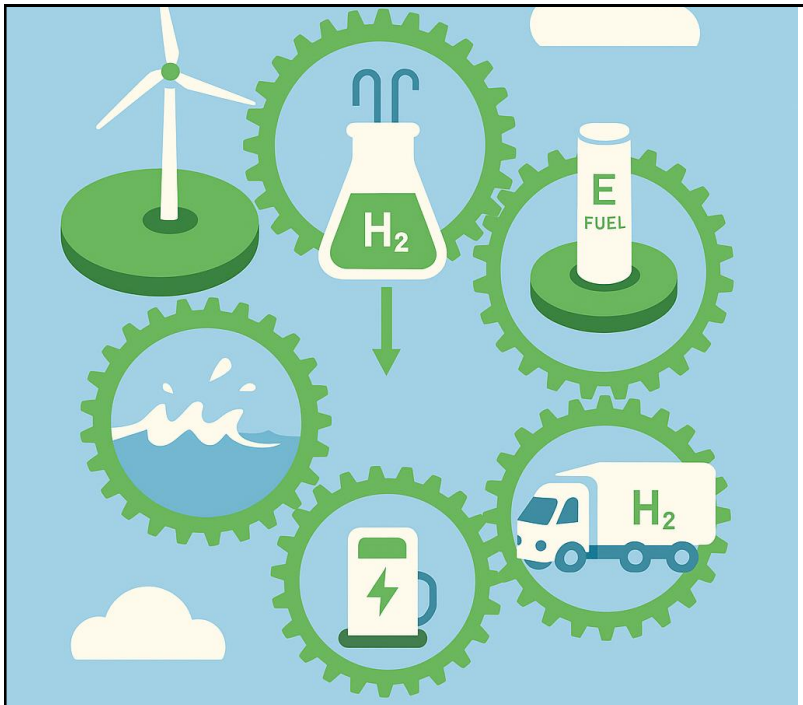

Green molecules for balancing energy systems: enhancing grid security and resilience

Prof. Sadegh Seddighi,

Balanced Energy Systems Research Center, HAN University, Netherlands

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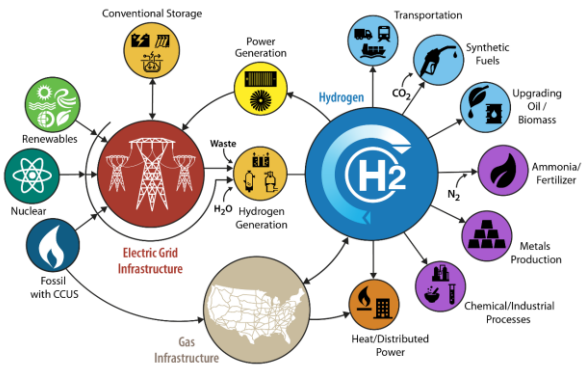
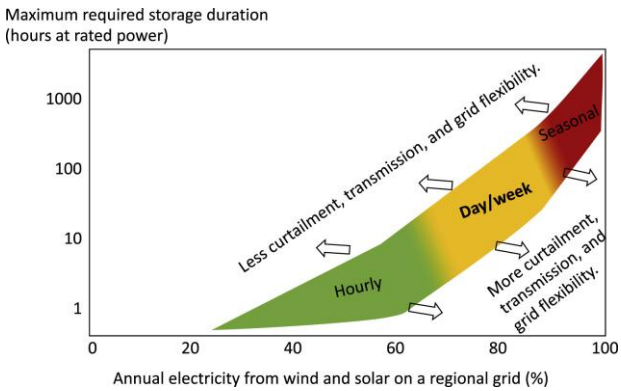
Why Hydrogen/Green Molecules Matter

- Electrification raises peaks → congestion and curtailment
- Storage duration needs grow with VRE share
- Batteries handle hours–days;
- Molecules cover weeks–seasons



Ref: DOE Report



Ref: Albertus et al, Joule, 2020

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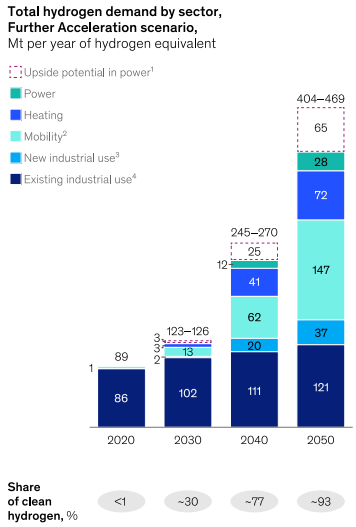
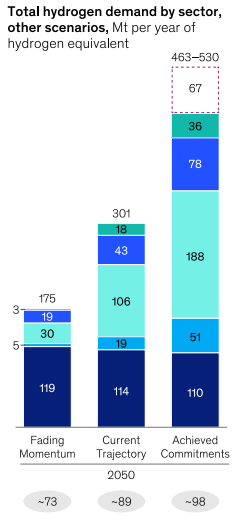
Global hydrogen momentum

Over 1,500 hydrogen projects announced worldwide, with €600+ bn investment — yet deployment still lags.





Ref: McKinsey Hydrogen Insights 2024

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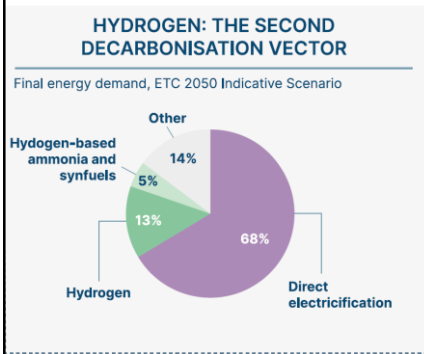
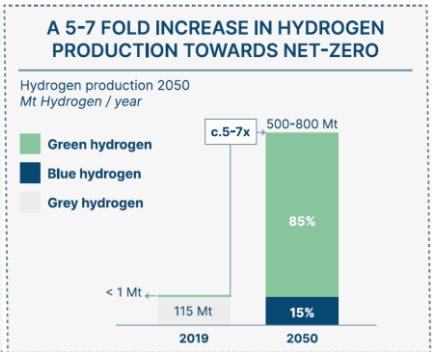
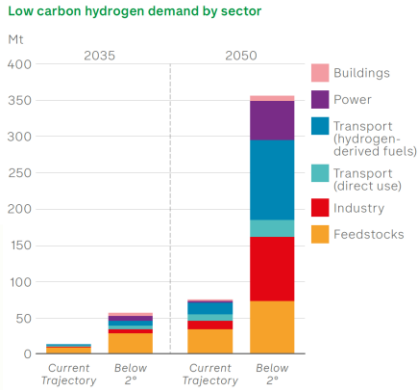
Energy transition big picture

- Hydrogen becomes the “fourth pillar” after electrification, renewables, and storage
- Growth in various scenarios (IEA, BP, McKinsey)
- By 2050: significant share of final energy







Ref: BP Energy Outlook: 2025 edition

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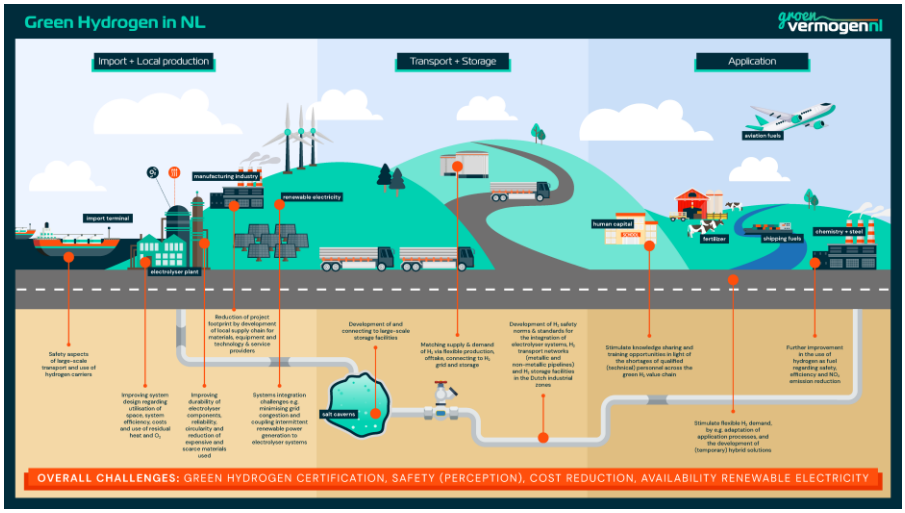
NL practical pathway I: Connectr , GVNL

- Connectr and Electricity Campus: real-world hydrogen pilots
- Universities involved in applied science and training
- GVNL → €838 m national hydrogen programme



Ref: GVNL

5

Energy Business park example: Electricity Campus, Netherlands

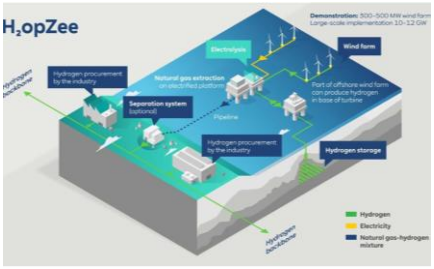
- Former KEMA site transformed into a national energy innovation campus
- 17 ha testbed with HV/MV labs, storage pilots, certification, and R&D partners

6

Flagship projects (NL/EU)

From backbone pipelines to offshore pilots and solar hubs, the Netherlands is building hydrogen at scale: PosHYdon offshore, H_2Hollandia onshore, and a national H_2 grid.

NL hydrogen pipeline

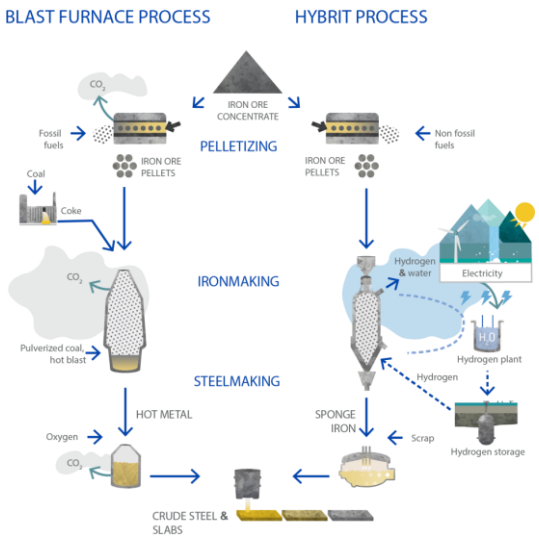


PosHYdon (offshore demo)

H2Hollandia (solar-to-hydrogen)

Use case: Industrial decarbonisation

- Steel, fertilizers, chemicals need high-T fuels
- Hydrogen/e-fuels displace natural gas



Hybrit Project, Sweden

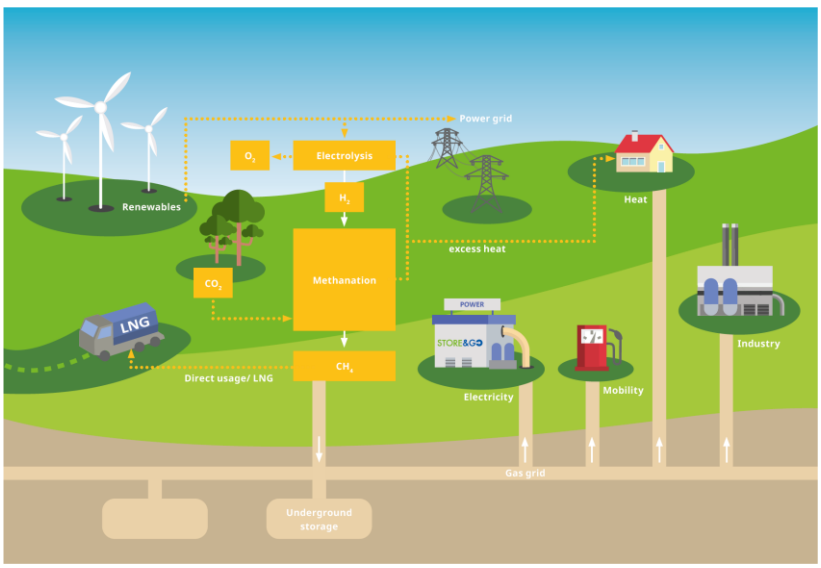
Use case: Flexible power / grid balancing

- Battolyser concept (battery + electrolyser in one unit)
- Turns off-peak electricity into hydrogen
- Relief for congested grids

Battolyser Systems

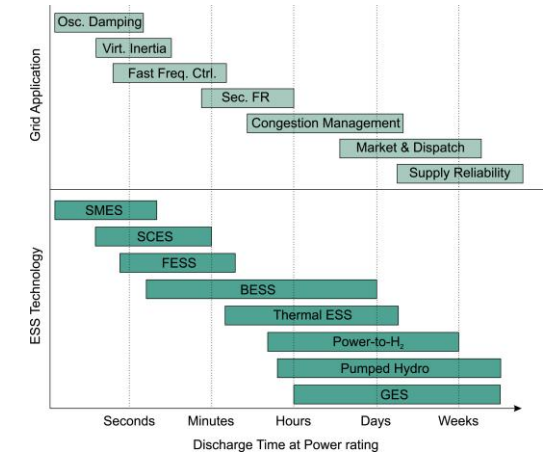
EU pathway: Power-to-Gas

- Electrolysis + CO_2 → e-fuels (methanol, ethylene, CH_4) for storage, transport, chemicals.

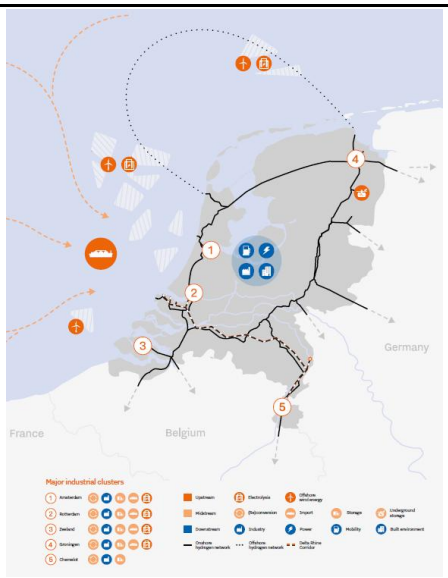


Energy Security

- Diversifies energy sources → less import dependency
- Seasonal storage in caverns = resilience
- NL/Nordics: corridors ensure redundancy
- Strategic energy autonomy



Ref: De Carne et al, Electric Power Systems Research, 2024

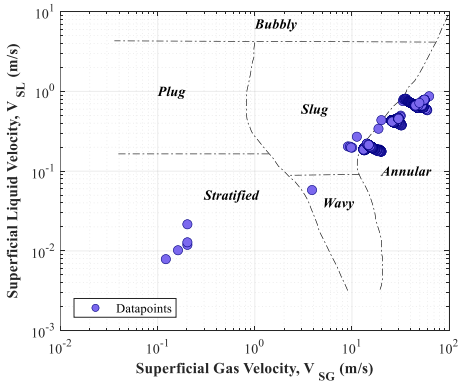


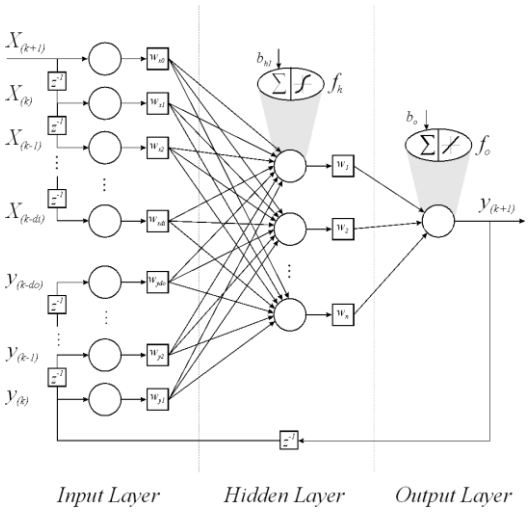
Netherlands hydrogen transmission network
Ref: Netherlands Enterprise Agency (RVO), Excelling in Hydrogen

11

Advanced digital methods

- Advanced digital methods increase production and flexibility.
- **Physics-based** AI critical for industrial use.



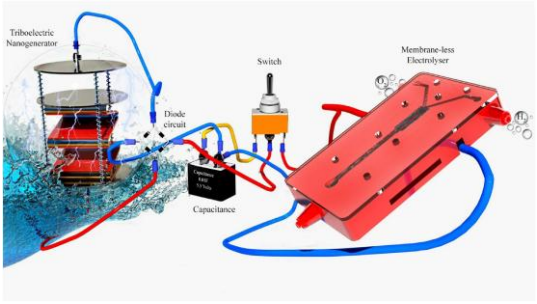


Ref: Manami, Seddighi, Örlü, Measurement Journal, 2023

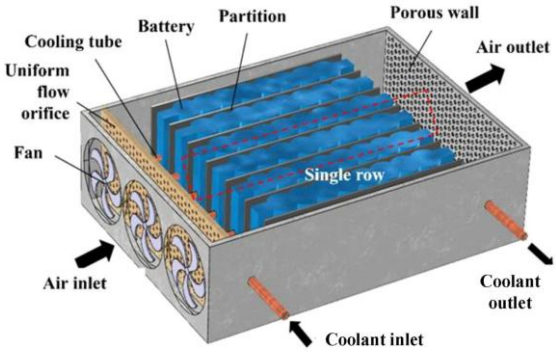
12

Technical challenges: Materials, Intermittency and Thermal Management

- Materials remain costly and fragile.
- Integration across scales is immature.
- Heat management and intermittency limit scaling.



Ref: Elahi and Seddighi, Journal of Power Sources, 2024

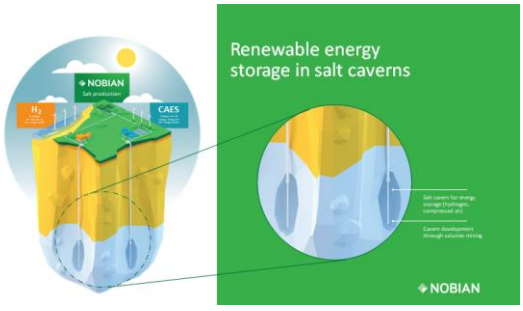


Schematic of the composite battery thermal management system

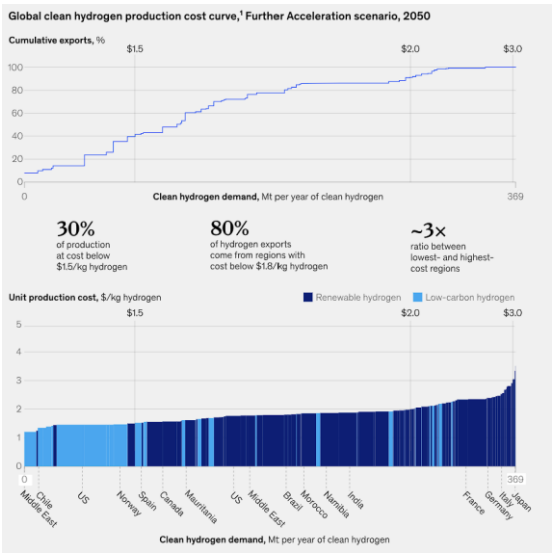
Ref: Zhao et al, Applied Thermal Engineering, 2023

Market interface

- Hydrogen economy spans diverse strategies
- Nobian: green chemicals route
- Major players: energy majors, utilities, logistics
- Storage (salt caverns) underpins all business models



Large-scale hydrogen storage in salt caverns
Ref: Nobian



Ref: Global Energy Perspective 2023: Hydrogen outlook

Concluding remarks

Policy:

- Create enabling regulation for H_2 infrastructure.
- Fund cross-border hydrogen corridors.

Industry:

- Commit to scaling projects (industry, transport, shipping).
- Invest in digital twins & flexible demand.

Academia:

- Develop circular materials & advanced electrochemical systems.
- Train next generation engineers (Human Capital Agenda).