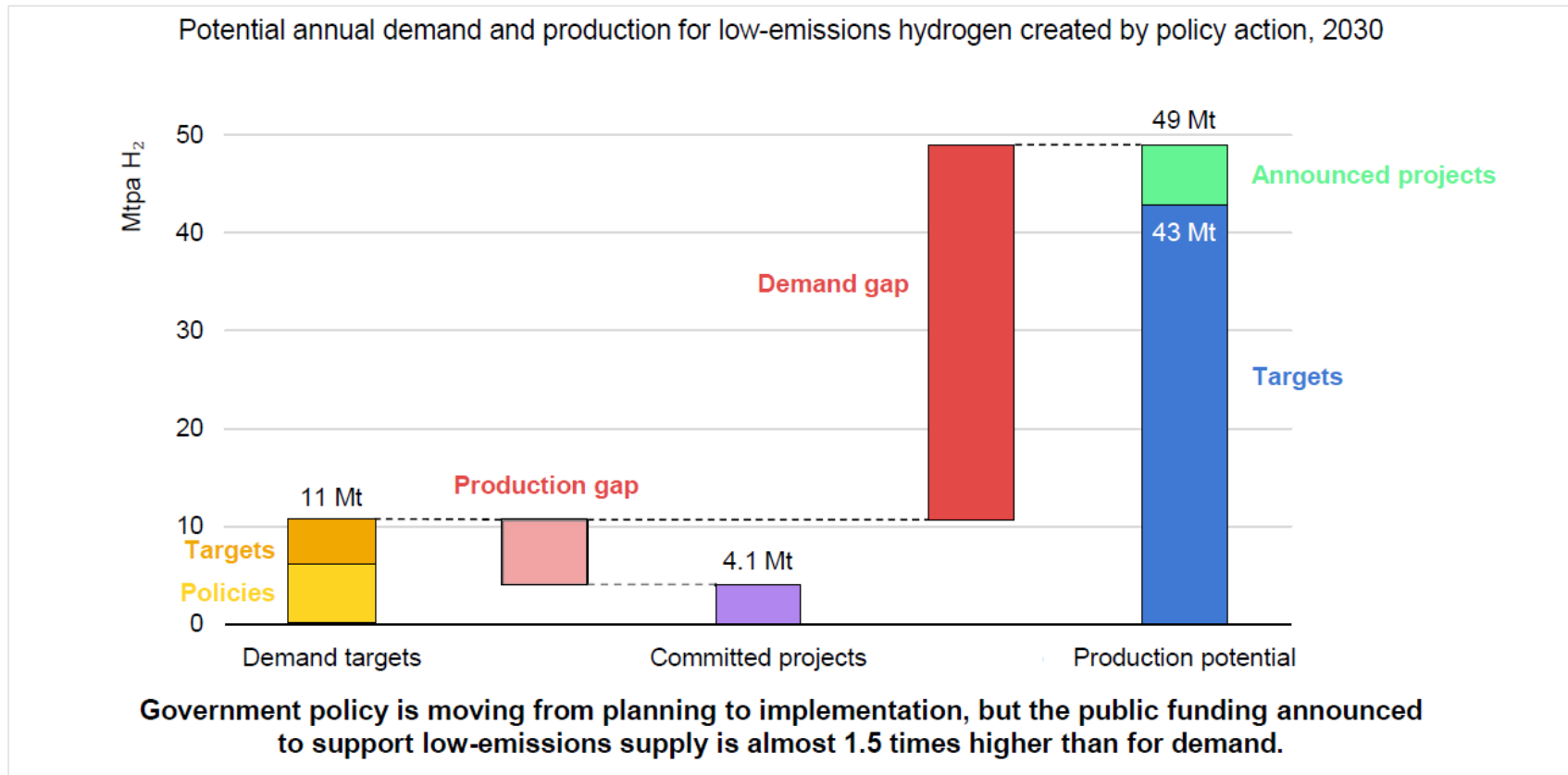
Page 5

[https://www.iea.org/  
events/global-hydrogen-review-2024-technical-webinar](https://www.iea.org/events/global-hydrogen-review-2024-technical-webinar)



# 청정수소 정책의 수요-공급 사이 격차가 문제

## Growing gap in policy ambitions between production and demand



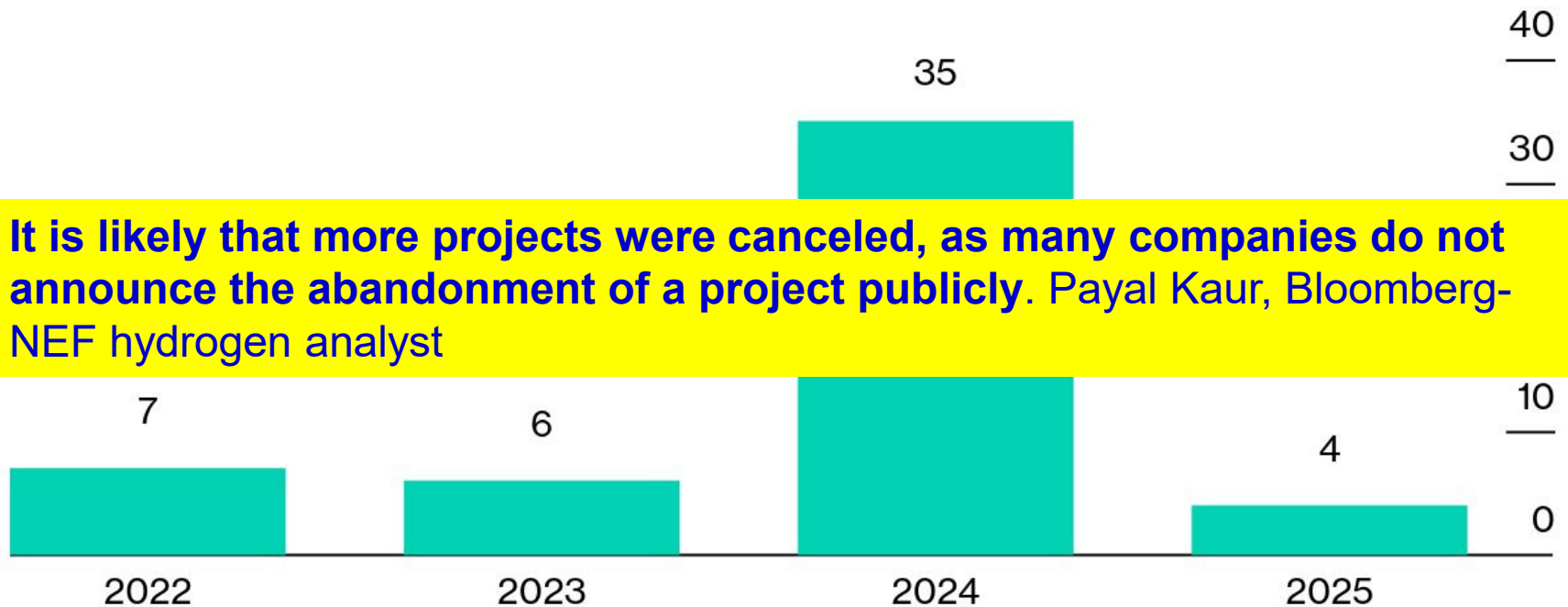
IEA 2024. CC BY 4.0.

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# 전세계적으로 2024 그린수소 사업 취소 폭증

## Green Hydrogen Project Cancellations Skyrocketed in 2024

Number of green hydrogen projects canceled in a given year



Source: BloombergNEF

Note: Data as of March 11, 2025. Data for 2022 includes cancellations made in prior years.

BloombergNEF

<https://mail.google.com/mail/>

[u/0/#inbox/FMfcgzQZTgRPQrZhlvMRpvmjXgqWgrQ](https://mail.google.com/mail/u/0/#inbox/FMfcgzQZTgRPQrZhlvMRpvmjXgqWgrQ)

# 강연 구성



수소와 수소경제



천연수소의 浮上



개발동향 및 전망

# 천연수소 주목의 계기: 지하 대량 저장 보고

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 43 (2018) 19315–19326



Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

ScienceDirect

journal homepage: [www.elsevier.com/locate/he](http://www.elsevier.com/locate/he)



## Discovery of a large accumulation of natural hydrogen in Bourakebougou (Mali)



Alain Prinzhofer<sup>a,\*</sup>, Cheick Sidy Tahara Cissé<sup>b</sup>, Aliou Boubacar Diallo<sup>b</sup>

<sup>a</sup> GEO4U, Rua Tavares Bastos 123, Catete, 22221-030, Rio de Janeiro, Brazil

<sup>b</sup> PETROMA, Mali

### ARTICLE INFO

Article history:

Received 12 July 2018

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24 August 2018

Accepted 28 August 2018

Available online 25 September 2018

### ABSTRACT

Recent exploratory wells in Mali ( success and provide a new unde (Bougou-1), and a comprehension c extensive gas data of a pioneer w dozen exploratory wells in the v extensive hydrogen field featuring



# 천연수소의 정의와 다양한 명칭

천연수소: 전통적인 석유나 천연가스처럼 자연적으로 생성돼 지하에 **저장되어 있거나 지속적으로 생성되고 있는** 수소

Natural / Native Hydrogen

Geologic(al) Hydrogen / Geohydrogen (**지질수소**)

Natural Geologic Hydrogen

Hidden Hydrogen

**White** Hydrogen

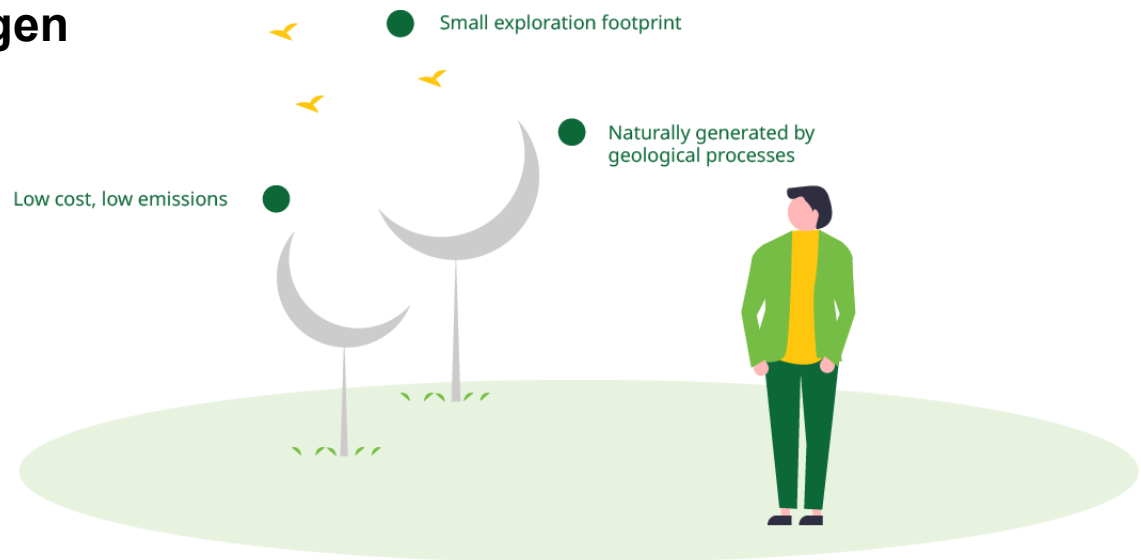
**Gold** Hydrogen

Free Hydrogen

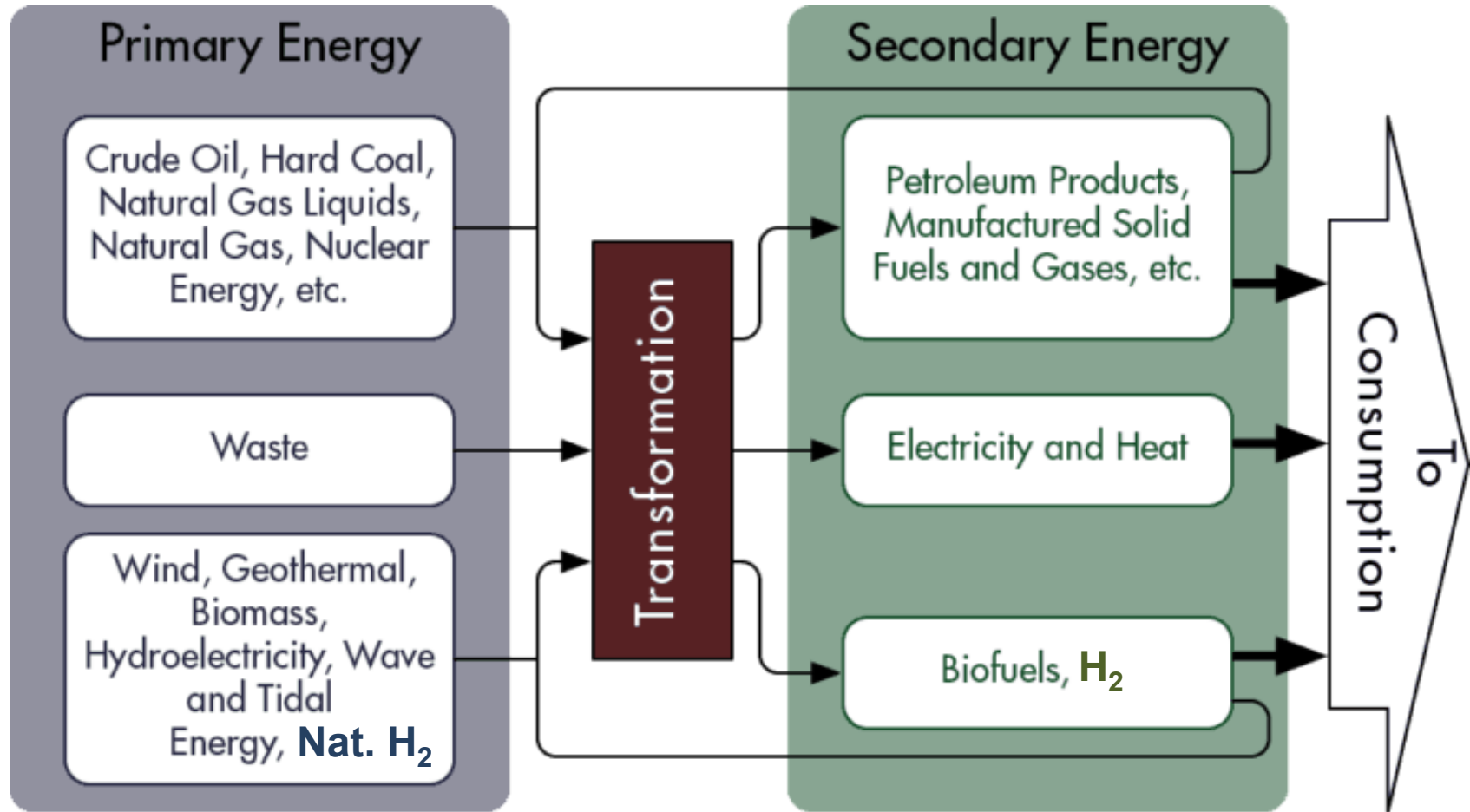
Underground Hydrogen

**Orange** Hydrogen

= Stimulated/Enhanced (Geologic) Hydrogen (**자극수소 / 増産수소?**)



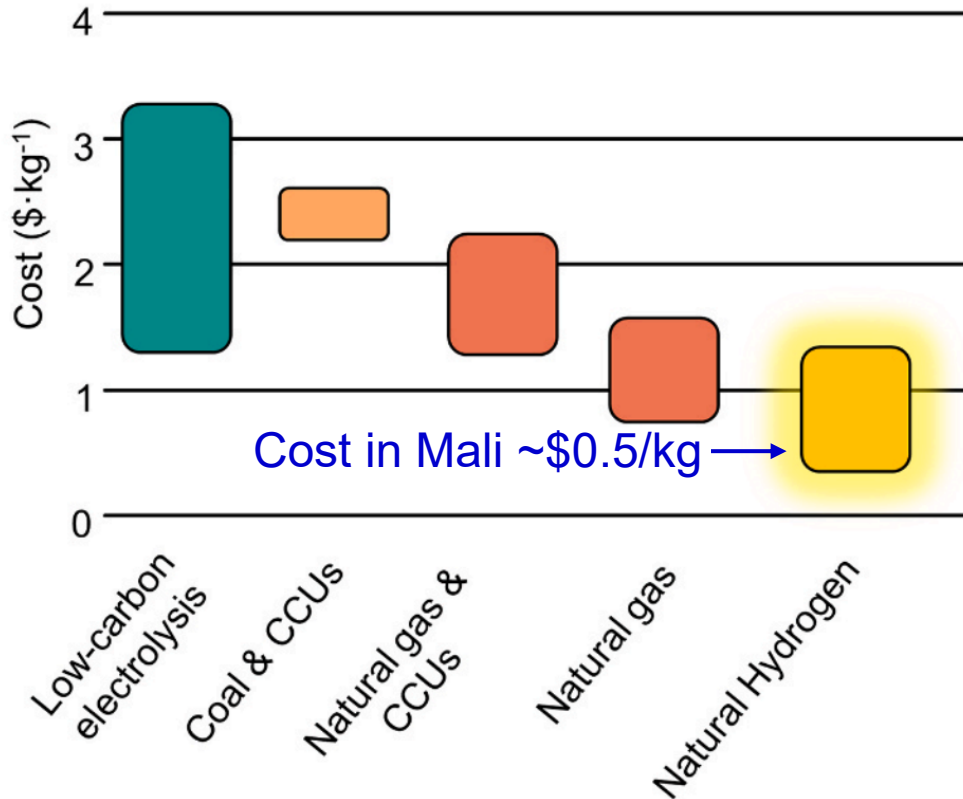
# 에너지 흐름에서 수소의 자리매김 **변동**



(Renewable) Energy Resource ← Energy Carrier

# 천연수소는 Game Changer로서 잠재력 충분

## Estimated H<sub>2</sub> Cost in 2050



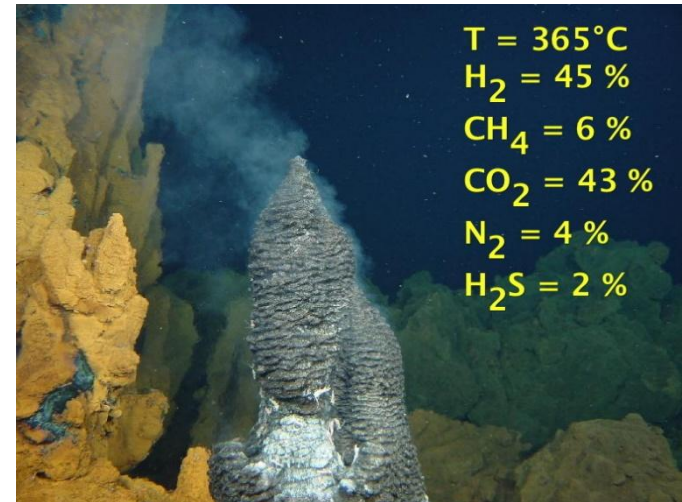
## 천연수소 특성

강력한 가격 경쟁력 예견

엄청난 총매장량(USGS **5조 톤**으로 추정, 후술 참조)

낮은 탄소발자국 등 환경친화

세계 여러 곳에서 생성 보고



<https://www.geo-ocean.fr/en/Science-for-all/Our-classrooms/Hydrothermal-systems/Hydrothermalism/Synthesis-of-hydrogen-methane-and-hydrocarbons>



# 천연수소 생성 지구과학을 본격 概觀한 논문

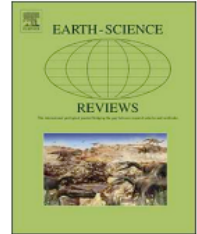
Earth-Science Reviews 203 (2020) 103140



Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Earth-Science Reviews

journal homepage: [www.elsevier.com/locate/earscirev](https://www.elsevier.com/locate/earscirev)



## The occurrence and geoscience of natural hydrogen: A comprehensive review



Viacheslav Zgonnik

Natural Hydrogen Energy LLC, French branch: 31 rue Raymond Queneau, 92500 Rueil Malmaison, France

### ARTICLE INFO

#### Keywords:

Hydrogen  
Natural hydrogen  
Gas seeps  
Faults  
Earthquakes  
Atmosphere  
Microorganisms  
Energy

### ABSTRACT

Using an interdisciplinary approach, this paper reviews current knowledge in the field of natural hydrogen. For the first time, it combines perspectives on hydrogen from the literature of the former Eastern bloc with that of the West, including rare hardcopies and recent studies. Data are summarized and classified in three main sections: hydrogen as a free gas in different environments, as inclusions in various rock types, and as dissolved gas in ground water. **This review conclusively demonstrates that molecular hydrogen is much more widespread in nature than was previously thought.** Hydrogen has been detected at high concentrations, often as the major gas, in all types of geologic environment. A critical evaluation of all the proposed mechanisms regarding the origin of natural hydrogen shows that a deep-seated origin is potentially the most likely explanation for its abundance in

# 대중적 관심을 촉발한 것은 Science誌 기사



630 17 FEBRUARY 2023 • VOL 379 ISSUE 6633

Corrected 21 February 2023 and 24 February 2023. See full text

science.org SCIENCE

science.org on February 23, 2024

# 천연수소 Gold Rush FT 보도와 매장량 추정

Hydrogen power

+ Add to myFT

## Geologists signal start of hydrogen energy 'gold rush'

SCIENCE ADVANCES | RESEARCH ARTICLE

### GEOLOGY

## Model predictions of global geologic hydrogen resources

Geoffrey S. Ellis\* and Sarah E. Gelman

Geologic hydrogen could be a low-carbon primary energy resource; however, the magnitude of Earth's subsurface endowment has not yet been assessed. Knowledge of the occurrence and behavior of natural hydrogen on Earth has been combined with information from geologic analogs to construct a mass balance model to predict the resource potential. Given the associated uncertainty, stochastic model results predict a wide range of values for the potential in-place hydrogen resource [ $10^3$  to  $10^{10}$  million metric tons (Mt)] with the most probable value of  $\sim 5.6 \times 10^6$  Mt. Although most of this hydrogen is likely to be impractical to recover, a small fraction (e.g.,  $1 \times 10^5$  Mt) would supply the projected hydrogen needed to reach net-zero carbon emissions for  $\sim 200$  years. This amount of hydrogen contains more energy ( $\sim 1.4 \times 10^{16}$  MJ) than all proven natural gas reserves on Earth ( $\sim 8.4 \times 10^{15}$  MJ). Study results demonstrate that further research into understanding the potential for geologic hydrogen resources is merited.

Several recent studies have claimed that natural hydrogen generation rates are rapid enough to potentially offset anthropogenic extraction rates from reservoirs, thereby constituting a renewable resource.

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# 최근 대륙지각의 천연수소 蓄積量 연구 발표

## Earth's Crust May Hold Hydrogen Equal to 170,000 Years of Oil Use: Study



<https://www.esgtimes.in/energy/hydrogen/earths-crust-may-hold-hydrogen-equal-to-170000-years-of-oil-use-study/>

Ballentine, C. J. et al., Natural hydrogen resource accumulation in the continental crust, Nature Reviews Earth & Environment, Vol. 6, May 2025

# 미국 DOE, 천연수소 개발 지원 및 목표 제시



## U.S. Department of Energy Announces \$20 Million to 16 Projects Spearheading Exploration of Geologic Hydrogen

*16 Projects Spanning 8 States Set to Receive Funding to Explore Geologic Hydrogen Stimulation and Reservoir Management, Reinforcing President Biden's Efforts to Build a Clean Hydrogen Economy*

02/08/2024

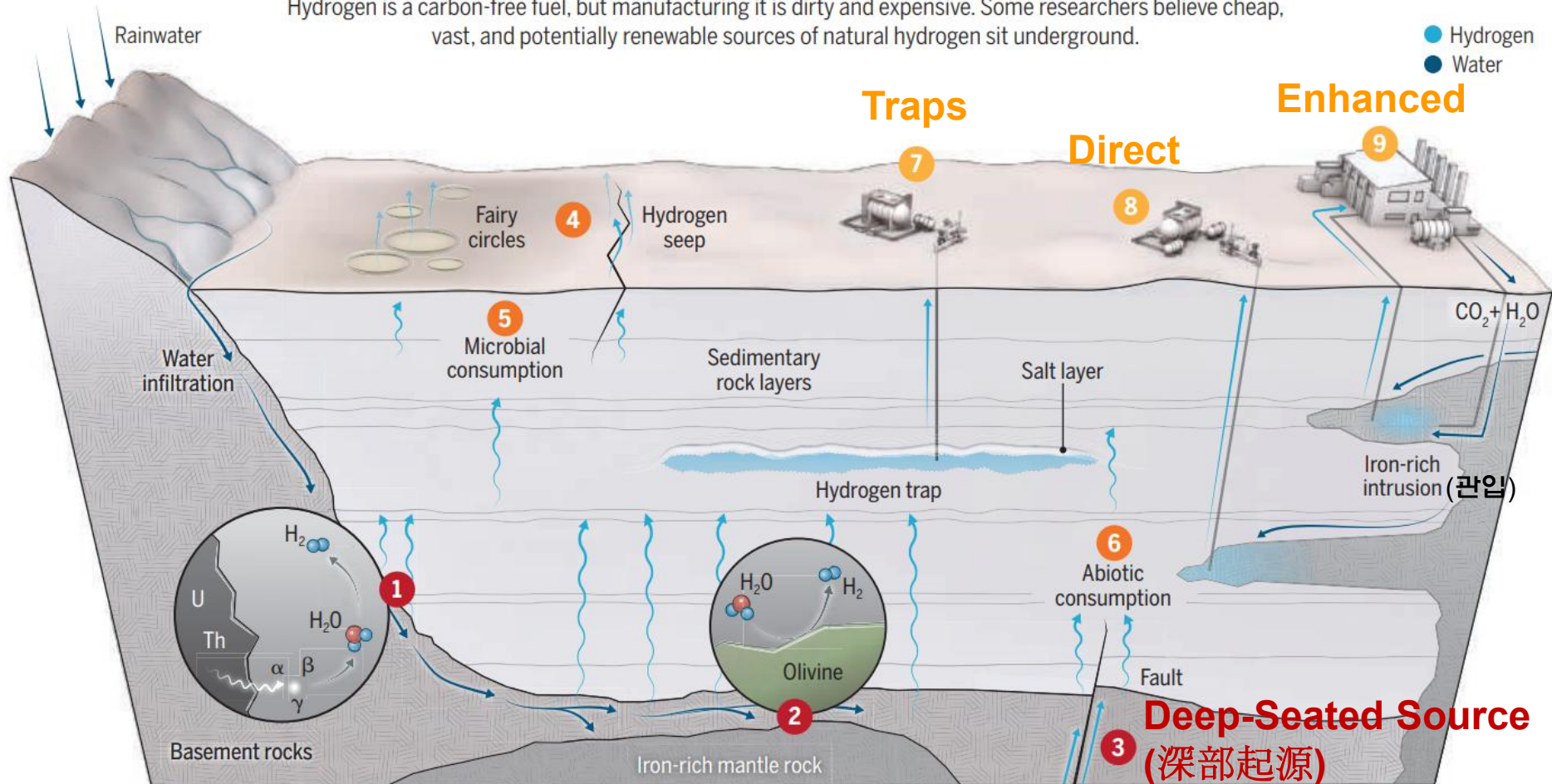
<https://arpa-e.energy.gov/news-and-media/press-releases/us-department-energy-announces-20-million-16-projects-spearheading>

## ARPA-E Targets for Geologic Hydrogen Production

Metric	Geologic H <sub>2</sub> Target
H <sub>2</sub> cost at the well-head	<\$1/kg H <sub>2</sub>
H <sub>2</sub> GHG (from production)	<0.45 kg CO <sub>2</sub> e/kg H <sub>2</sub>
Hydrogen purity	>20% (volumetric) at the well-head
Deposit potential	>10 Mt H <sub>2</sub>
Deposit production (from formation)	>1 million m <sup>3</sup> /day H <sub>2</sub> (>30,000 tonnes/year H <sub>2</sub> )

# 천연수소 생성: Earth's Hydrogen Factory

Hydrogen is a carbon-free fuel, but manufacturing it is dirty and expensive. Some researchers believe cheap, vast, and potentially renewable sources of natural hydrogen sit underground.



**Radiolysis (방사선분해) ~20% Serpentinization (사문석화) >80%**

Generation

Loss mechanisms

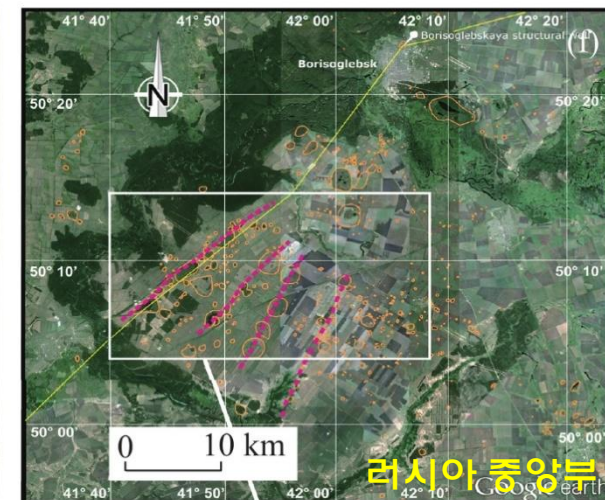
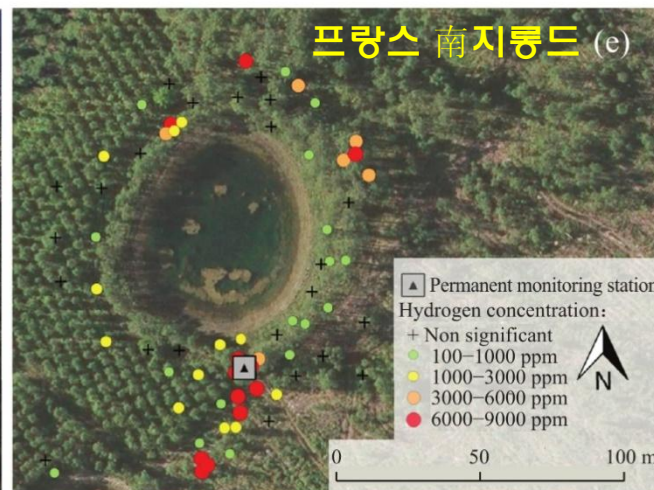
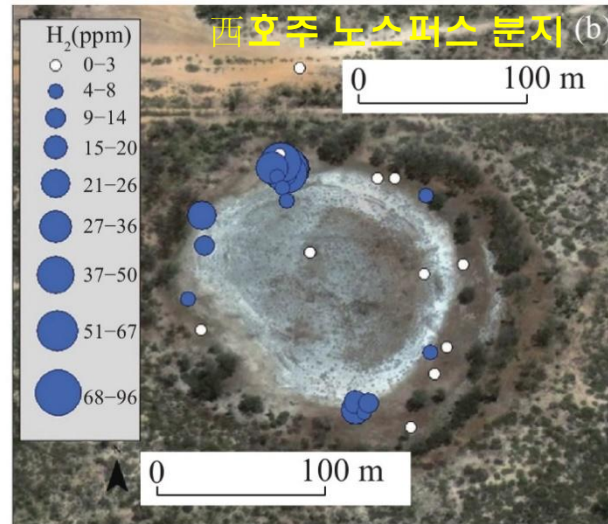
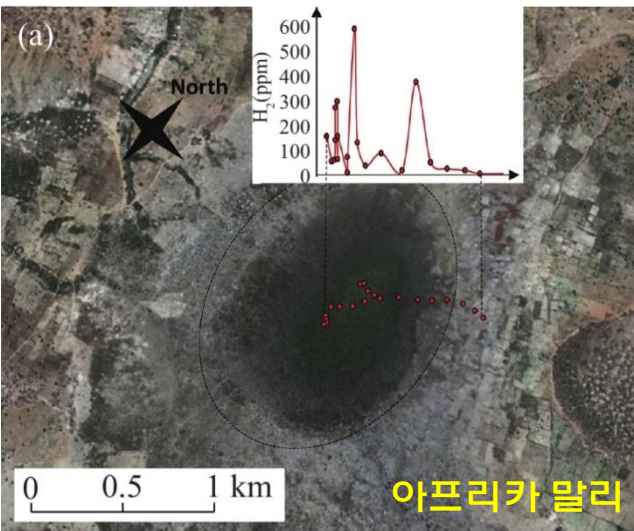
Extraction

Hidden hydrogen: Earth may hold

vast stores of a renewable, carbon-free fuel | Science | AAAS



# 지표 누출흔적은 半圓形 함몰지(Fairy Circle)

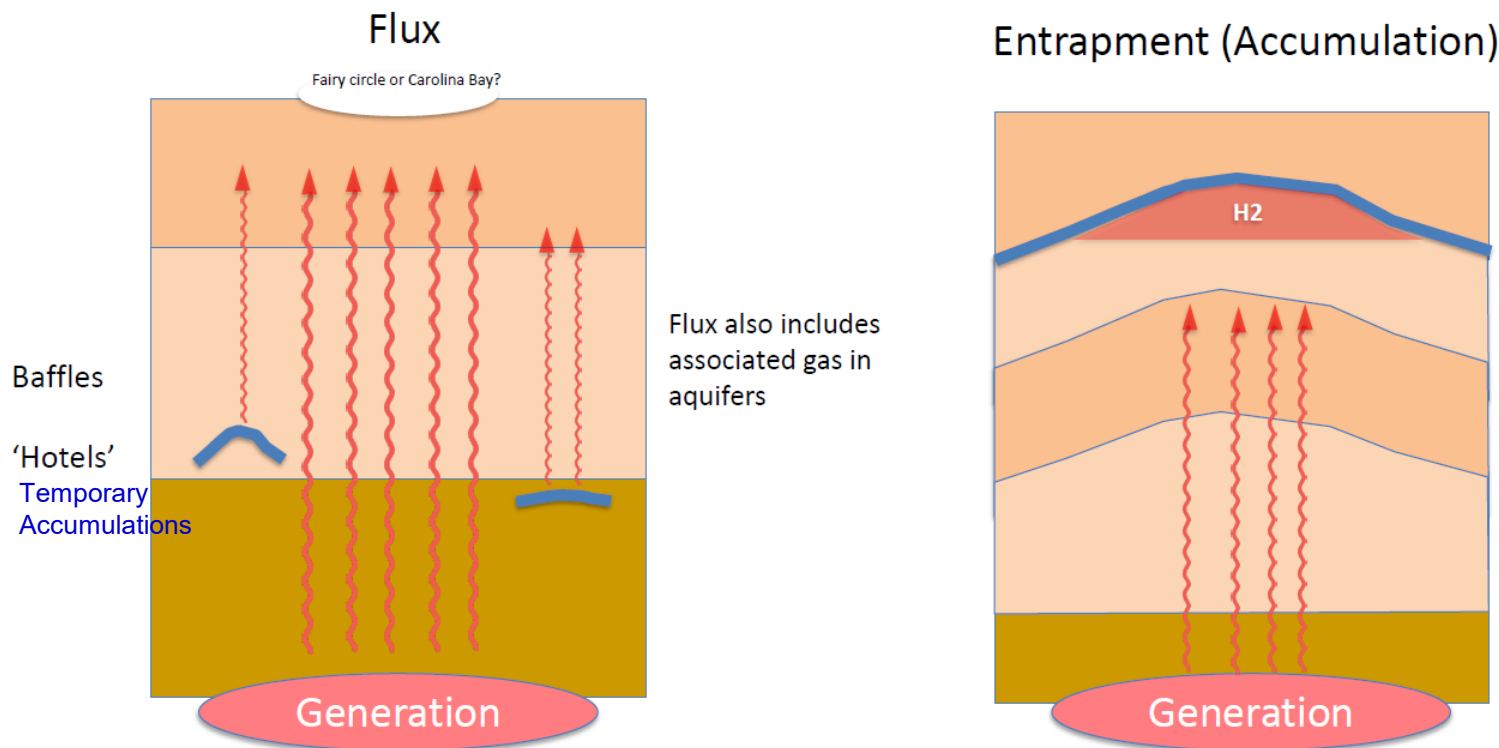


Semicircular Depressions (SCDs), Ovoids, Witch Rings or Water Basins



# Natural Hydrogen Resources Evaluation

## Flux vs entrapment

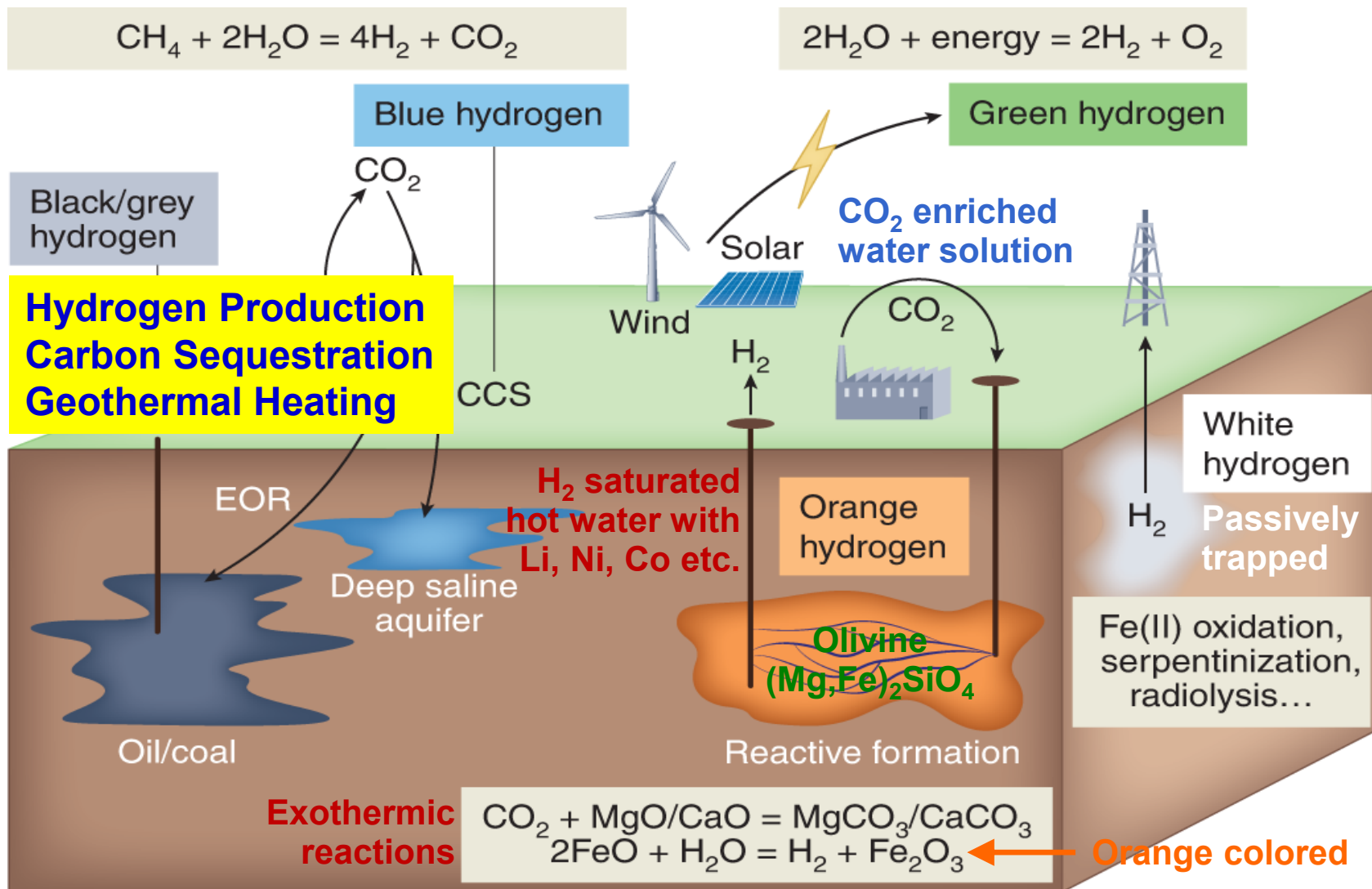


**Hydrogen system is a dynamic system that is recharged while producing.**  
(Maiga, O. et al., Scientific Reports 13:11876, 2023)

<https://riscadvisory.com/wp-content/uploads/2024/06/>

DEVEX-Natural-H2-expl-and-estimating-the-resource-web.pdf

# Orange Hydrogen is the New Green



Osselin, F. et al.,

# 강연 구성



수소와 수소경제



천연수소의 浮上



개발동향 및 전망

# 2023부터 천연수소 관련 상업적 관심本格化

## Rapidly developing commercial interest



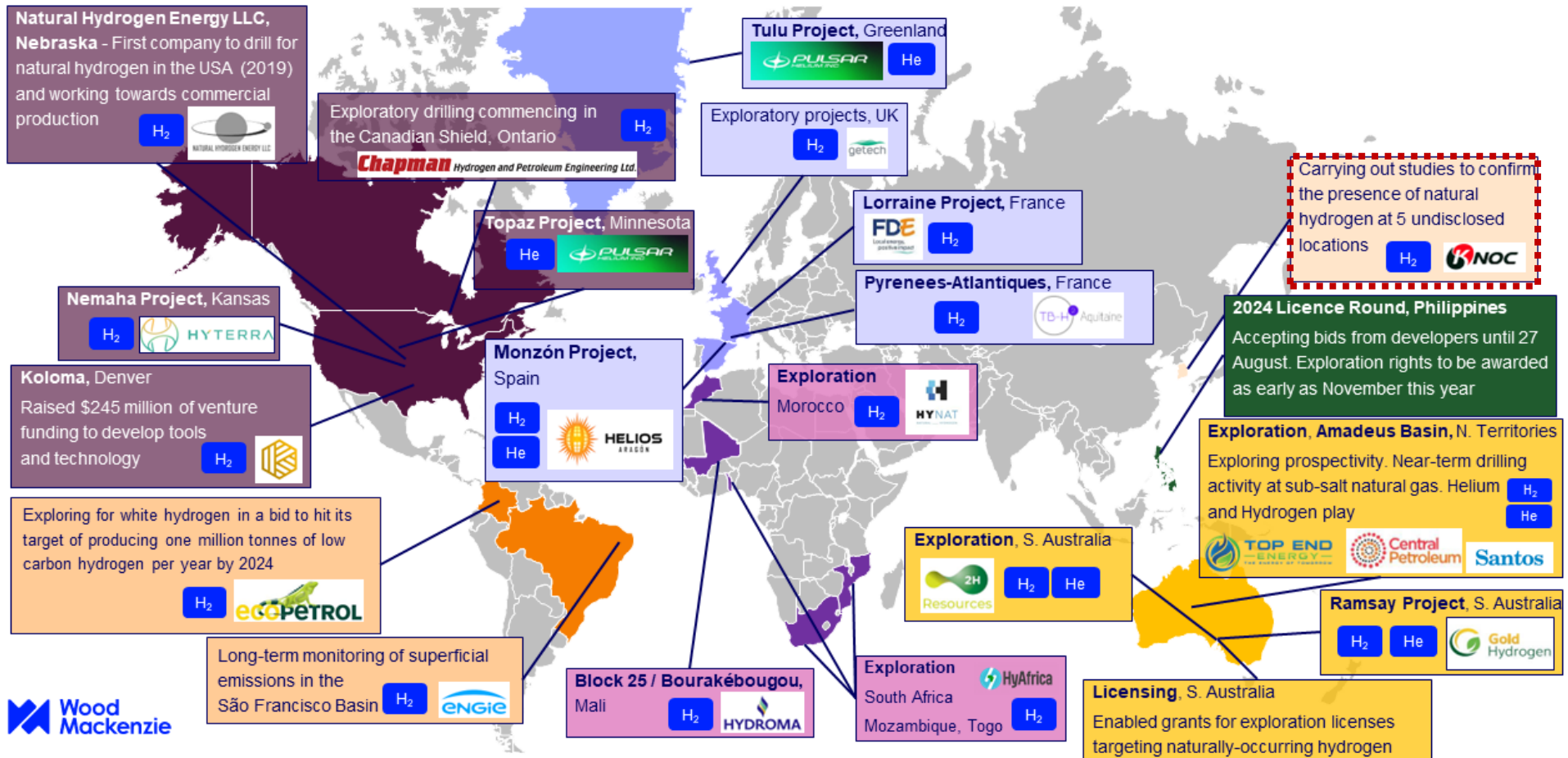
Not simply drilling – companies cover wide range of technology needs



Publicly disclosed >\$450M investments in 2 years

# 천연수소 (및 헬륨) 탐사 프로젝트(July 2024)

Projects and exploration activity: naturally occurring hydrogen and helium



# TRL in Natural H<sub>2</sub> Exploration/Production

<b>0</b>	<b>IDEA</b> Unproven concept, no testing has been performed	<b>IDEA</b>	0 Discovery of H <sub>2</sub> at the Earth surface	Done
<b>1</b>	<b>BASIC RESEARCH</b> You can now describe the need(s) but have no evidence		1 Systematic research of H <sub>2</sub> seepages in various environments	Done
<b>2</b>	<b>TECHNOLOGY FORMULATION</b> Concept and application have been formulated		2 Short time monitoring of sites	Done for 2-3 sites
<b>3</b>	<b>NEEDS VALIDATION</b> You have an initial 'offering'; stakeholders like your slideware		3 Understanding of the origin of H <sub>2</sub>	Done for 2-3 sites
<b>4</b>	<b>SMALL SCALE PROTOTYPE</b> Built in a laboratory environment ("ugly" prototype)	<b>PROTOTYPE</b>	4 Small Scale prototype of permanent H <sub>2</sub> fluxes / Numerical modelling of the H <sub>2</sub> permanent seepages Global understanding of the Hydrogen system	In Progress in Academia
<b>5</b>	<b>LARGE SCALE PROTOTYPE</b> Tested in intended environment		5 Median Scale prototype (1200 m) Perennial production of a demonstrator over several years	Hydroma (Mali)
<b>6</b>	<b>PROTOTYPE SYSTEM</b> Tested in intended environment close to expected performance	<b>VALIDATION</b>	6 First deep borehole (3000 – 5000 m)	Natural hydrogen energy LLC Desert Mountain Energy
<b>7</b>	<b>DEMONSTRATION SYSTEM</b> Operating in operational environment at pre-commercial scale		7 First Exploration plan at regional scale First delineation / Several boreholes	In progress Santos (Australia)
<b>8</b>	<b>FIRST OF A KIND COMMERCIAL SYSTEM</b> All technical processes and systems to support commercial activity in ready state	<b>PRODUCTION</b>	8 Prototype of Production of the first discovery	No
<b>9</b>	<b>FULL COMMERCIAL APPLICATION</b> Technology on 'general availability' for all consumers		9 Scaling-up / Commercial exploitation	No

Technology Readiness Levels as adapted by the CloudWATCH2 project

현재 진행 중인 프로젝트는 TRL 4-7에 걸쳐 있으며, TRL 8이 가장 큰 고비일 듯

Gaucher, Eric C. et al., The place of natural hydrogen in the energy transition: A position paper. European Geologist, 55, 2023



# TRL 4: Orange H<sub>2</sub> 생성 촉진 연구개발

## University of Texas at Austin – Austin, TX

Sustainable H<sub>2</sub> Production from Abiotic Catalyst-Enhanced Stimulation of Iron-Rich Rocks - \$1,700,000

The University of Texas at Austin is investigating effective and economical catalyst-enhanced reaction mechanisms to spur geologic hydrogen production. The team will analyze reaction catalysts that exist naturally in iron-rich rock, including nickel and platinum group elements, that could increase serpentinization reaction rates and lower the required reaction temperatures. The study will evaluate the most likely regions for geologic hydrogen production in North America, including mafic basalts in the Midcontinent Rift system, which have the potential to be a large source of geologic hydrogen.

<https://arpa-e.energy.gov/technologies/exploratory-topics/geologic-hydrogen>



<https://news.utexas.edu/2024/03/04/producing-hydrogen-from-rocks-gains-steam-as-scientists-advance-new-methods/>



# 한국석유공사 국내 5곳 천연수소 탐사 시작



*Hydrogen Insight* has not been able to find evidence that naturally occurring H<sub>2</sub> has ever been discovered in South Korea.

[https://m.knoc.co.kr/sub11/sub11\\_1.jsp?page=1&num=730&mode=view&field=&text=&bid=NEWS&ses=USERSESSION&psize=12](https://m.knoc.co.kr/sub11/sub11_1.jsp?page=1&num=730&mode=view&field=&text=&bid=NEWS&ses=USERSESSION&psize=12)

# TRL 5: 프랑스 대규모 천연수소 매장지 확인

46 Mt of natural hydrogen valued at \$92B

Discovered by researchers from the GeoRessources lab and the CNRS

Located 1,250 m underground

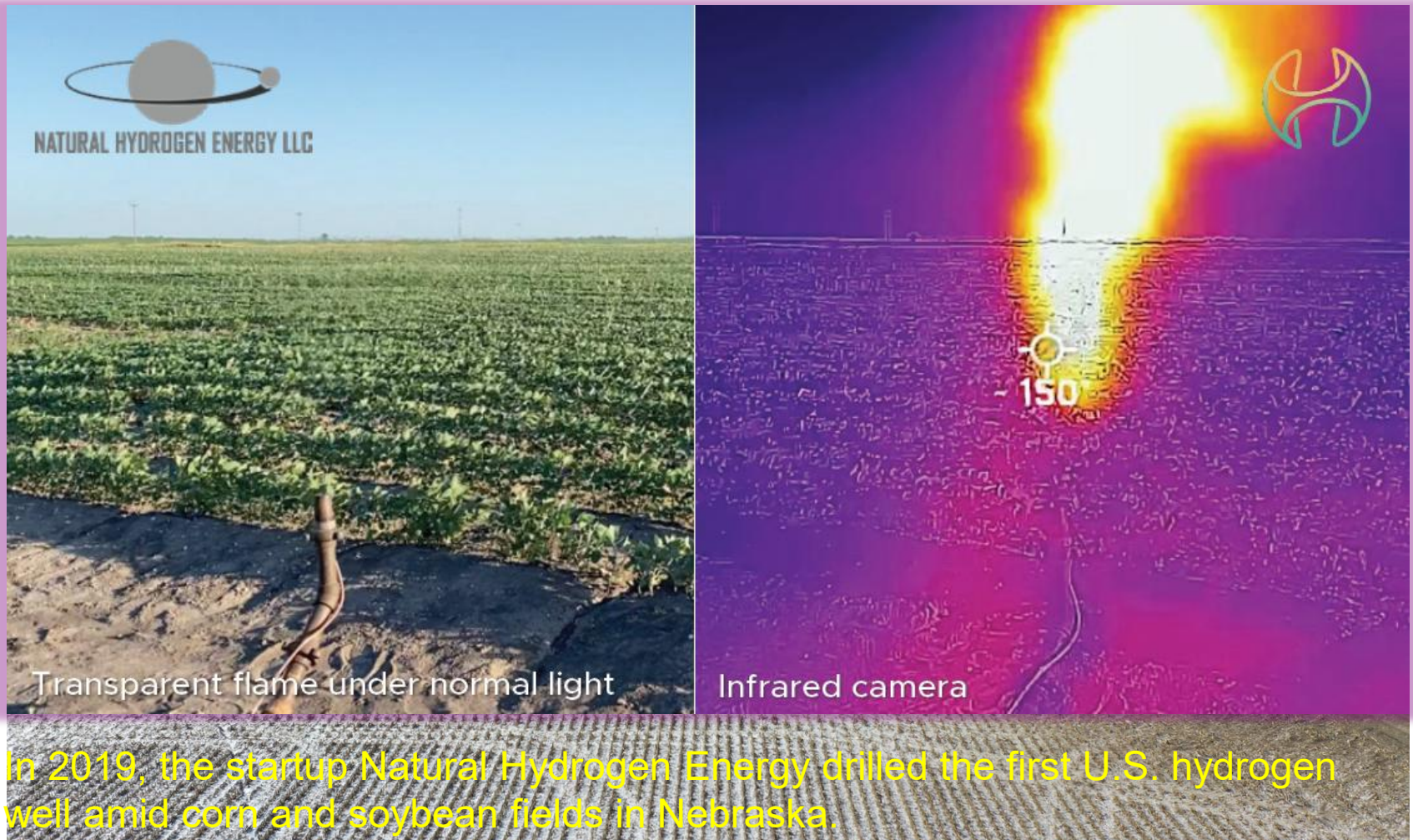


Aerial view of Folschviller in the Moselle region, France

<https://www.sustainability-times.com/energy/the-us-admits-were-jealous-of-france-unthinkable-wealth-beneath-their-feet-as-france-uncovers-92-billion-hydrogen-goldmine-the-worlds-largest-r/>



# TRL 6: 최초의 Deep Borehole Drilling



<https://www.science.org/content/article/>

hidden-hydrogen-earth-may-hold-vast-stores-renewable-carbon-free-fuel

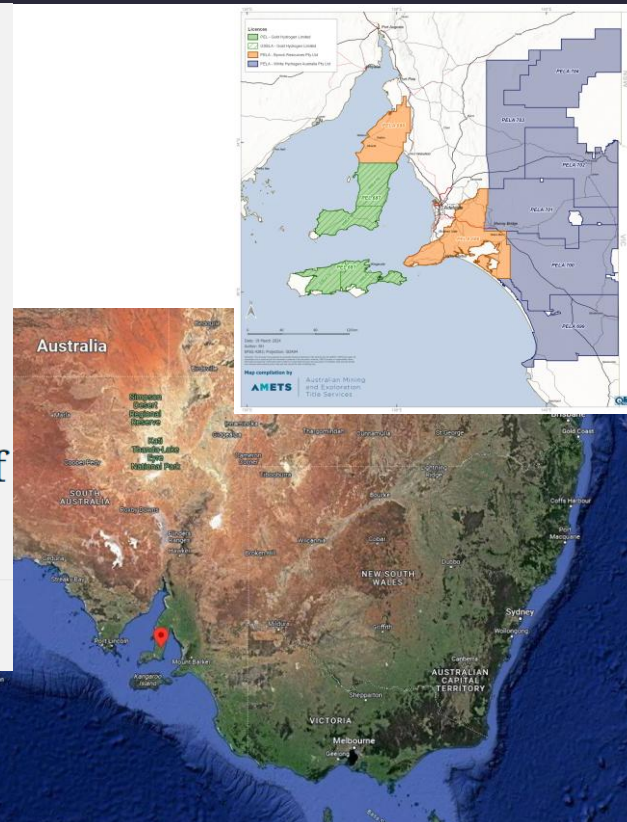
# TRL 7: Exploration Plan at Regional Scale

## 'Significant concentrations' of natural hydrogen detected at Australia's first exploration well – raising hopes of world-first commercial exploitation

Brisbane-based Gold Hydrogen confirms 'active hydrogen system' with H<sub>2</sub> concentrations of 73.3%, with discovery of helium adding to potential value of site

1 November 2023 11:56 GMT *UPDATED 1 November 2023 12:16 GMT*

By **Leigh Collins**



<https://www.hydrogeninsight.com/production/significant-concentrations-of-natural-hydrogen-detected-at-australias-first-exploration-well-raising-hopes-of-world-first-commercial-exploitation/2-1-1546424>



# 다수 Startup이 北美大陸中央裂谷帶를 탐사

BNN  
Bloomberg

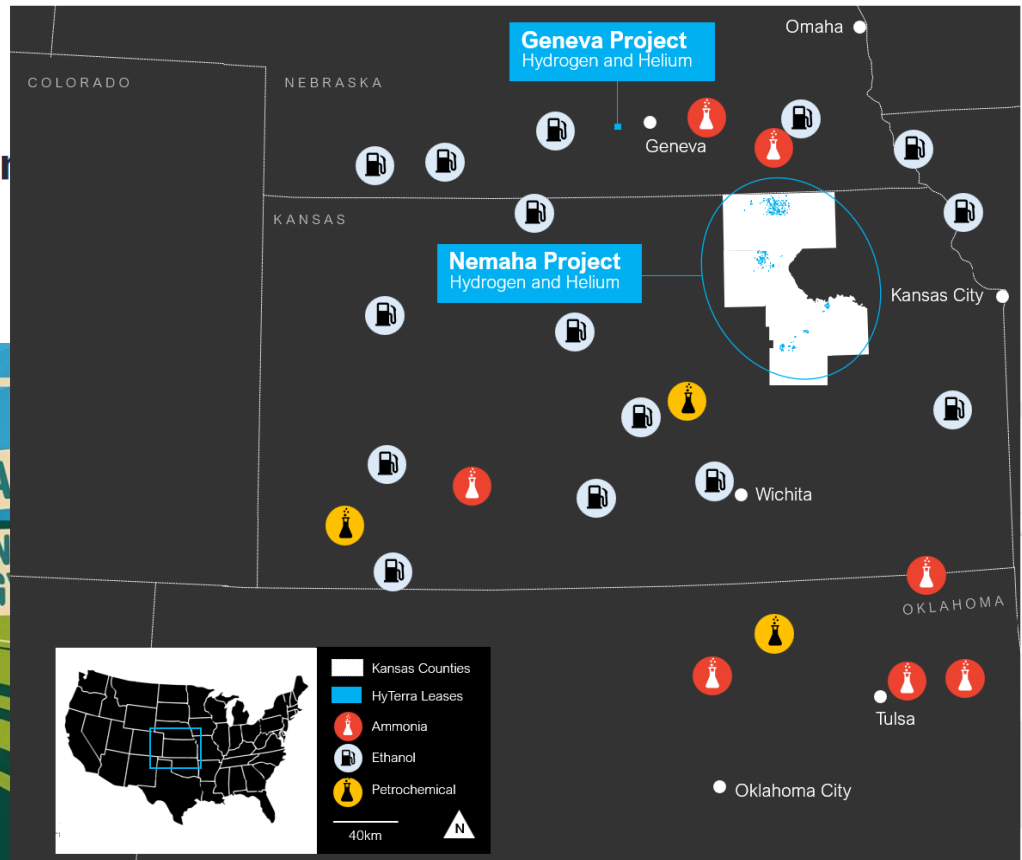
## Commodities

### Hydrogen Wildcatters Are Betting

By Michelle Ma and David R Baker

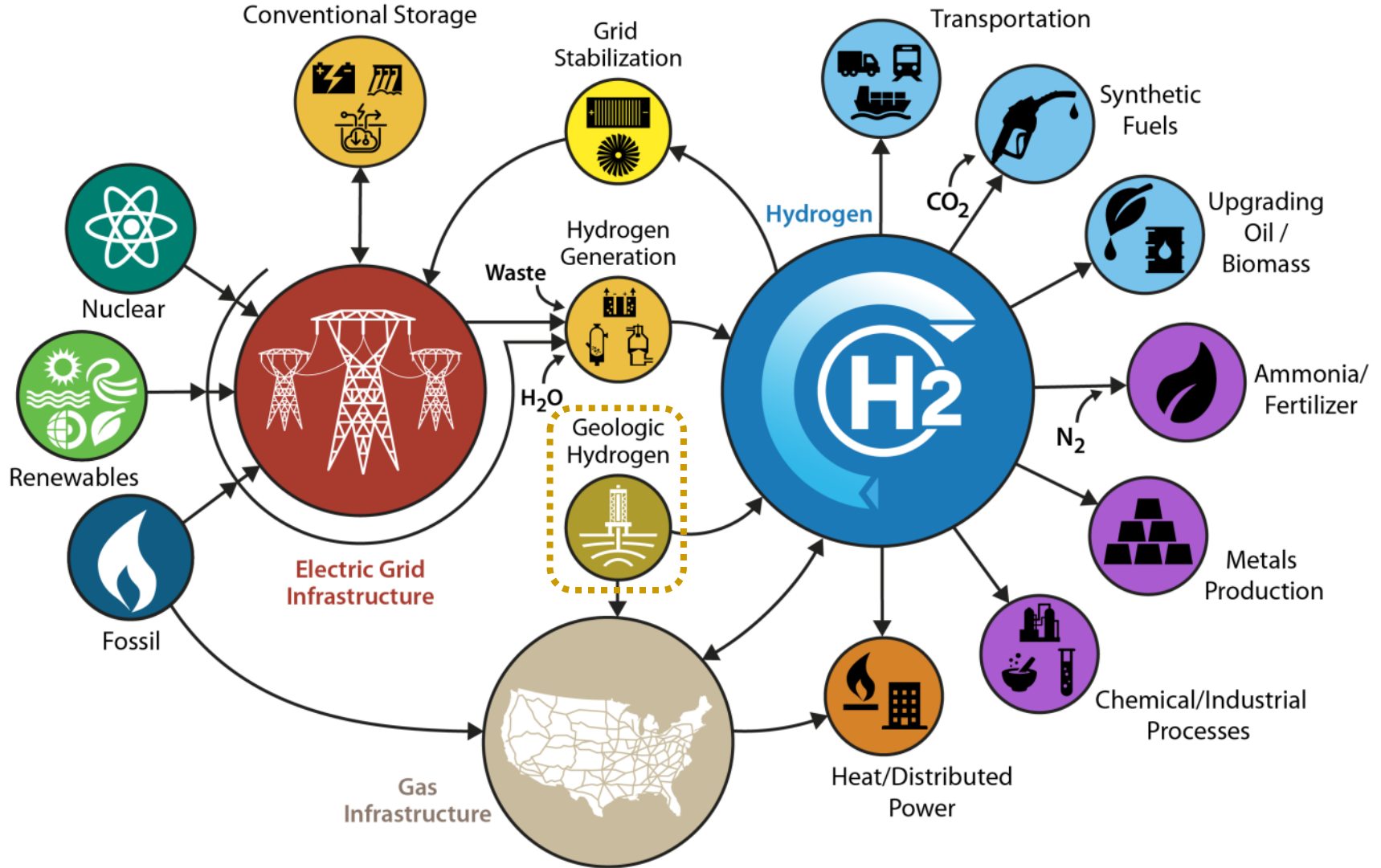
November 16, 2024 at 10:30AM EST

including Koloma, HyTerra,  
Top End Energy etc.



<https://www.bloomberg.com/news/features/2024-11-16/in-kansas-hydrogen-wildcatters-are-make-big-bets-on-striking-it-rich>

# 천연수소 포함 수소경제 구현은 가능한가?



# 이제부터 천연수소 시대의 到來에 대비해야!



“It always seems impossible until it's done.”

- Nelson Mandela  
1918-2013