



Hydrogen Europe
Research

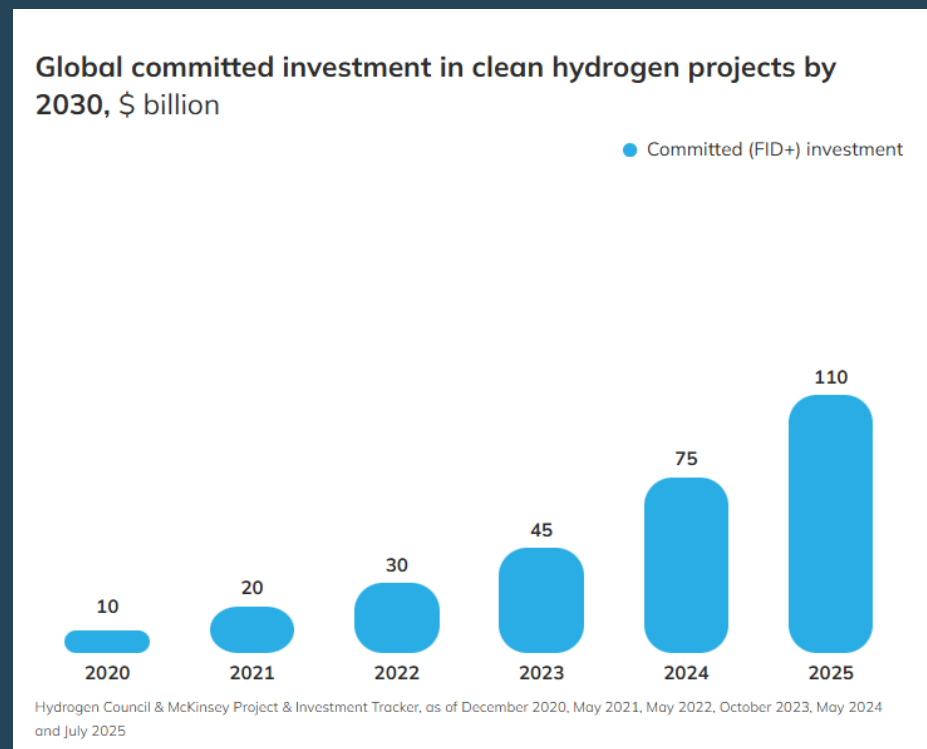
Advancing Hydrogen Technologies – 2025 Extended Edition

KEY RESEARCH AND INNOVATION PRIORITIES

The European Hydrogen Momentum

- Europe has become the global testing ground for the hydrogen economy
- Over **1,400 global projects**; **> 500 B€** investment pipeline (Hydrogen Council, 2025)
- Clean Hydrogen Partnership: **> 400 projects**, **€2.8 B EU contribution**, **> 50%** industry co-funding
- Yet, *implementation and innovation* must advance hand-in-hand

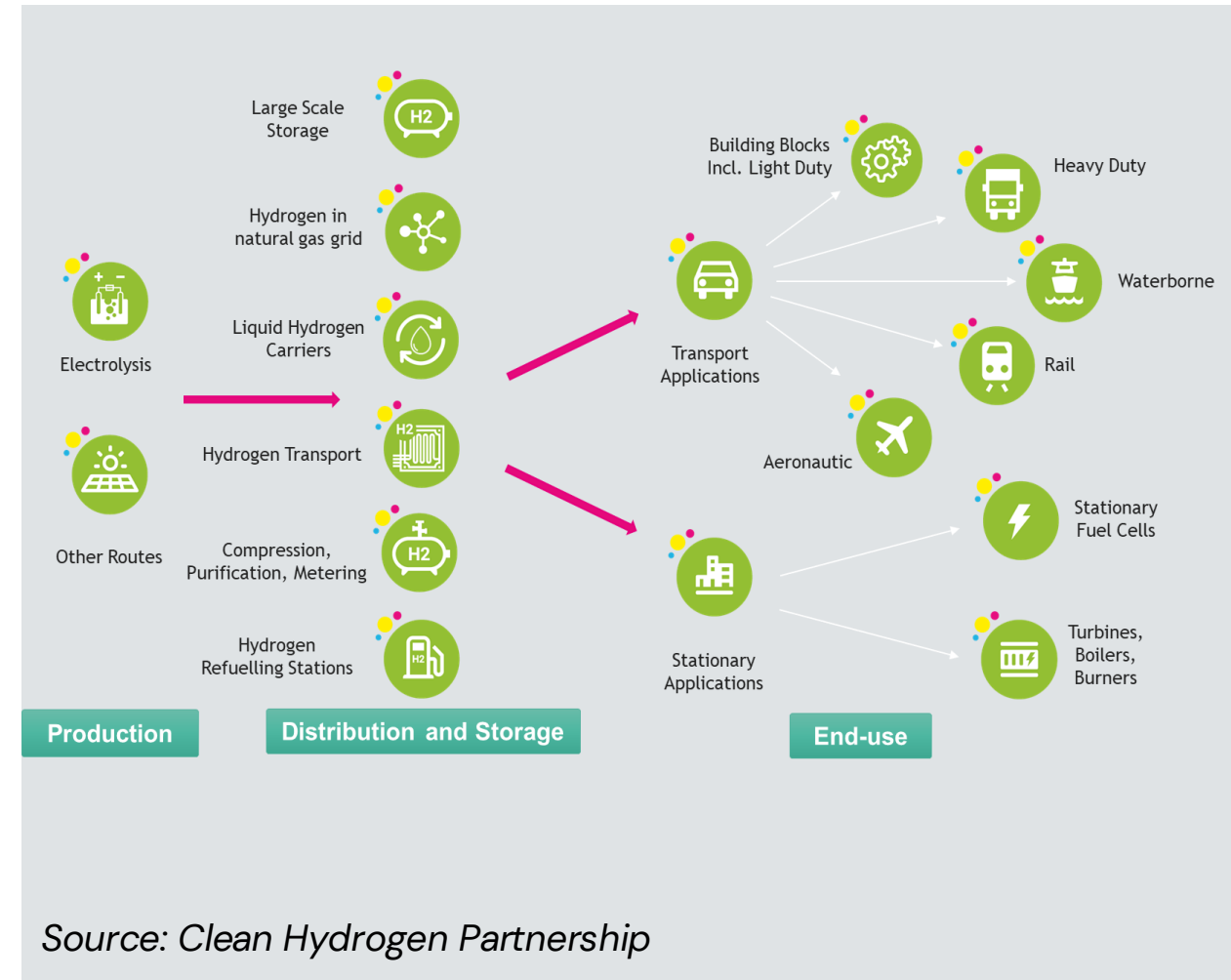
From targets to transformation: the role of R&I is decisive



Source: Hydrogen Council 2025

The Hydrogen Economy: From Strategy to System

- Hydrogen is no longer a single-vector solution, but a **cross-sectoral system**:
 - Production ↔ Infrastructure ↔ End Uses
↔ Skills ↔ Society
- It bridges **energy security, industrial competitiveness, and climate neutrality**
- Research drives **coherence and integration** across these pillars and the sectors



WHAT IS MISSING / NEEDED?

- Research
- Innovation
- Start ups
- First industrial Development

Technology Competitiveness

Industrial Scaling Up

- Investments
- Public support for funding gap
- Industrial policies
- Early markets development

- Full technology readiness
- Incentives
- Bancability
- Infrastructures (e.g., HRS)

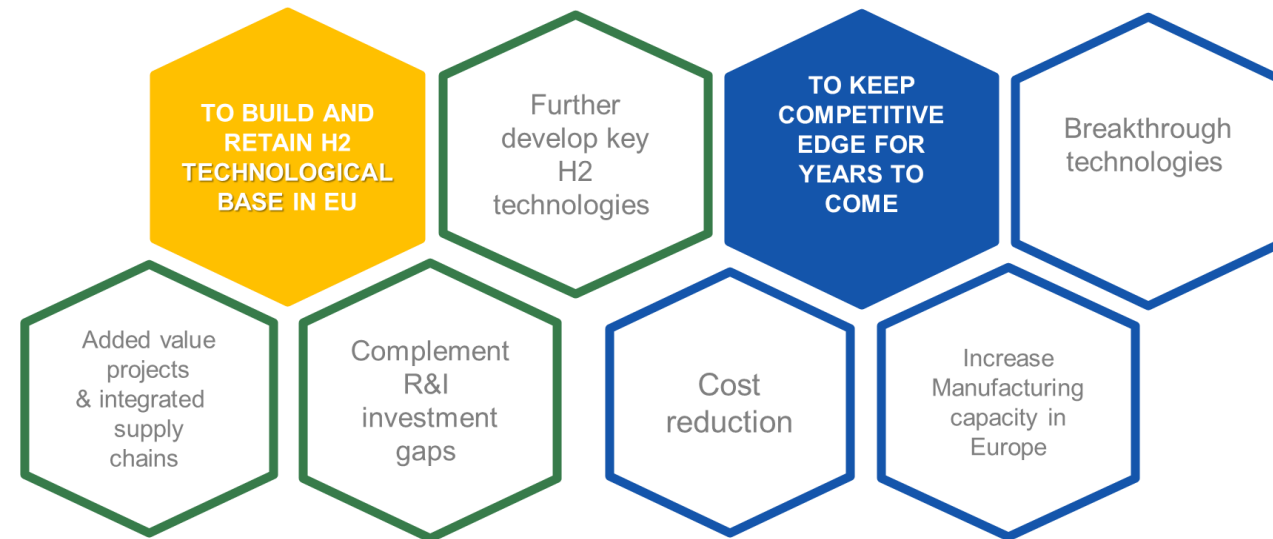
Economic Viability

Market Activation

- Standardization
- Policies and Regulatory framework
- Hydrogen Valleys and Regional Ecosystems
- Stimulate demand & Long term contracts

The Next Frontier: From R&D to Deployment

- We are entering the “**industrial demonstration decade**”
- The challenge: bridge the gap between **innovation and investment, research and scaling up**
- Keeping the support for **Fundamental Research**
- Requires a new **Clean Hydrogen Partnership 2.0**:
 - **Deal with** large-scale pilots, supporting industrial scaling up
 - **multi-level governance** (EU–MS–Regions)
 - **Developing early markets: Hydrogen Valleys 2.0** as test-beds and innovation accelerators
 - **Retain value in the EU** for a Competitive Europe



Role of Research in developing the Hydrogen Value Chain

Long-term vision – sectors like hydrogen or next-generation batteries take decades to mature, but today’s research lays the foundation

Building the value chain – it’s not just about the product, but also the entire infrastructure (production, logistics, standards, regulation).

MARKET

HYDROGEN VALUE CHAIN

RESEARCH

Green transition – these sectors are enablers of decarbonization and sustainability.

Strategic competitiveness – countries investing now will lead when the market takes off.

Risk reduction – research anticipates technological bottlenecks and lowers future costs.



“HER Position Paper for Hydrogen Research”

Published in November 2024

A new, more in-depth paper on
Research Priorities
will be published by the end of 2025

*Hydrogen Europe Research is starting a
collaboration with **Mission Innovation** on the
identification of Global Research Goals*

Advancing Hydrogen Technologies

Key Research and Innovation Priorities



Hydrogen Production



Electrolysis: novel catalysts, PFAS-free membranes, explore hybrid & depolarized electrolysis routes



Alternative pathways: photocatalytic, thermochemical, and biomass-based routes for long-term diversification

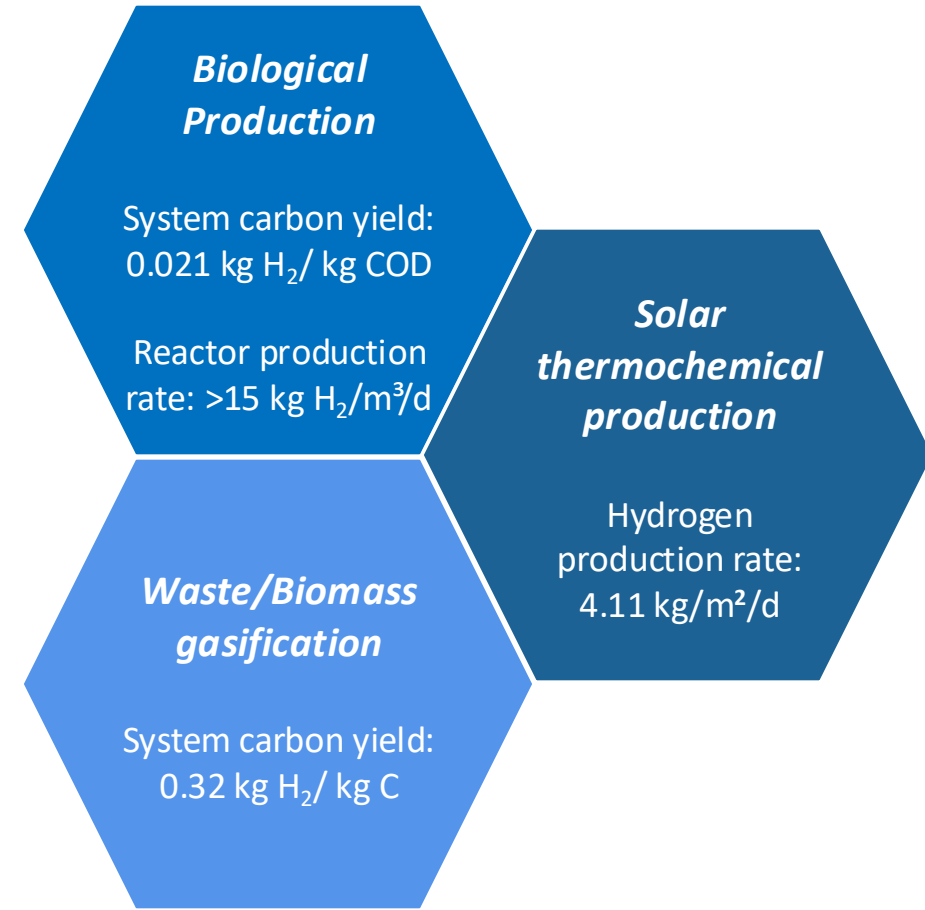


Reversible & co-electrolysis: bidirectional operation, production of synthetic fuels



Geological hydrogen: exploration & understanding biological processes

Main Clean Hydrogen JU KPI targets for the next 5 years



Hydrogen Storage, Transport, and Distribution



Solid-state storage: novel hydrides, high-entropy alloys, MOFs with improved kinetics



Underground storage: salt caverns, depleted fields, cushion gas optimization



Pipelines: Retrofitting, polymer-based transport



Hydrogen carriers: green ammonia, LOHCs, synthetic fuels



Compressed & liquid H₂ storage: new materials, safety, embrittlement studies

Main Clean Hydrogen JU KPI targets for the next 10 years

Hydrogen carriers

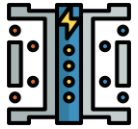
Ammonia
Dehydrogenation
efficiency:
0.83 kg H₂ produced/
kg H₂ input

6.8 kg NH₃ input /
kg H₂ produced

Hydrogen liquefaction

H₂ liquefaction
energy intensity:
7 kWh/kg

Hydrogen Applications - *Transport*



Fuel Cells: Next-gen concepts, hybrid, novel cooling, passive-feed designs



Aviation: Storage & cooling technologies for in-flight use, minimise boil-off/evaporation, develop compact, energy-dense fuel cells



Maritime Transport: Safe hydrogen storage, hydrogen leak detection, containment systems, emergency response protocols, standardised safety and regulatory frameworks for shipping

Fuel Cell Building Blocks

FC module availability: 99%

FC stack durability: 30,000h

Fuel Cells for planes

FC module durability: 45,000h

FC system efficiency: 62%

Main Clean Hydrogen JU KPI targets for the next 10 years

PEM Fuel Cells for Ships

Hydrogen bunkering rate: 10-ton H₂ /h

Maritime FCS lifetime: 120'000h

SOFC KPIs for ships

H₂ derived fuel bunkering rate: 100 ton H₂ /h equivalent

Hydrogen Applications - *Industry & energy*



Metal production: hydrogen plasma, water vapour content and its effect on system performance



Combustion: flame stabilisation mechanisms, limited accuracy of kinetic models, insufficient studies on shock waves, explosion dynamics and backflash risks



Ceramics production: kiln & burner adjustments, metal depletion, acidification, foam formation in melt



Energy Systems: Flexible combined heat & power (CHP) units, hydrogen turbines and hybrid systems, integration of hydrogen into power-to-gas infrastructures

Main Clean Hydrogen JU KPI targets for the next 10 years

Turbines (DLE combustion)

Minimum ramp rate:
25 % load / min

Max. efficiency
reduction in H2
operation: 1@100%
H2/ % points

Transversal Activities



Sustainability: replacement of PFAS, recycling, development of life cycle inventories



Sustainable manufacturing: additive manufacturing, reduced CRMs



AI Applications: Develop routes for accelerated implementation with diagnostic, prognostic and control tools



Modelling tools: Modelling and characterisation of materials behaviour, developing more comprehensive models and scenario analysis tools



Education & training: modular programs, workforce upskilling



Research and Technology Infrastructures: technology-type-focused infrastructure planning, improved digitalisation and AI-driven tools

Main Clean Hydrogen JU KPI targets for the next 5 years

Recycling

Number of eco-design guidelines developed for hydrogen and/or fuel cell technologies: 10

Replacement of PFAS materials (e.g. in membrane) in PEM-based stacks: TRL 6

Education and Public Awareness

Trained pupils in primary and secondary education: 15,000

Trained professionals: 100,000

Research Targets (2030–2035)

Ceramic membranes – structural stability

- Multi-layer sintering without defects – control of nano/micro/macro porosity
- Multi-phase composites & high-entropy oxides
- **Use of AI and multi-scale modelling for materials / process design**
- Validation for cyclic operation under high temperature & mechanical stress

Objective: **+40% durability / –30% cost reduction**

Polymer-based transport components

- European qualification standards for polymeric materials under high pressure.
- Predictive models for lifetime vs. permeation & decompression damage.
- Need for a European performance database of certified materials.

Objective: **Standardised qualification for H₂ pipelines at TRL 7**

Position Paper



Challenges in Manufacturing

Structurally Stable
Ceramic Membranes

Diletta Giurini
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Maja Rücker



November 2025

Position Paper



Compatibility of polymer-based materials

for the hydrogen
transport infrastructure

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Priority Research Areas – Complementary to Electrolysis

Depolarized Electrolysis (SO₂ / N-based routes)

- Voltage target < **1.0 V @ 500 mA/cm²** with >50% H₂SO₄ concentration
- Dedicated stack design for SDE / nitrogen electrolysis → **never realised yet**

Biomass & thermochemical cycles

- Two-stage anaerobic digestion routes for H₂ production
- Pressurized pyrolysis → **local/decentralised production**
- Co-production of chemicals → OPEX reduction

Objective: Requires **feedstock screening + integrated LCA models**.

Position Paper



Alternative hydrogen production processes

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Andrea Fasolini



RCS – Regulations, Codes & Standards

IGF Code for maritime — hydrogen adaptation

- Complex ventilation strategies needed.
- Below-deck integration & enclosure safety.
- Jet fires & bunkering protocols → **requires CFD simulation + physical testing.**

Self-venting composite tanks (TPRD-less)

- μ LNB concept validated → **non-explosive under any fire scenario.**

Target: TRL 4–6 (Type IV) → scale-up to TRL 7 industrial

Requires: permeability control + industrial guidelines

Position Paper



Development of IGF Code for hydrogen

Providing comprehensive scientifically based safety recommendations for maritime applications

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Vladimir Malinov
Dmitry Malinov
Viviana Cignolatti
Giovanni Di Iorio



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Position Paper



Explosion free in any fire self-venting (TPRD-less) composite tanks:

fundamentals and manufacturing guidance

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Dmitry Malinov
Luca Annaloni



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ADVANCED MANUFACTURING

Non-Conventional Manufacturing Routes

(additive manufacturing, roll-to-roll, hybrid processes)

- Material waste reduction >30%
- Digitalisation of supply chain enabled by AI
- Real-time quality control via automated data-driven systems

Policy intervention required – incentives & ESG compliance tools

Research & Technology Infrastructures (RTIs)

Need to transition from lab → **mid-scale piloting**

Multi-level model:

1. Standardised components →
2. Custom systems →
3. Industrial demonstrators

RTIs recognised as Europe's fifth freedom as the free movement of knowledge, data, researchers and research infrastructures across Europe – enabling research to become a true strategic capability

Policy Perspective



Non-Conventional and Advanced Sustainable Manufacturing Technologies for Fuel and Electrolytic Cells

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Marcello Romagnoli
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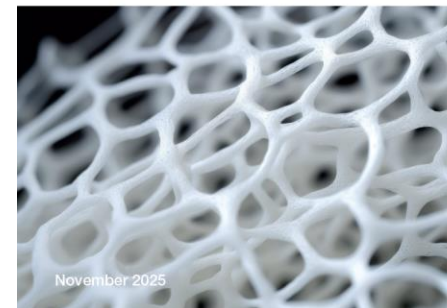


Position Paper



From Detection to Substitution: Scientific Challenges of PFAS in Hydrogen Technologies

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Research and Technology Infrastructures

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Low-pressure H_2 storage

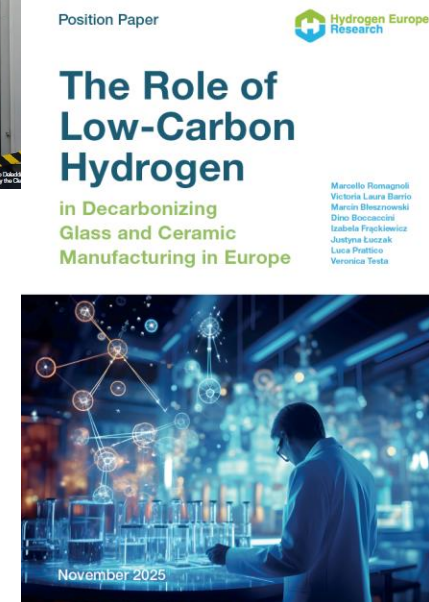
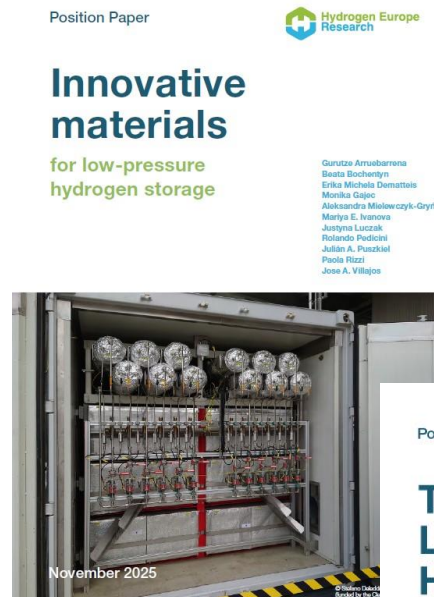
- Metal hydrides / High Entropy Alloys / MOFs
→ densities up to **150 kg/m³**.
- Key issues: thermal management, scale-up, recycling.
- Lifecycle assessment & circularity are mandatory.

Glass and ceramics industries

- Early industrial trials already ongoing → **H_2 as fuel in industrial furnaces.**

Key challenges: product quality & safety

Opportunity: brand positioning & green premium



Research is not the beginning of the chain Research is the foundation of the entire chain

Hydrogen will grow only through **integration**:
research links technologies, sectors, policies and people

Europe is entering the **industrial demonstration decade** —
but **demonstration without research becomes imitation**.

If Europe wants leadership, it must **protect research** as its strategic
asset.

Today's research = tomorrow's hydrogen system

THANK YOU!



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