CLEAN HYDROGEN MISSION

R&I Workshop: Opportunities, Challenges and Way Ahead

04.08.22

Agenda

CLEAN HYDROGEN MISSION

- Welcome and Introduction of the Clean Hydrogen Mission : Madhu Madhavi, BEIS, UK
- Cost Reduction Potential for clean hydrogen – an overview from IRENA : **Herib Blanco**, IRENA
- Analysis of main challenges for rapid H2 deployment : **Paul Lucchese**, Hydrogen Technology Collaboration Programme
- A global overview of Hydrogen RD&D : **Dan O'Sullivan and Vicky Au**, CSIRO, Australia
- Global industry perspective : **Daria Nochevnik** , Hydrogen Council
- Hydrogen Testing and Production Blueprint: Gap Analysis and Next steps : **Robert Sorrell**, Henry Royce Institute, UK
- Discussions & Launch of Working Groups.

The Clean Hydrogen Mission

Overview

- The Challenge: Clean hydrogen has the potential to decarbonise hard to abate sectors, such as industry and heat, which are responsible for two thirds of global emissions and help unlock the full potential of renewable energy. However, today it is up to three times more expensive than hydrogen produced directly from fossil fuels.
- The Goal: to increase the cost-competitiveness of clean hydrogen by reducing end-to-end costs to USD 2 per kilogram by 2030
- The Mission: We will catalyse cost reductions by increasing research and development in hydrogen technologies and industrial processes and delivering at least 100 hydrogen valleys covering production, storage and end-use worldwide by 2030, to unleash a global hydrogen economy.

International Partners:

- IPHE,
- Clean Energy Ministerial (Hydrogen Initiative),
- UNFCCC (Green Hydrogen Catapult),
- World Bank Group (Energy Sector Management Assistance Program),
- World Economic Forum (Accelerating Clean Hydrogen Initiative),
- Hydrogen TCP (Technology Cooperation Programme)

Co-leads

Australia
Chile
European Union
United States
United Kingdom

Members

Germany
Saudi Arabia
Austria
Canada
China
France
India
Italy
Japan
Morocco
Norway
Republic of Korea
United Arab Emirates
Finland
Netherlands

CLEAN HYDROGEN MISSION

Mission Pillars

- **To achieve its goal, the Mission is working through a three-pillar structure.**
- **The Mission will be aligned and coordinated with other R&I programmes, private sector, and international organisations.**
- **The Mission, with its members, will focus on specific actions to foster innovation and develop strategies to achieve its overarching goals.**

Clean hydrogen 2 USD/kg

Research and innovation

Focus on innovation in technologies and industrial processes that unlock cost reductions

Support to the Demonstration pillar

Demonstration (incl. Hydrogen Valleys*)

Large scale demonstration projects

Systemic approach covering hydrogen production, storage, transportation and end use

Enabling environment

Cooperation with other initiatives to identify and overcome deployment barriers, e.g. standards, regulations, demand-pull

*A Hydrogen Valley is a geographical area (a city, a region, an island or an industrial cluster) where several hydrogen applications are combined together into an integrated hydrogen ecosystem that consumes a significant amount of hydrogen, improving the economics behind the project. Hydrogen valleys are referred to as hydrogen hubs in some countries. The Mission will include international, national, regional, local and sectoral hydrogen valleys.

MI CLEAN HYDROGEN MISSION

Clean Hydrogen Mission Blueprint

Set a global goal

▶ Identify tipping point

- Analyse what will shift topic from RD&D to deployment

▶ Convene high-ambition coalition with commitments

- Identify key governments critical to achieve mission
- Identify key partners (e.g. private sector, IEA, etc)
- **Mission Pact:** Agree commitments to demonstrate ambition and 'skin in the game'

▶ Put in place Mission Team

Ensure Director and sufficient support in place

▶ Strong narrative & comms

Discussion Paper

▶ Publish a Discussion Paper

- Map existing initiatives and national activities (e.g. pilot, demo projects)
- Assess and prioritize critical innovation gaps
- Identify what enhanced domestic and/or international effort is required
- Identify policy, finance & demand prerequisites to support goal

Mission Action Plan

▶ Agree milestones and sprints to deliver mission.

- Agree what additional efforts the mission will deliver:
- Early-stage RD&D
- Prizes / challenges
- Demonstration projects

- Further analysis and set theory of change

- Investment levels needed

Demand-pull actions required (to be delivered in partnership with others): Procurement, Policies

▶ Agree on relevant KPIs

- Identify key metrics to track progress towards the mission goal

Implementation

▶ Build partnerships to deliver actions

- Collaborative R&D
- Blueprint for zero-carbon value chain demos

- Roundtables, working groups to develop proposals

- Deliver through existing frameworks

- Knowledge sharing

- Partnership with demand-pull initiative

▶ Mission 'sprints'

Review & Momentum

▶ Monitor progress against KPIs

- Monitor commitments
- Monitor global progress towards goal
- Integrate metrics into existing reporting

▶ Maintain momentum

- Events
- New commitments
- New participants
- New projects

Launch Mission → Publish report → Roundtable to agree Action Plan & announce specific commitments to develop activities → Ongoing work programme → Annual Ministerial Roundtables to review progress and agree new actions and activities

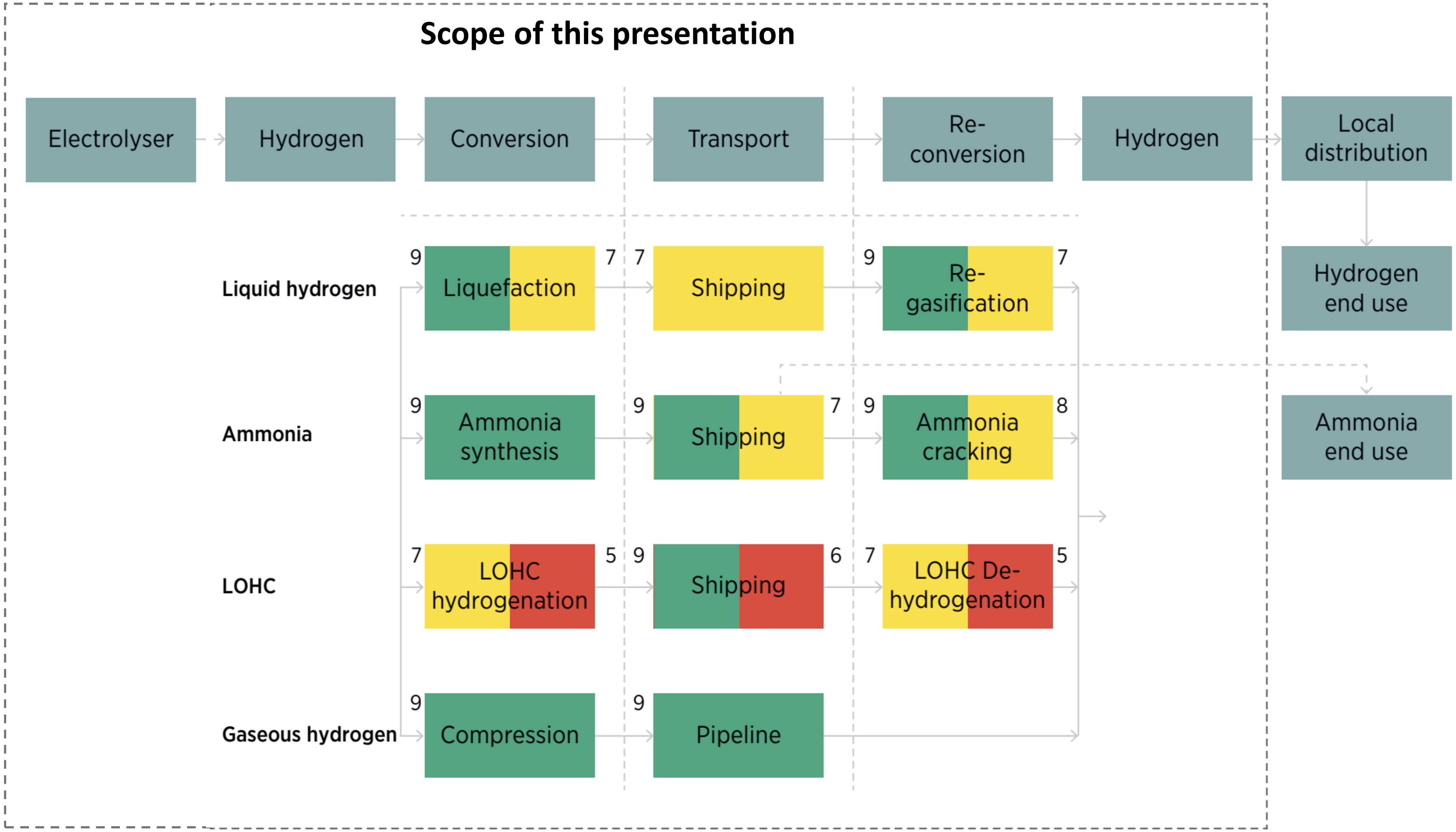
IRENA
International Renewable Energy Agency

Cost reduction potential and research gaps

Herib Blanco
IRENA Innovation and Technology Center

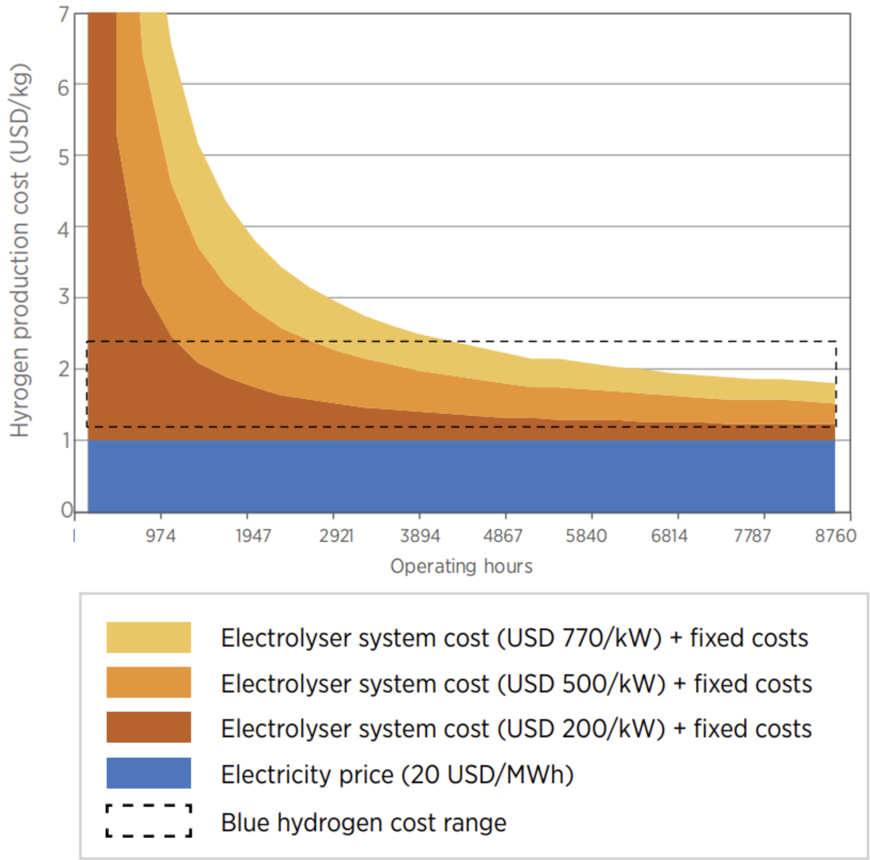
4 August 2022

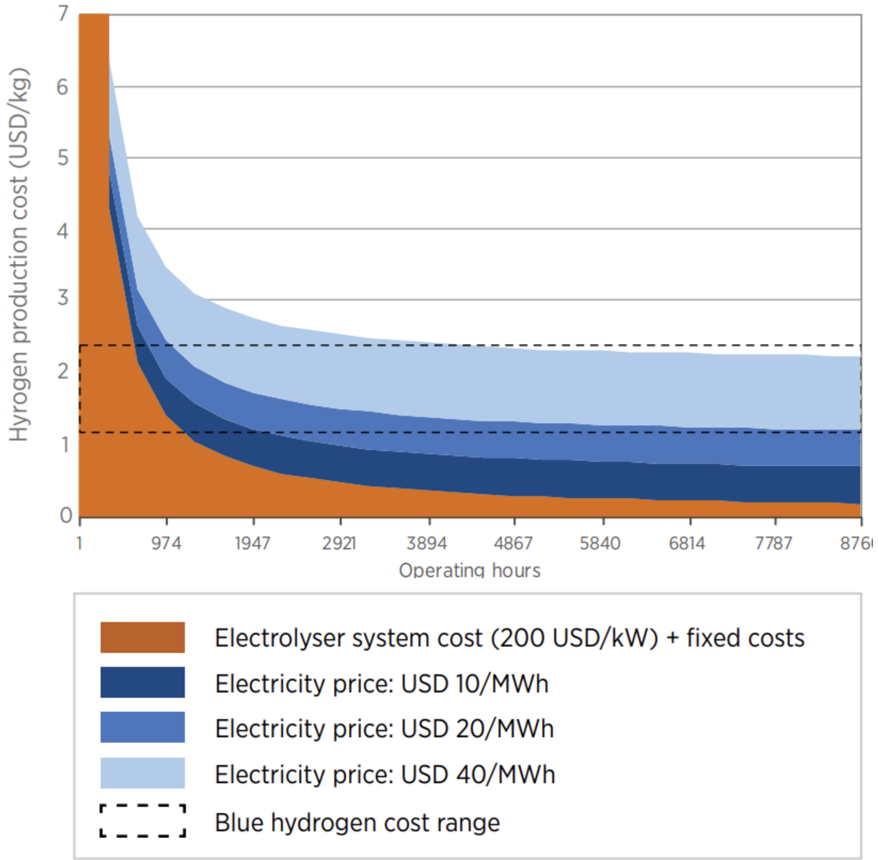
Scope of the presentation is on renewable hydrogen production and long-distance transport



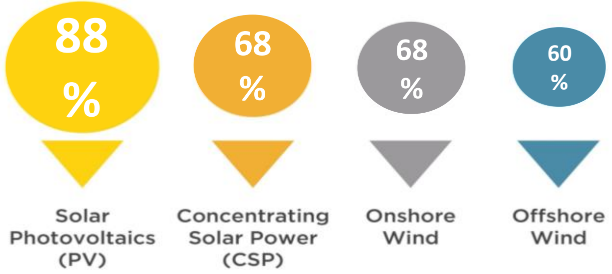
https://www.irena.org/publications/2022/Apr/Global-hydrogen-trade-Part-II

Production cost is driven by electricity cost which is already on a sustained decreasing trend





Electricity cost 2010-2021



https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction
https://irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021

Electrolyzer cost is more than the stack and it has decreased by over 90% since 2005

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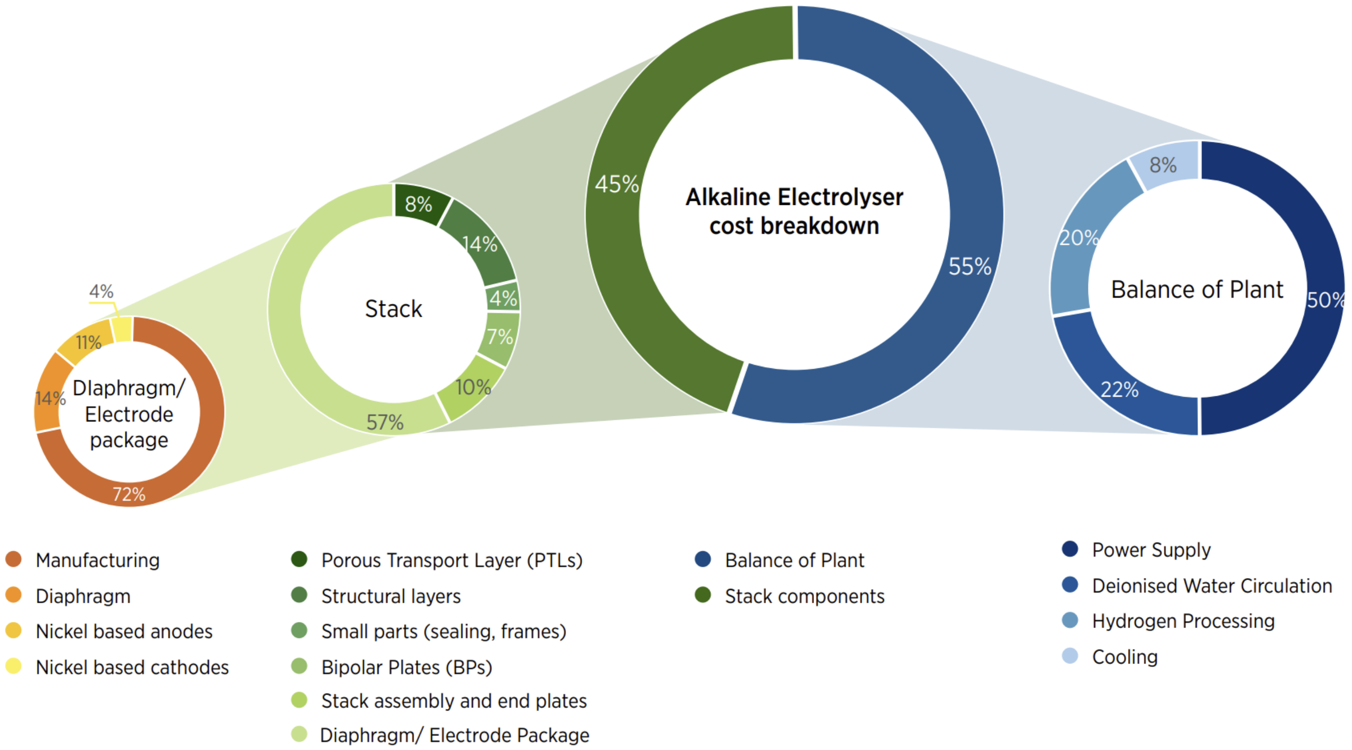

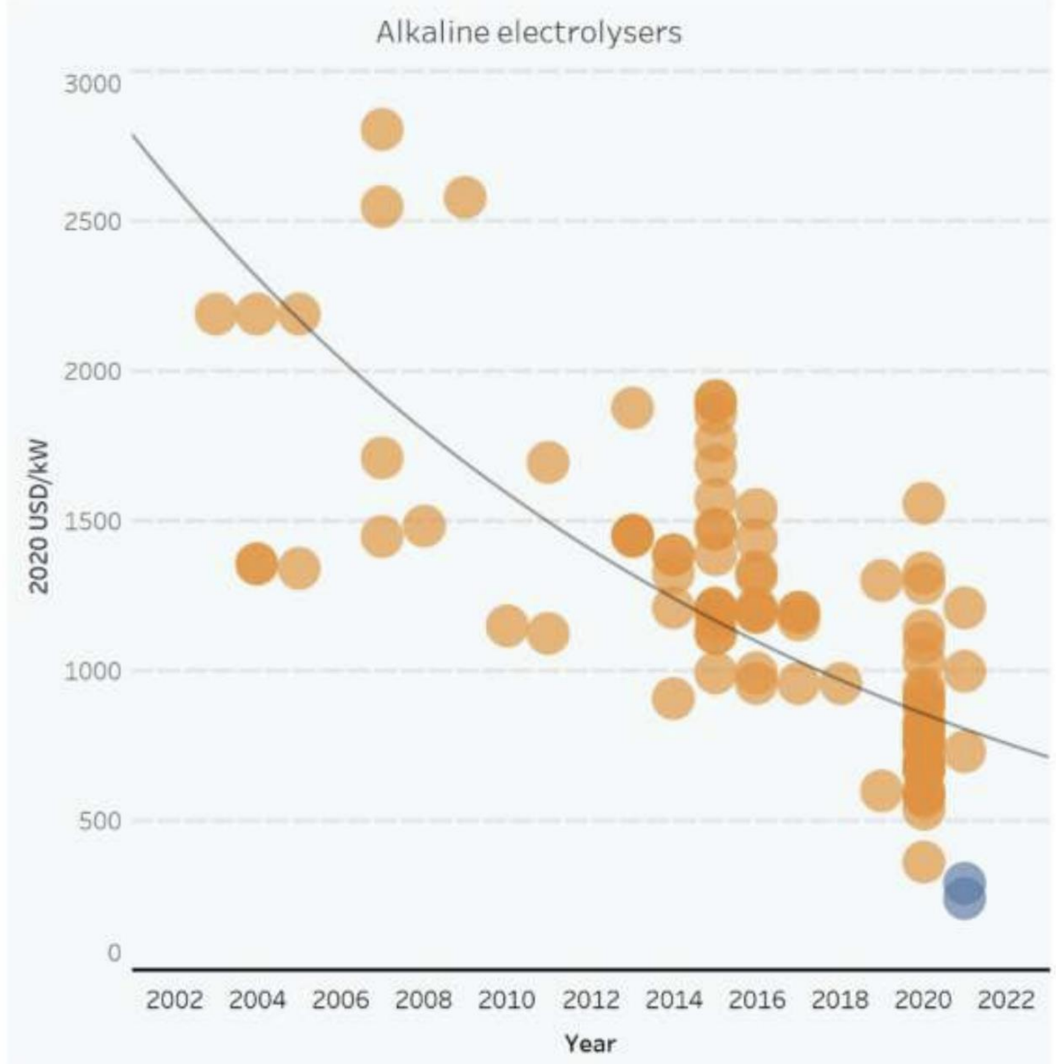

https://www.irena.org/publications/2022/Mar/Renewable-Technology-Innovation-Indicators
https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

There are multiple strategies to reduce electrolyzer costs tackling different aspects

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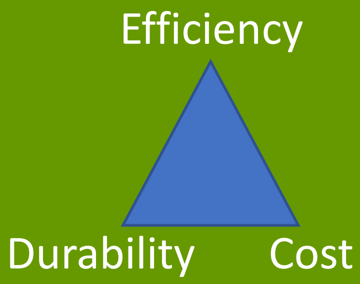
International Renewable Energy Agency

1. Innovation

- ✓ Materials

- ✓ Stack design

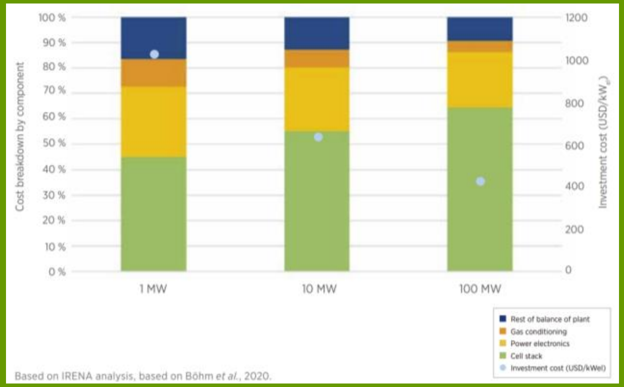


- ✓ System design
  - Flexibility
  - Balance of plant
  - Integrated design

2. Scaling up manufacturing

Economies of scale → >1 GW/yr → Automatize Standardize Competition

3. Scale up modules



- ✓ > 100-MW projects
- ✓ Low-cost for balance of plant
- ✓ Dependent on application

4. Learning by doing

Similar cost declining rates as solar → Capacity targets in strategies → 40% cost reduction by 2030

https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

Innovation is needed to improve performance of the electrolyzer but there are trade-offs

International Renewable Energy Agency

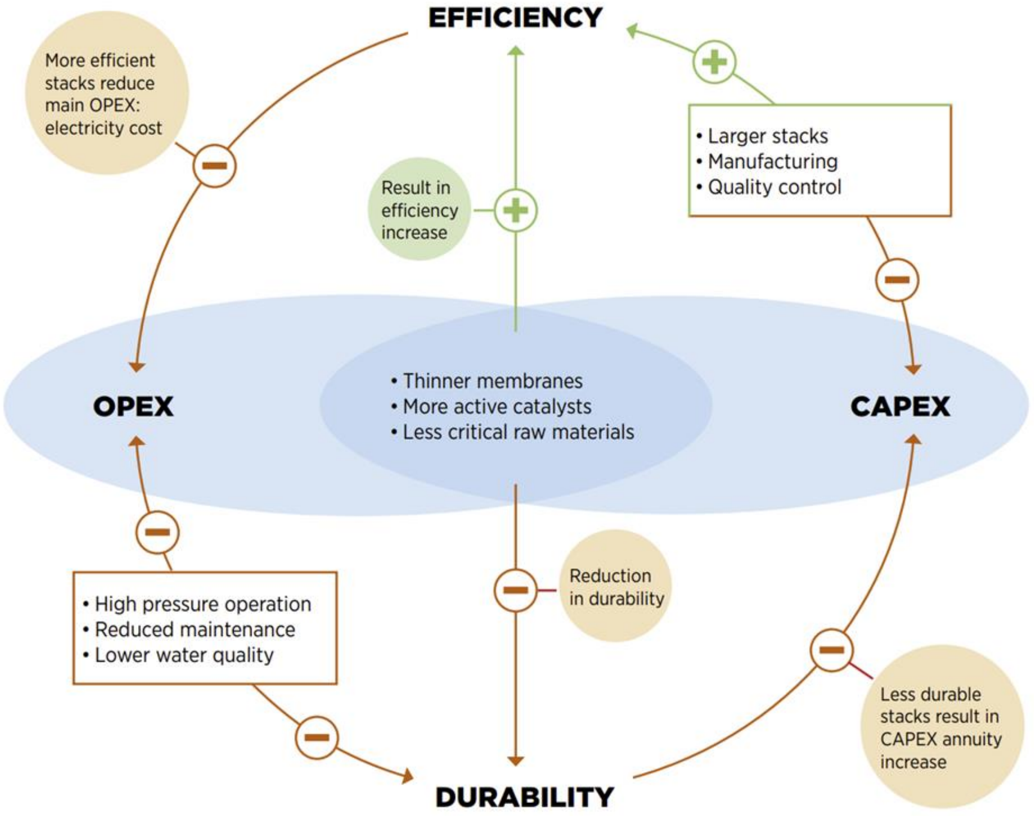
↑ Current densities → ↑ Production rate

↓ Membrane thickness → ↑ Efficiency

↓ Gas permeation → ↑ Purity, lifetime

↓ Catalyst layers → ↑ Lifetime

↓ Critical materials → ↑ Cost ↓ Lifetime



One parameter can usually not be improved without a detrimental effect in another one, which leads to optimizing design based on trade-offs and applications

https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

Critical minerals can become a barrier for PEM and SOEC if left unaddressed

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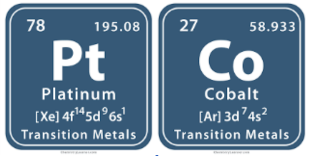
Alkaline	Proton Exchange Membrane	Solid Oxide	Anion Exchange Membrane
		❌ Gd, Zr, La, Ce, Y	✅ No critical materials

Alkaline:



- ✓ Already today some manufacturers provide Pt-, Co-free designs

Proton Exchange Membrane:

Global Pt production = 200 GW/yr

Global Ir production = 3-7.5 GW/yr

Current government targets for 2030 = 105 GW

- ✓ Reduce materials
- ✓ Increase yield
- ✓ Recycling

Parameter	Today	Future
Current density (A/cm^2)	2	5
Electrode area (cm^2)	1200	5000
Iridium loading (g/kW)	1.3	0.4
Platinum loading (g/kW)	0.5	<0.1

PEM electrolyzer has the most limitations from materials supply. Several strategies are already part of the research agenda and can help overcoming this barrier

https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

With these strategies, production costs could reach levels of around USD 1/kg in the long term

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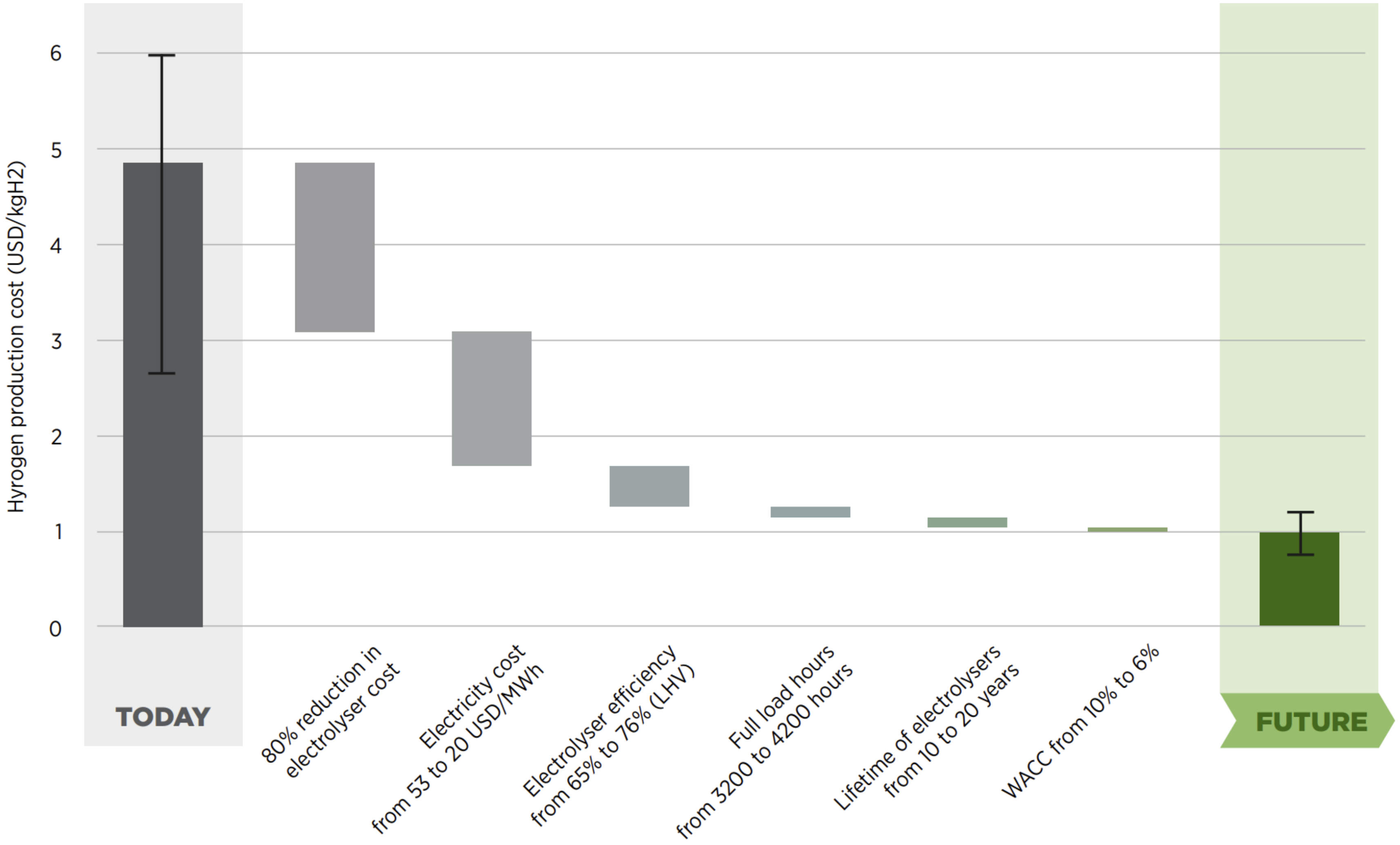

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Pipelines are the most attractive for short distances and ammonia for seaborne transport

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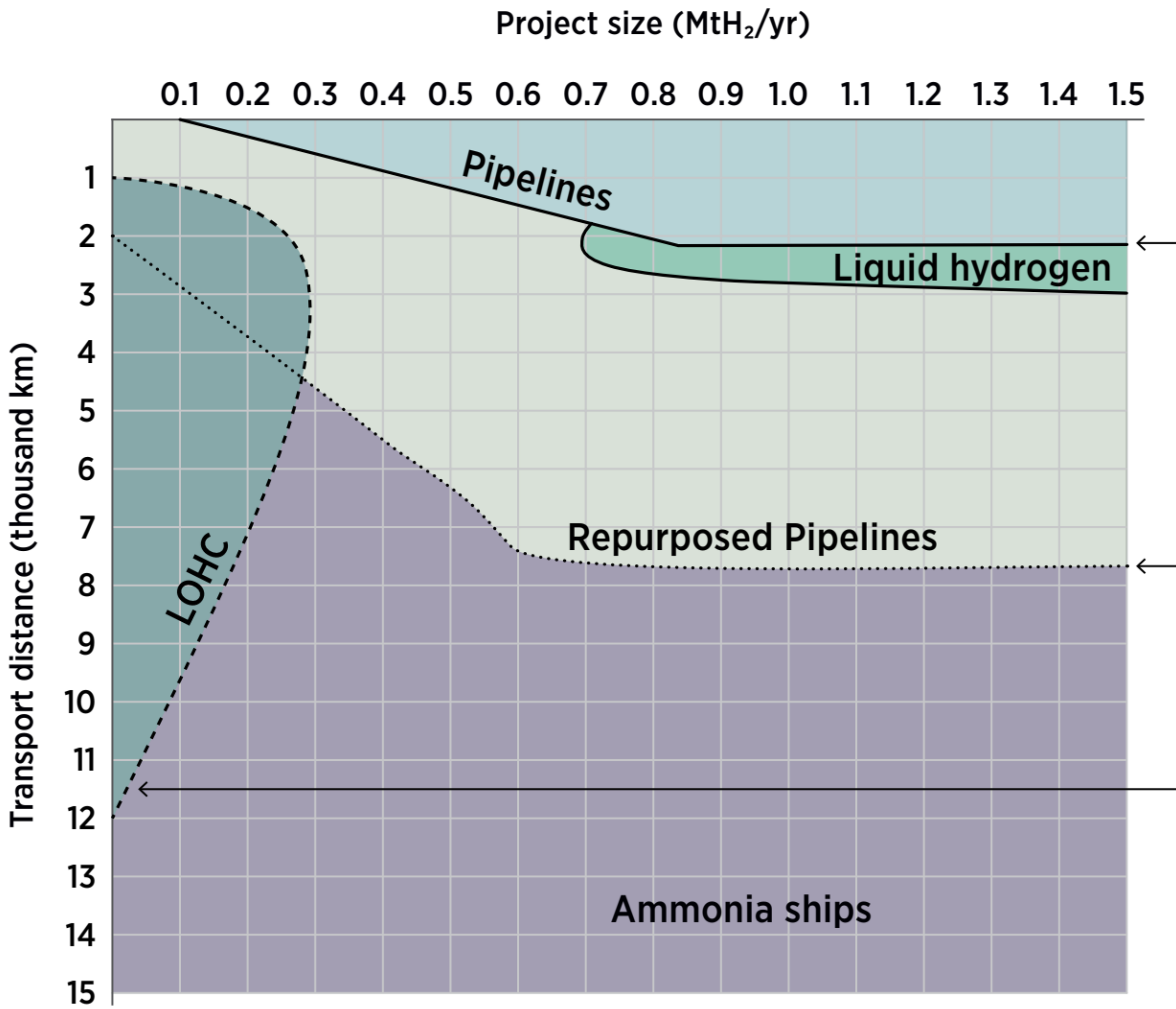


Solid lines are the base case. Pipelines are attractive for short distances, liquid hydrogen has a niche role and ammonia shipping is the most attractive for most combinations

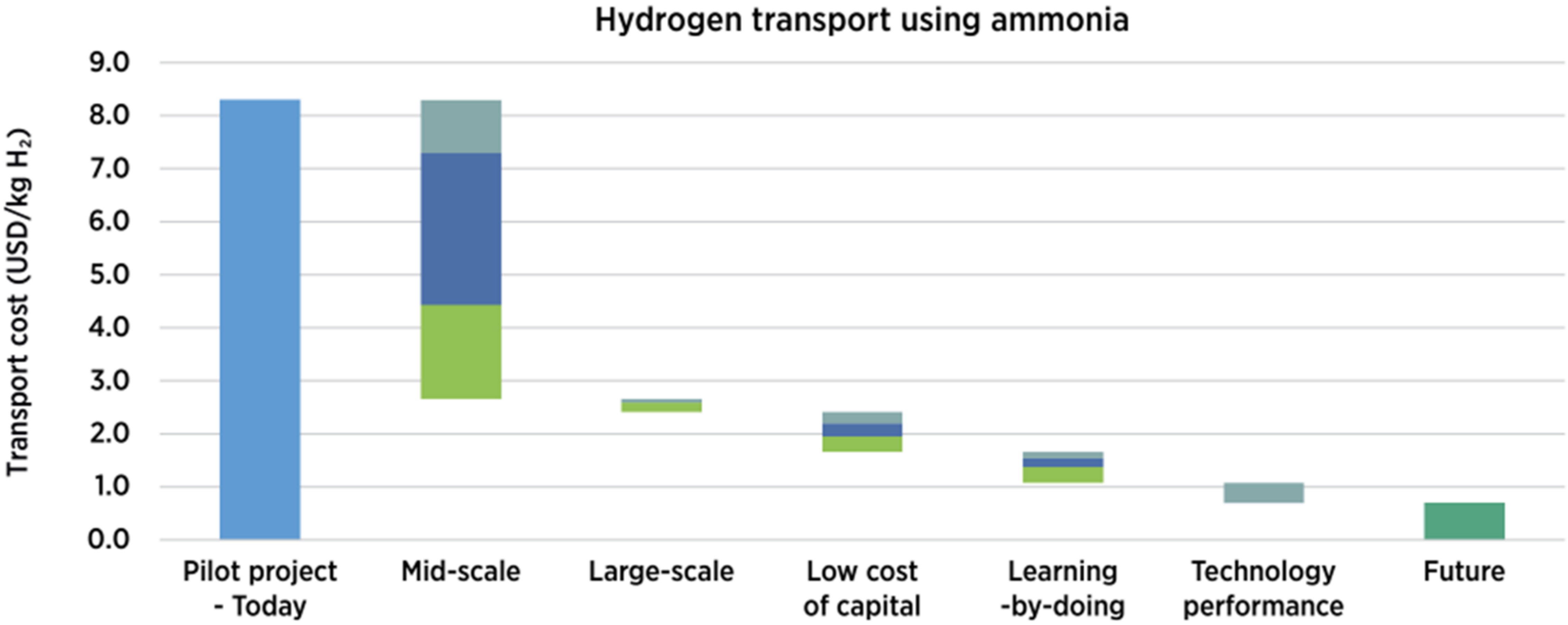
Dotted lines are for regions that have an existing network that can be repurposed to hydrogen, expanding significantly the area where pipelines are attractive

Dashed lines represent a case where innovation is slower and all the costs are higher. In this instance, LOHC can be attractive for smaller projects

https://www.irena.org/publications/2022/Apr/Global-hydrogen-trade-Part-II

The largest lever for cost reduction of transport is economies of scale

International Renewable Energy Agency



https://www.irena.org/publications/2022/Apr/Global-hydrogen-trade-Part-II

A critical area for innovation is energy consumption for (re)conversion technologies

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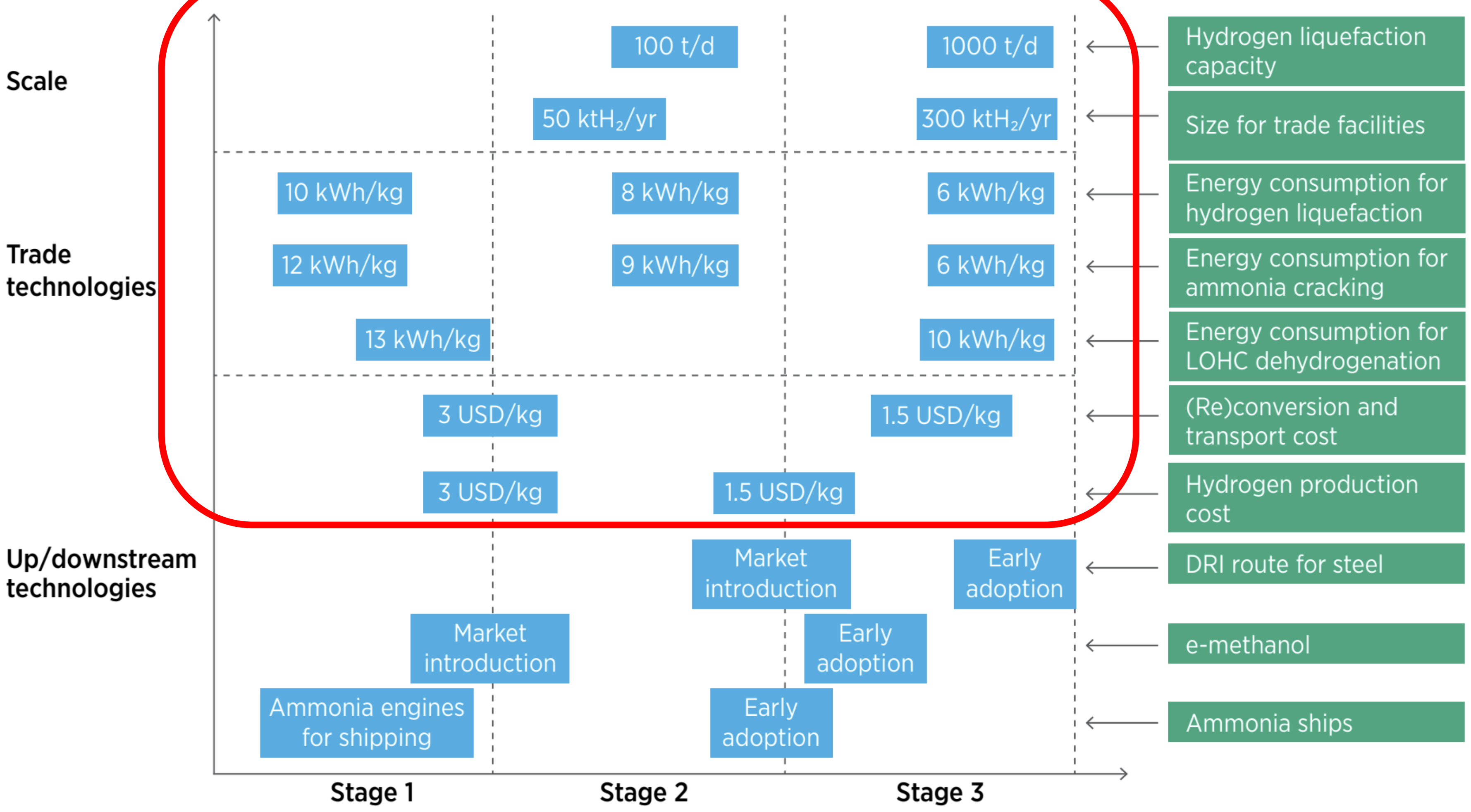
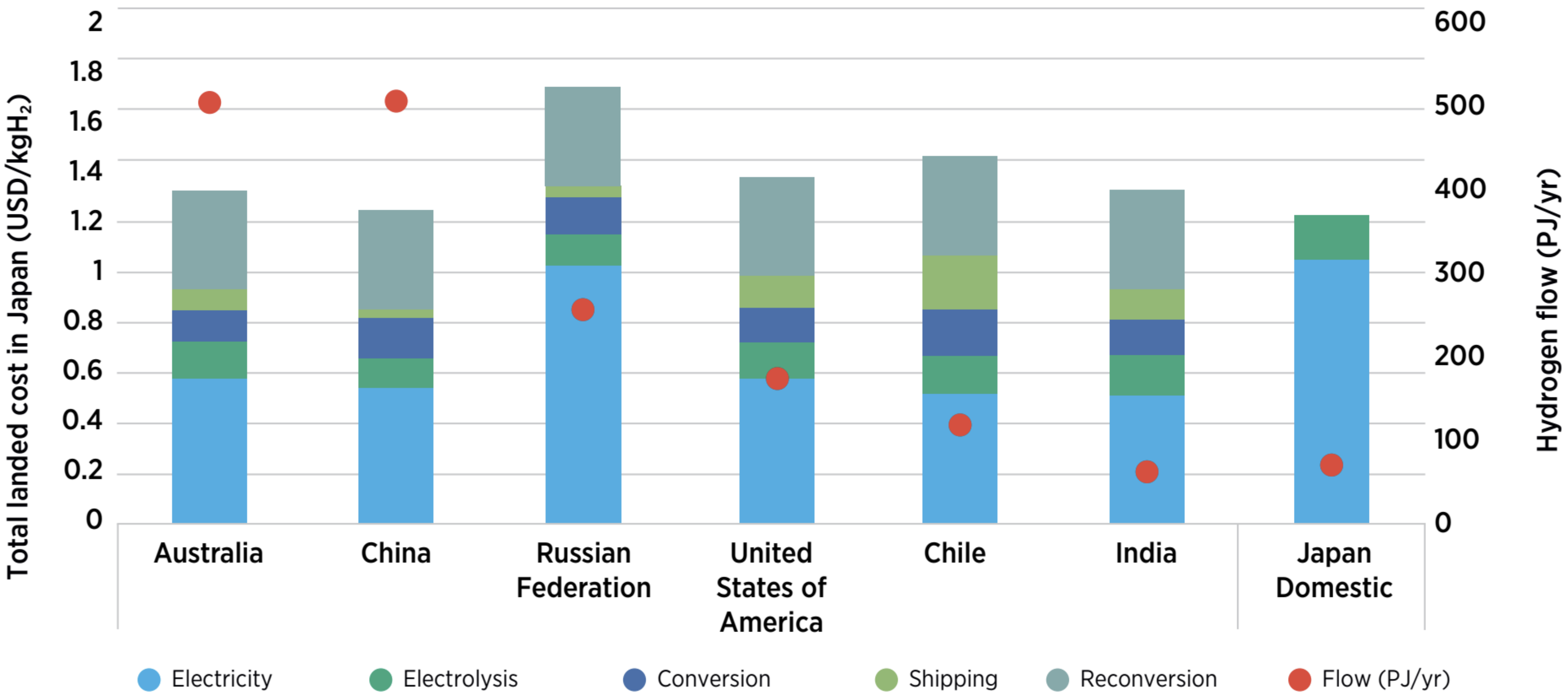
International Renewable Energy Agency



Note: DRI = direct reduced iron; LOHC = liquid organic hydrogen carrier; 1 MtH2/yr = 10 GW of electrolysis (running 60% of the time)

https://www.irena.org/publications/2022/Jul/Global-Hydrogen-Trade-Outlook

If low costs are achieved, each country could have multiple trading partners within a narrow range



Note: 2050 scenario with low costs for production and transport

https://www.irena.org/publications/2022/Jul/Global-Hydrogen-Trade-Outlook

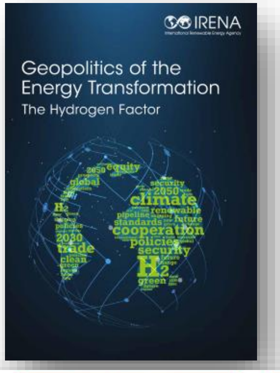
Thanks for your attention

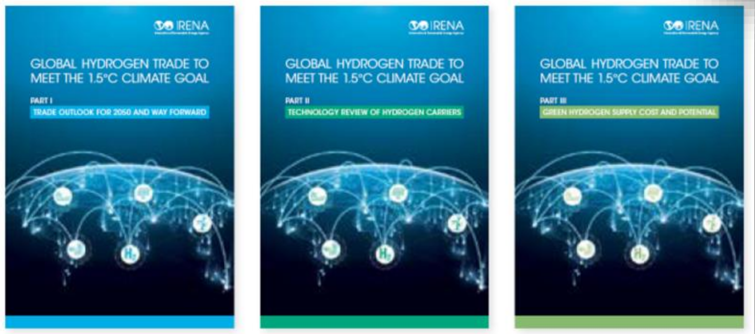
Supply

Electrolysis

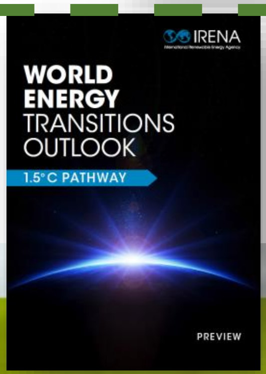
Sector coupling

Trade





Demand



Cross cutting

Policies

Main challenges for rapid hydrogen deployment

Clean Hydrogen Mission Workshop

R&I: Opportunities, Challenges and Way Ahead

4th August 2022

Paul Lucchese, Hydrogen TCP Chair

The Hydrogen TCP in a nutshell

*Established in **1977** under the auspices of the **IEA** to pursue international collaborative research in hydrogen*

33 Members

24 Member Countries
7 Sponsors
European Commission + UNIDO

40+ Tasks

4 Ongoing
39 Finished
≅ **6** in definition

250+ Experts involved

In collaborative research on hydrogen and hydrogen technologies

The immense challenge of scaling up H_2 production

Our goals…

- NZE 2050 scenarios (1,5°C) estimate clean hydrogen production 400 - 800 Mt/year *(IRENA, IEA, ETC, BNEF, Hydrogen Council…)*
- Need to install 4000-5000 GW electrolysis by 2050
- That means 160 GW/year!

Vs Where we are…

- The current portfolio of projects is around 280 GW to become in operation in the next decade (that means around 30 GW/year)
- To be on track we would need to launch every year for the next 30 years…

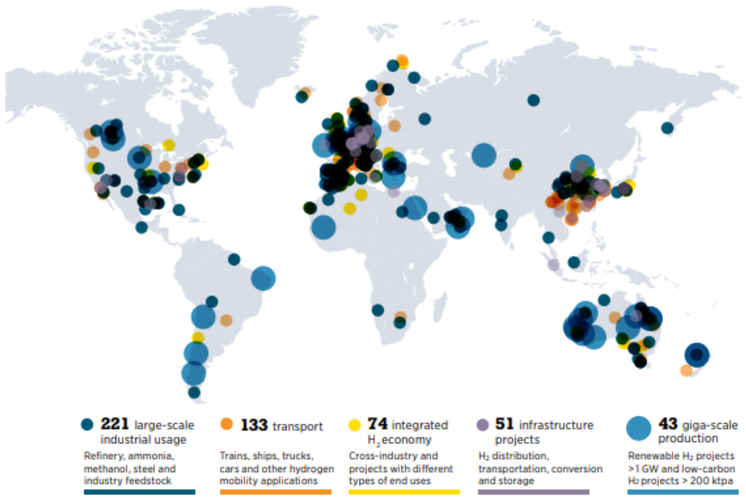
  2,5x "HyDeals" (67GW)

  or 11x "Asian Renewable/Oman Green Energy Hubs" (14 GW)

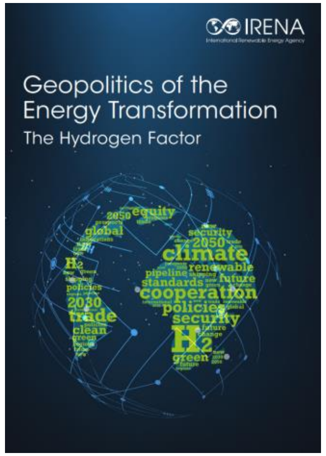
Despite an impressive portfolio of projects… our pace is still too slow and subject to many hurdles

Hydrogen TCP

Figure 3.3 Clean hydrogen projects and investment as of November 2021



Source: Hydrogen Council (2021). Map source: Natural Earth, 2021
Note: The figure describes large-scale projects only, including commissioning after 2030. It does not include more than 1000 small-scale projects and project proposals. GW = gigawatt; H_2 = hydrogen; ktpa = kilotonnes per annum.



jects

1. **HyDeal Ambition (67GW)** .... Western Europe
2. **Unnamed (30GW)** .... Kazakhstan
3. **Western Green Energy Hub (28GW)** .... Australia
4. **AMAN (16GW)**[a] .... Mauritania
5. **Asian Renewable Energy Hub (14GW)** .... Australia
6. **Oman Green Energy Hub (14GW)**[a] .... Oman
7. **AquaVentus (10GW)** .... Germany
8. **NorthH2 (10GW)** .... Netherlands
9. **H2 Magallanes (8GW)** .... Chile
10. **Beijing Jingneng (5GW)** .... China
11. **Project Nour (5GW)**[a] .... Mauritania
12. **HyEnergy Zero Carbon Hydrogen (4GW)**[a]. Australia
13. **Pacific solar Hydrogen (3.6GW)** .... Australia
14. **Green Marlin (3.2GW)** .... Ireland
15. **H2-Hub Gladstone (3GW)** .... Australia
16. **Moolawatana Renewable Hydrogen Project (3GW)**[a] – Australia
17. **Murchison Renewable Hydrogen Project (3GW)** – Australia
18. **Unnamed (3GW)** .... Namibia
19. **Base One (2GW)**[a] .... Brazil
20. **Helios green Fuels Project (2GW)** .... Saudi Arabia

Main challenges for rapid H_2 deployment

We are in a race against the clock, but some things just require time…

- R&D cycles, including “pilots” + learning by doing (demos)
- Scale-up
- Overcome cost barrier incumbent option and vested interests

- Aligning value chains
- Required “human capital”
- Rate of replacement

- Adjusting / new regulations
- Gaining social acceptance

Main challenges for rapid H_2 deployment

Cost
- Technology (e.g. catalysts)
- Production
- Transport, storage, distribution

Technology
- Scale up Manufacturing
- TRL for some technologies
- Safety Challenges

Resources
- Human capital (skilled labor)
- Critical materials
- Water consumption

Framework
- Standards, GO, certification
- Dedicated policies & regulatory framework
- Access to capital, investors trust

What do we need?
- National strategies and **Action Plans**
- Public support, specially in **early years**
- R & D & **Innovation**
- **International collaboration**

Main challenges for rapid H_2 deployment

R&D is needed at all stages of development

R&D in lower TRL: alternative technologies that could be complementary in the future to our current technological landscape or even outperform some mature technologies. E.g. production pathways, alternatives for storage…

R&D in higher TRL: towards optimization, changes in materials, processes… that may result in improved efficiency and/or reduced costs. E.g. testing different catalysts or different quantities of catalyst under different conditions, new materials for the cells in the stacks or new material treatments that result in overall efficiency…

Why is R&D key for rapid / large –scale hydrogen deployment?

While we focus on implementing already proven and mature technology as soon and as quickly as possible we will need continuous work on **optimizing costs, reliability, durability, energy efficiency and flexibility, as well as scaling-up challenges**, that can only be faced with R&D and alternative thinking.

Additionally, studies to support policy making are important (choice/design policy instruments for effective support; market structure and development etc.) and R&D on cross-cutting issues such as development of safety standards.

Why the Hydrogen TCP will play a key role?

- ✓ 40+ years of delivering high-value technical results to the hydrogen community
- ✓ 40+ successful Tasks
- ✓ Historical focus on R&D needs
- ✓ Results and findings publicly available on the Hydrogen TCP website
- ✓ Network of proactive Member States on hydrogen with the capability to mobilize hundreds of experts from around the world for a permanent effort over 3-4 years at a time
- ✓ The Hydrogen TCP covers the whole hydrogen value chain, when not alone in collaboration with…
- ✓ 2022 strategic activity on TRL Assessment
- ✓ The Hydrogen TCP can be the technical/operational branch to other international initiatives who could propose new topics for Tasks for ExCo consideration

Task portfolio status (July 2022)

Preliminary Idea
- LCA
- Hydrogen in Industry
- Sustainable aviation fuels (with AMF)
- E-fuels (with AMF)
- Hydrogen in Islands
- Marine Applications + Ports

Project Definition Phase
- **Hydrogen Certification**
- Natural Hydrogen
- **Hydrogen Export Value Chains**
- **Off-shore Hydrogen Production**
- **Hydrogen from Nuclear Energy**
- **Renewable Hydrogen**

Kick-off
- **Task 43 - Safety and RCS of Large-Scale Hydrogen Energy Applications** (27th June)

Active
- Task 40 – Energy Storage and Conversion
- Task 41 – Analysis and Modelling of Hydrogen Technologies
- **Task 42 - Underground H2 Storage**

Closing Steps

End
- Task 37 – Hydrogen Safety
- Task 38 – PtH & HtX
- Task 39 – Hydrogen in the Maritime

- Document review for other organizations (IEA, other TCPs, international groups…)
- Strategic activities: TRL Assessment, Hydrogen TCP Awards

Thank You!

For more information, please contact
Marina Holgado, Technical Secretariat Coordinator:
marina.holgado@ieahydrogen.org

CSIRO

Australia's National Science Agency

A global overview of Hydrogen RD&D

Introduction & context

Dr Vicky Au | 4 August 2022
Acting Mission Lead
Engagement & Strategy Lead
CSIRO Hydrogen Industry Mission

Who we are

Australia's national science agency

One of the world's largest multidisciplinary science and technology organisations

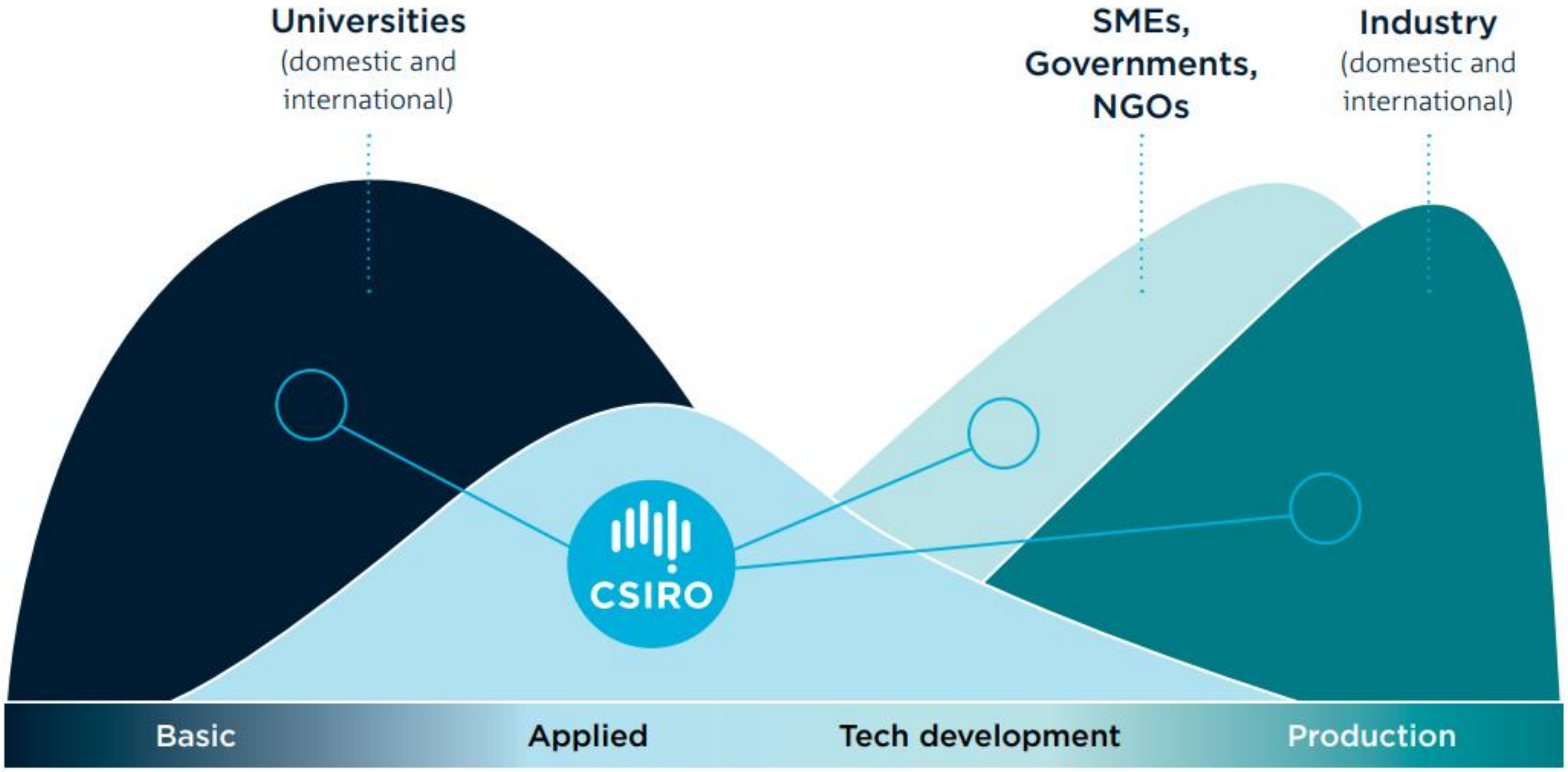
5,200+ dedicated people working across 58 sites globally

State-of-the-art national research infrastructure

We delivered $7.6 billion of benefit to the nation in FY21

CSIRO

CSIRO works across the innovation system



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CSIRO Hydrogen Industry Mission

A globally competitive Australian hydrogen industry in 2030 by lowering the cost of clean hydrogen to under $2 per kilogram

Hydrogen Knowledge Centre
Capturing and promoting hydrogen industry developments. Online modelling tools and educational resources

Feasibility Studies and Strategy
Trusted strategic & technical advice to de-risk projects in partnership with industry experts and project proponents

Demonstration Projects
RD&D in support of industrial technology deployment and hydrogen value chain validation

Enabling Science & Technology
Delivering technological solutions and socio-economic analysis to remove barriers to hydrogen industry scaleup

Australian Government
Department of Industry, Science, Energy and Resources

SWINBURNE UNIVERSITY OF TECHNOLOGY

AUSTRALIAN HYDROGEN COUNCIL

FMG Fortescue

ARENA Australian Government Australian Renewable Energy Agency

FUTURE FUELS CRC

NERA NATIONAL ENERGY RESOURCES AUSTRALIA

CSIRO

International Hydrogen Research Collaboration

Clean Hydrogen R&I: Opportunities, Challenges and Way Ahead

4 August 2022

Dan O'Sullivan
CSIRO Hydrogen Industry Mission

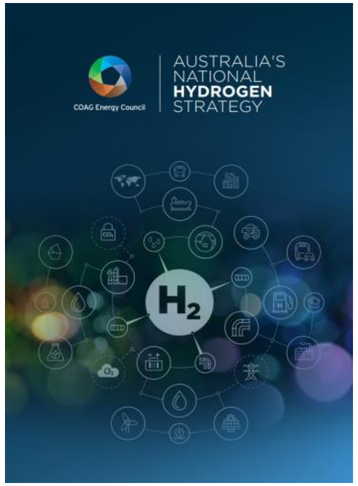
CSIRO

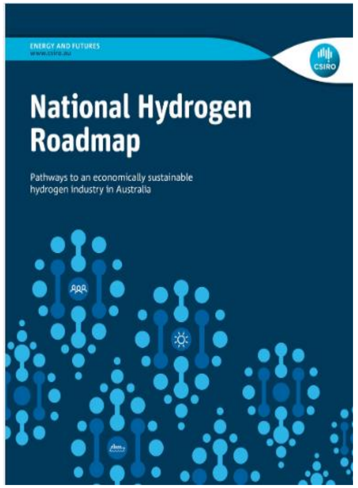
Why seek H2 international collaboration?

RD&D is required to meet global hydrogen production cost targets and emissions reduction goals, which requires a strategically driven collaborative program.

International collaboration will help:

- Avoid duplication of effort
- Leverage existing capability, infrastructure and talent
- Pool capital and risks
- Support international relationship building





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Hydrogen RD&D collaboration opportunities

The ***Hydrogen RD&D Collaboration Opportunities*** report series provides a global report and 10 detailed country reports to:

- Provide an understanding of countries that are highly active in hydrogen
- Highlight areas of strategic alignment
- Identify RD&D opportunities of mutual interest
- Provide engagement tool H2 RD&D stakeholders to facilitate engagement

Low Emissions International Partnerships

- $565.8 million for Low Emissions Technology Partnerships
- Partnerships with India, Japan, Singapore, Germany, UK, and Republic of Korea

Mission Innovation

- Clean Hydrogen Mission

MISSION INNOVATION

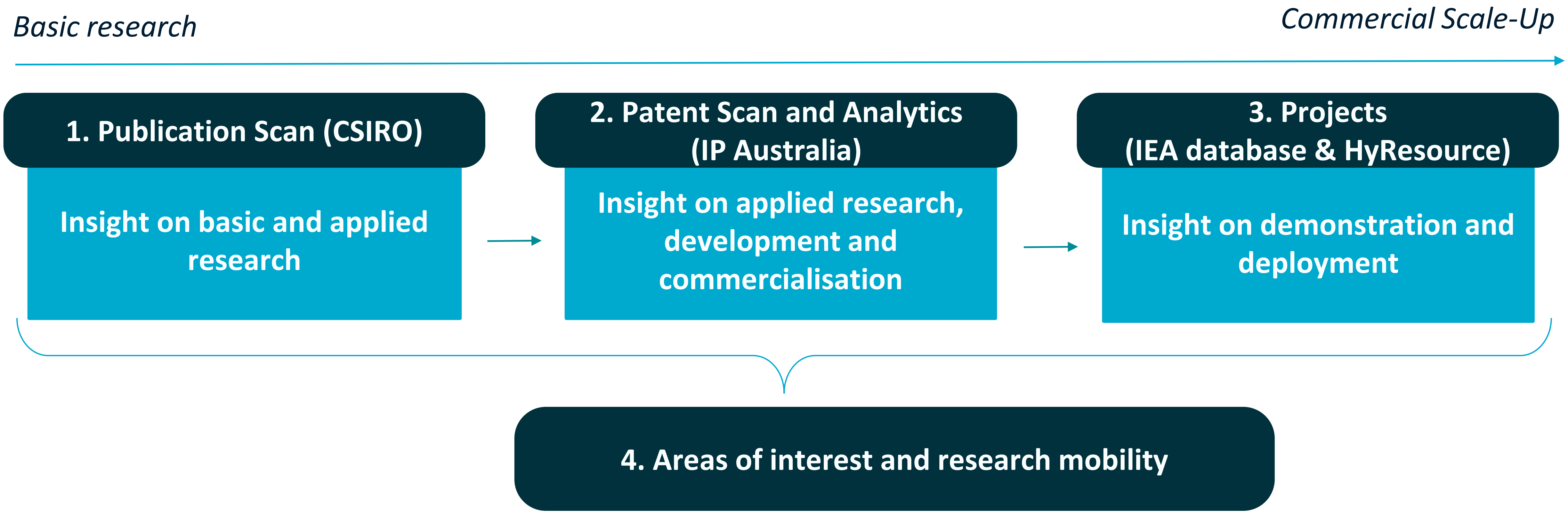
CSIRO

Identifying hydrogen RD&D collaboration opportunities

Country reports provide an overlay to compare countries to identify areas of mutual interest and engagement pathways. *What information would help to identify and pursue collaborations?*

Hydrogen Strategy	• Drivers • Strategic Priorities • RD&D Priorities
Hydrogen RD&D Ecosystem	• Government bodies, research agencies, peak bodies & consortia • Funding Mechanisms • Other key hydrogen policies, regulation and legislation • Domestic hydrogen RD&D programmes and projects • Hydrogen RD&D Clusters / Hydrogen Valleys
International Collaboration	• Country approach to international collaboration on hydrogen • Formalised international relationships • Joint International Hydrogen RD&D Programmes & Projects
Capability Metrics	• Key Players: Patent & Publications landscape

Assessment approach



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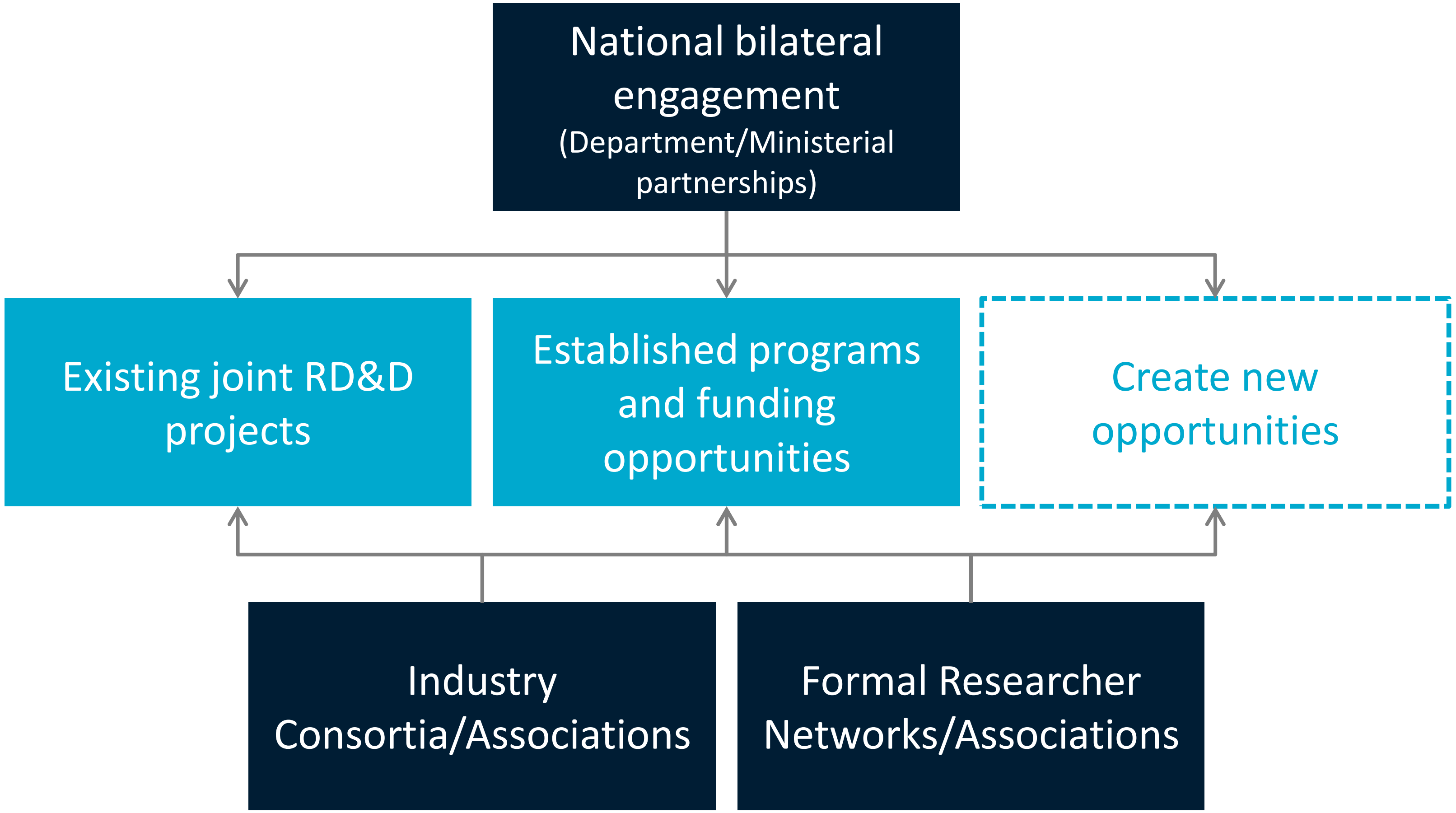
Forming research partnerships

The following approach was used to identify the engagement pathways for each country:

- **Leverage existing joint RD&D projects** and related relationships and networks. This includes projects in technology RD&D, cross-cutting research, and supply chain studies and demonstrations.
- **Target established programs and funding opportunities** where Australia is eligible to collaborate in overseas programs, and where countries have established international collaboration programs.
- **Create new opportunities** through multi-level, coordinated and tailored engagement (government, research and industry) – can take up 2+ years to set up



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Hydrogen RD&D International Collaboration Program

Overview

Goal: *To build domestic hydrogen RD&D capability by stimulating international research connectivity and knowledge sharing in support of Australia's hydrogen industry development.*

- Funding: $5M for 2 years (July 2021-Sept 2023)
- CSIRO led program, working closely with AHRN
- Governance: Steering Committee, AHRN, Industry Advisory Group

Program elements

International RD&D scans	Identifying international hydrogen RD&D collaboration opportunities
Hydrogen Knowledge Centre	Australian Hydrogen RD&D / industry development promotion & knowledge sharing
RD&D delegations	Enabling international connections for the Australian research community
Research Exchanges	Supporting early and mid career researchers in leading international hydrogen research labs
Hydrogen RD&D Conference	Local & international networking & collaboration development

Australian Government
Department of Climate Change, Energy, the Environment and Water

AHRN
THE AUSTRALIAN HYDROGEN RESEARCH NETWORK

CSIRO

Australian research delegations about to start…

Encouraging stronger research connections, collaboration pathways, knowledge sharing and international relations between Australia's research institutions and the world's leading international hydrogen research organisations after,

- *5 delegations this year (5-7 delegates per country*
- *Followed by up to 40 research fellows completing 3-12 month research activities*
- *Canada, China, India, Rep. of Korea, Singapore also in the mix…*

Current focus areas…

Germany
26 September 2022

UK
3 October 2022

Japan
5 Dec 2022

France
3 Oct 2022

USA
10 October 2022

Australian Government
Department of Climate Change, Energy, the Environment and Water

AHRN
THE AUSTRALIAN HYDROGEN RESEARCH NETWORK

CSIRO

Thank you

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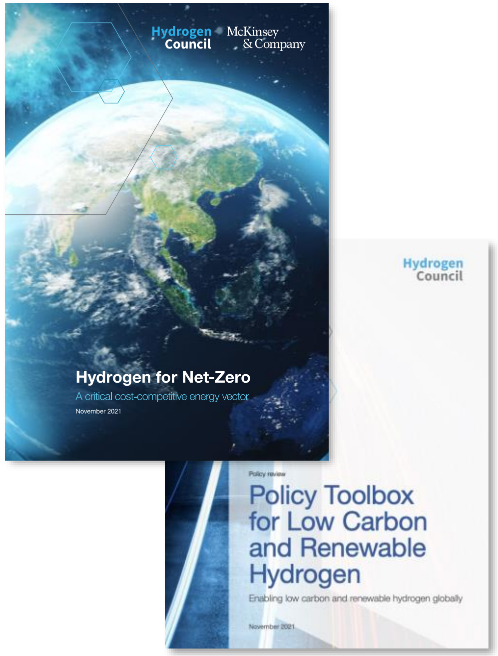
Global industry perspective

Clean Hydrogen Mission R&I Workshop: Opportunities, Challenges and Way Ahead

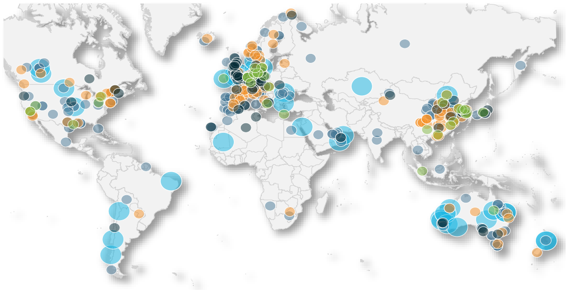
Hydrogen Council

Who we are

Thought Leader



Unique Source of Global Industry Data



Trusted Partner to Global Organisations

IRENA
International Renewable Energy Agency

iea
International Energy Agency

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

ISO
International Organization for Standardization

Program Portfolio

Sustainability Program	In collaboraiton with our international partners, facilitate the development of • International industry standards for assessment of H2 sustainability attributes • Robust tradeable certification systems • Reporting and disclosure standards
Industry Evolution Program	• Deliver insights into the evolution of the global industry based on data from >130 industrial leaders in hydrogen • Provide insights into tangible energy system-wide benefits of hydrogen • Identify cost-effective patterns for global cross-border trade in hydrogen
Safety/ Regulatory Program	• In collaboraiton with our international partners, facilitate the development of international safety regulations, codes and standards for the industry • Foster knowledge sharing and best practice exchange in the industry
Finance & Bankability Program	• Address barriers to project financing through collaboration with the Council’s Investor Group members • Foster knowledge sharing and best practice exchange among international investors

Unlocking social value of the hydrogen economy

Public-private cooperation will play a key role in unlocking the positive contribution that hydrogen can bring to several UN Sustainable Development Goals, including:

Good health and well being	⇒ Reducing air pollution
Diversity, equity and inclusion	⇒ Helping unlock diverse talent pool
Affordable and clean energy	⇒ A clean and versatile energy vector
Decent work and economic growth	⇒ Fuelling green growth & deliver sustainable jobs ⇒ Creating opportunities for indigenous communities through employment and new business creation
Industry, innovation and infrastructure	⇒ Fostering decarbonization of the industry, innovation and deployment of clean infrastructure
Sustainable cities and communities	⇒ Clean transportation and heating ⇒ Sustainable jobs for local communities
Climate action	⇒ Key solution to decarbonizing economies

Hydrogen History is Made January 2022

Left Kobe for Australia on December 24th, 2021

Maiden Voyage Ceremony at Port of Hastings on January 21st, 2022

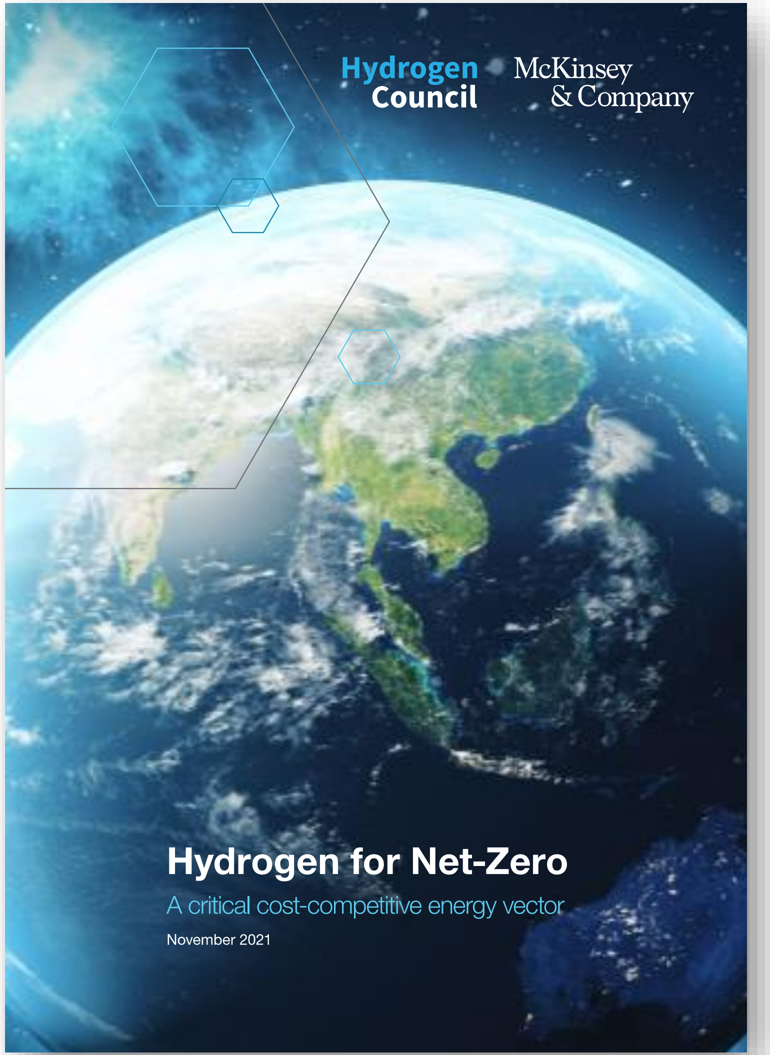
Return to Kobe in March, 2022

1869 Oil (153y)
1959 LNG (63 yrs)
2022 Hydrogen

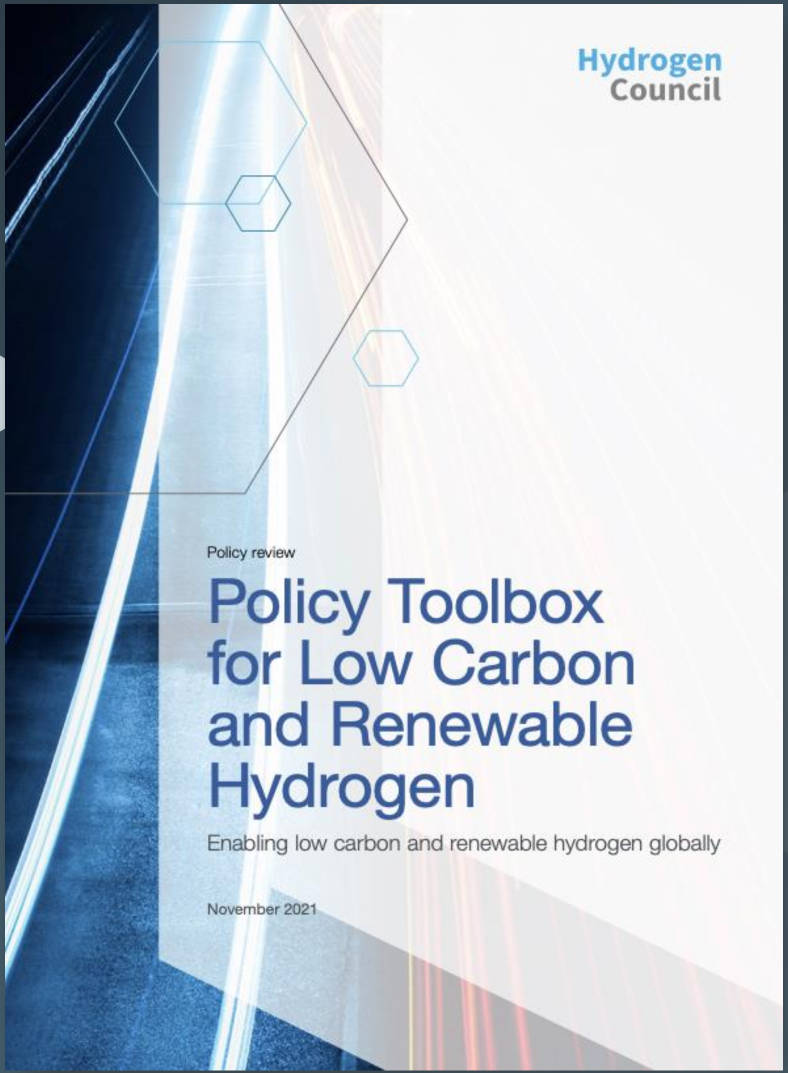
Hydrogen Council

Kawasaki
Powering your potential

Hydrogen can provide a cost-effective solution for >20% of final energy demand by 2050



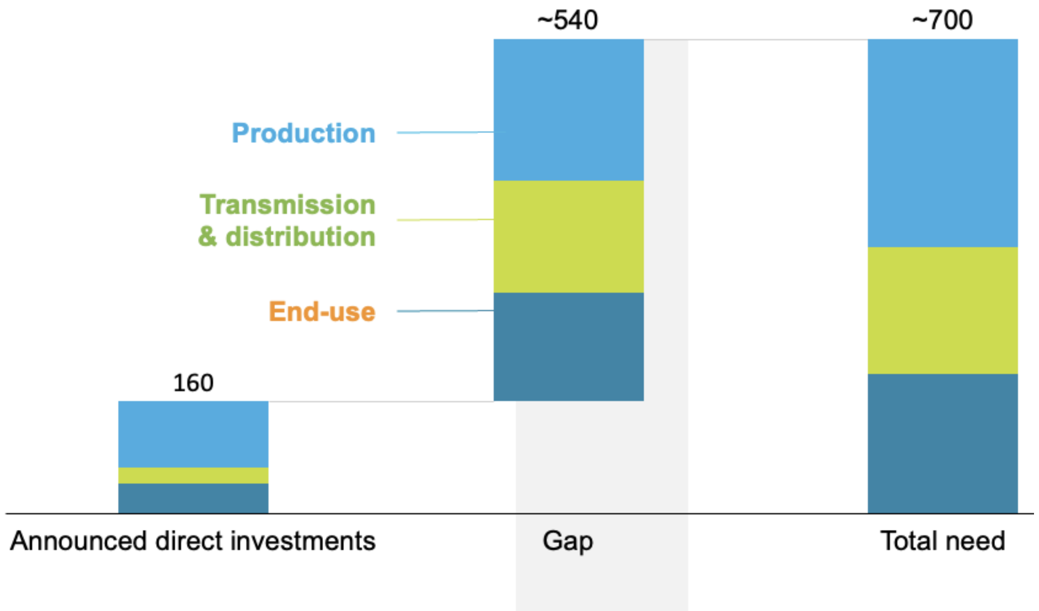
Effective policy design key to unlock the hydrogen potential



Hydrogen Council

Investment necessary to unlock H2 value chain by 2030

Announced and required direct investments into hydrogen
USD bn until 2030



540 bn of investment in the H2 well within reach

= 1/3 of the investments made in renewable energy between 2010 and 2019, or
= less than 15% of cumulative investments in upstream oil and gas in the same timeframe

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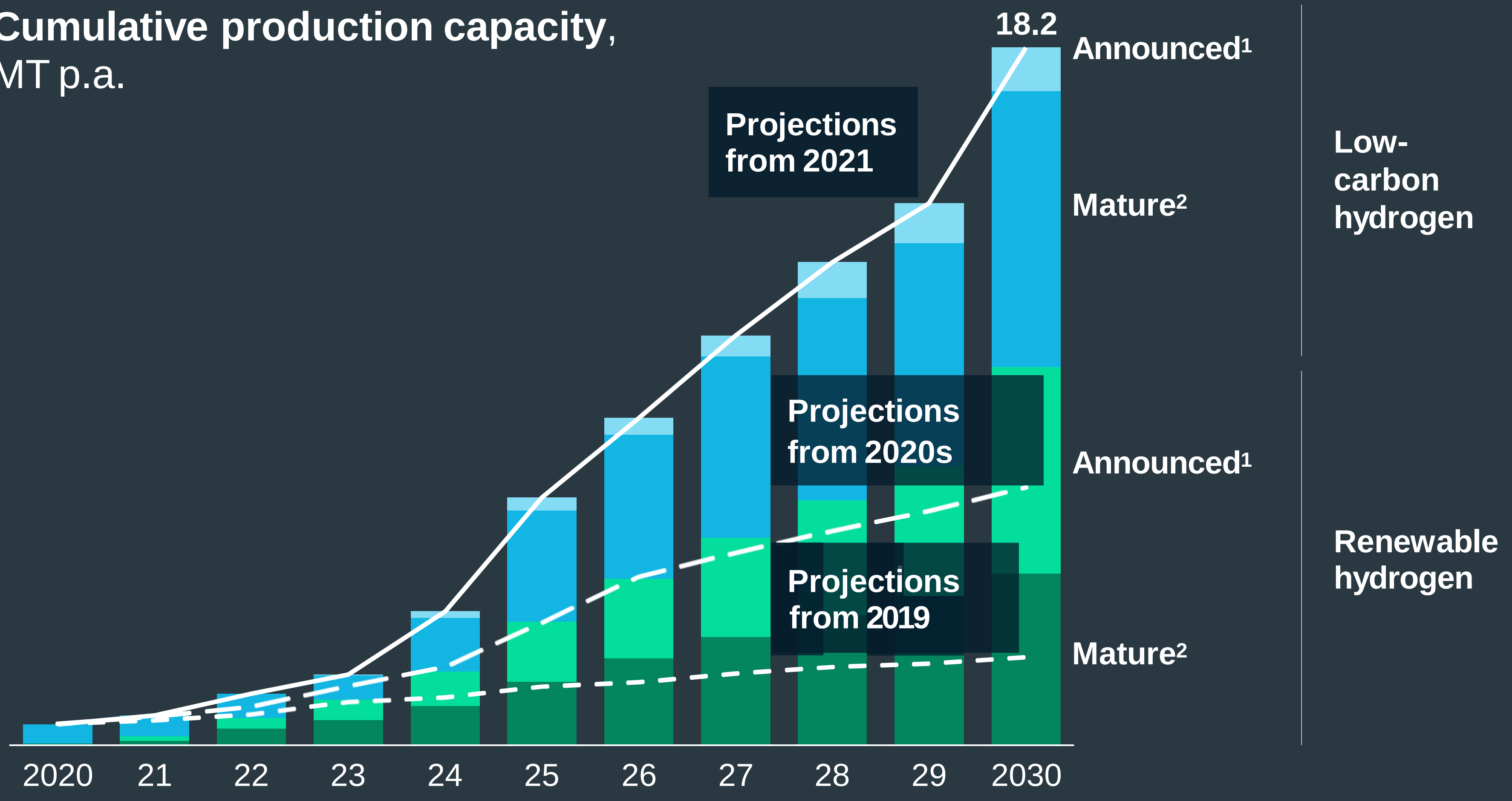
Announced clean hydrogen production capacity more than doubled since January 2021

Cumulative production capacity, MT p.a.



3x capacity

increase in capacity announced in the past 9 months

93 GW

electrolysis capacity by 2030 announced

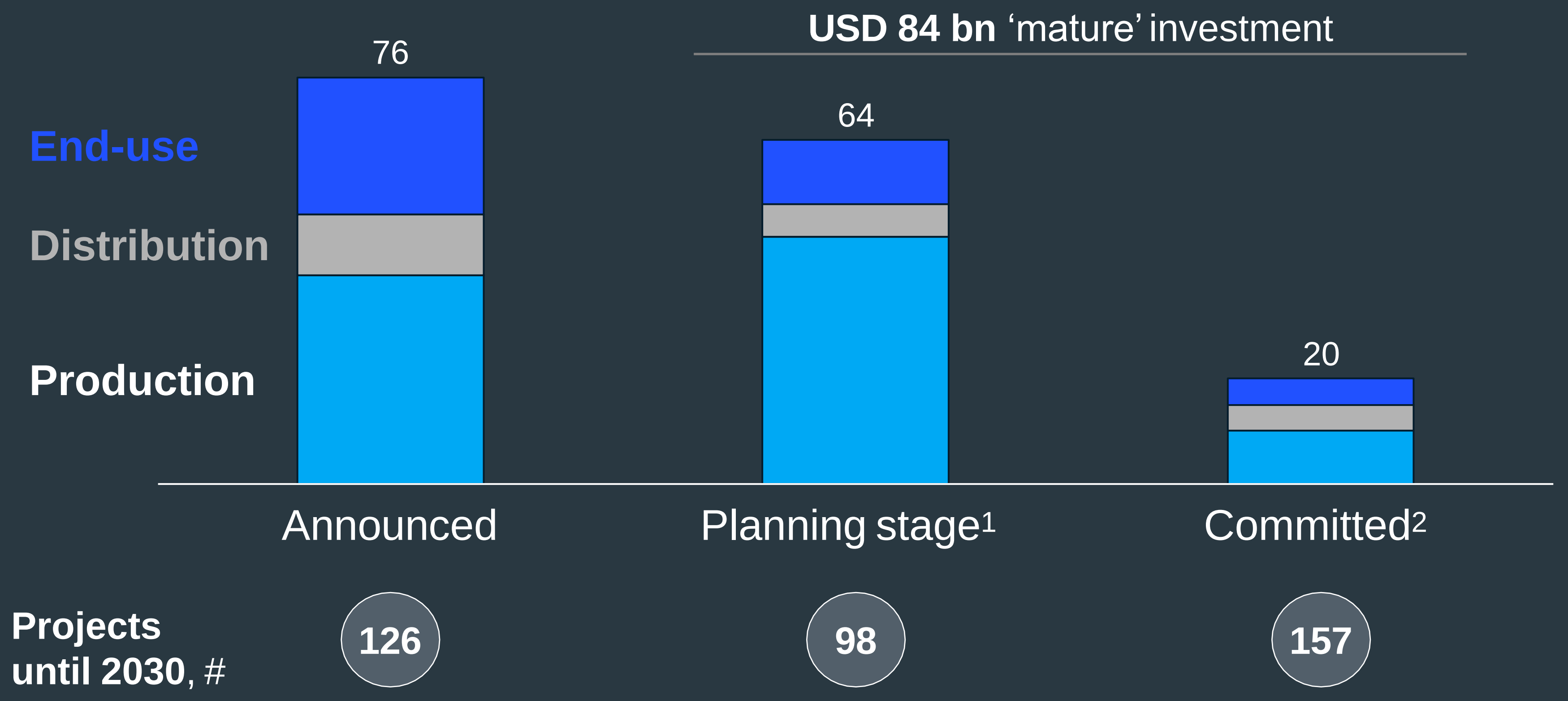
+13.2 MT

additional capacity (low-carbon and renewable) announced for post-2030

1. Preliminary studies or at press announcement stage
2. Feasibility study, front-end engineering and design stage, final investment decision has been taken, under construction, commissioned

USD 84 bn of announced direct investments are considered mature

Direct hydrogen investments until 2030,
USD bn



1. Feasibility study or at engineering study stage
2. Final investment decision has been made, already under construction or operational

USD 160 bn

announced direct private investments until 2030

USD 400+ bn

additional private investment to realize government targets and commitments and indirect investment from OEMs and suppliers

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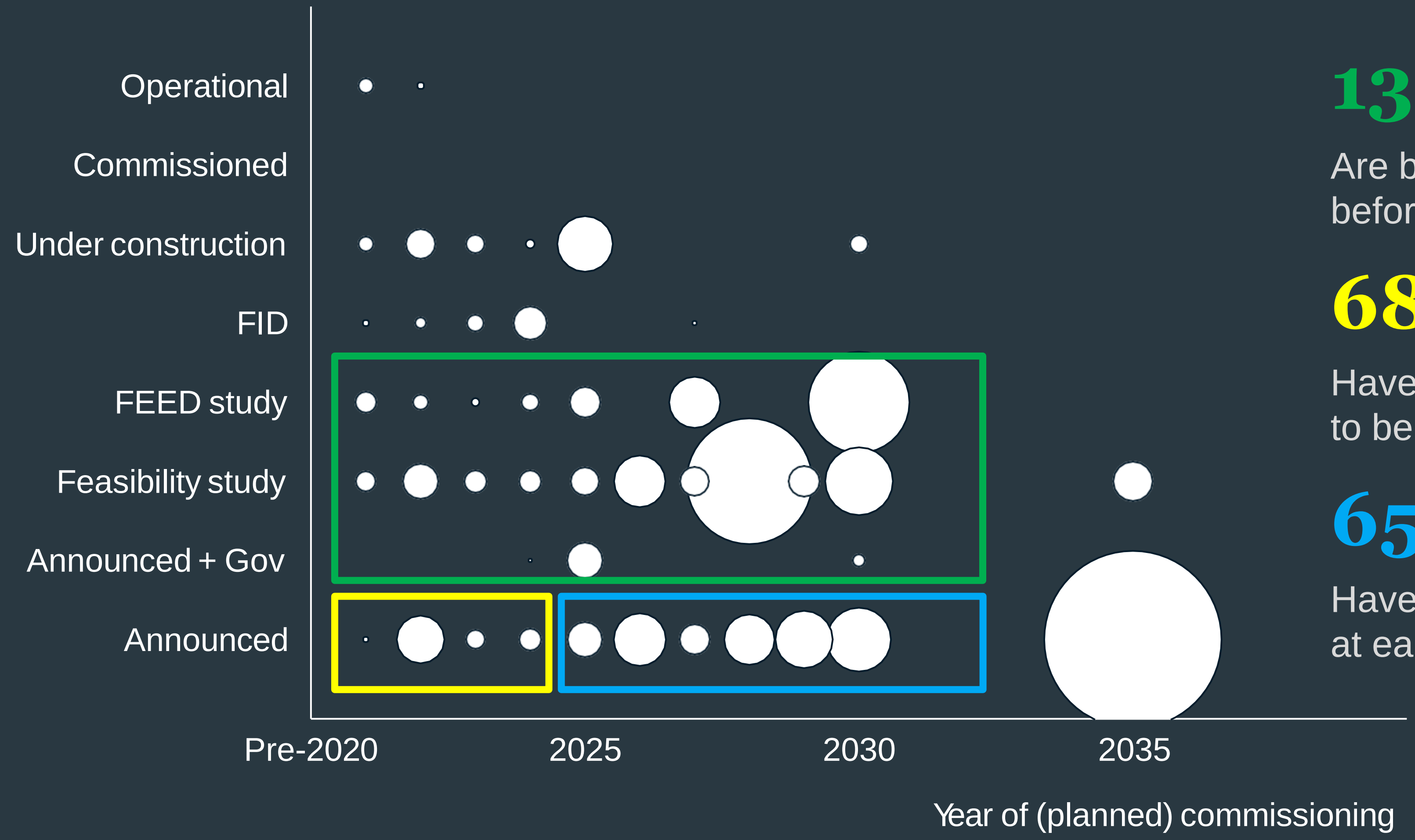
Project sizes are increasing
~78 bn of projects currently under development

Average estimated investment of announced projects[1]



135 projects, 78 bn

Are being developed and will seek funding before 2030

68 projects, 19 bn

Have been announced for < 2025, but need to be developed

65 projects, 49 bn

Have been announced for 2025-30 and are at early stage

1. Estimated deployed investment by 2030. Projects with commissioning date post-2030 show full investment

Hydrogen Council

6 pillars of efficient policy design for low carbon and renewable hydrogen

Hydrogen Council

1. Make use of local strengths & benefit from cross-border cooperation

Leveraging local strengths is an important starting point in policy design, which should be complemented by cross-border cooperation and trade to unlock efficiency gains.

2. Create certainty through targets and commitment

To drive down cost and attract investment, governments can reduce policy-risks and market uncertainty through targets, hydrogen strategies and revenue stabilization mechanisms.

3. Provide hydrogen-specific support across the supply chain

To catalyze and grow new markets, hydrogen-specific support is required across production, midstream infrastructure and end use sectors (focusing on demand-pull measures as a matter of priority).

4. Support robust carbon pricing

Robust regional carbon pricing mechanisms should be built up from existing schemes and work together with hydrogen-specific support to drive efficient and effective uptake in the longer term.

5. Adopt harmonized standards & certification systems

International standards and robust certification systems play a crucial role in the development of the hydrogen economy, enabling cross-border trade in hydrogen.

6. Factor in societal value and values

Societal value and values should be factored into policy decisions. Well-designed hydrogen policies can have a positive contribution to several UN Sustainable Development Goals.

HYDROGEN SUSTAINABILITY PROGRAM:

Joining forces with International Partners for global consensus-based standards, robust tradable certification systems and reporting and disclosure standards

HYDROGEN SUSTAINABILITY PROGRAM

Assess (ISO/ IPHE)	Incentivise (Reg/ ntl legislators)	Evidence (Reg/ ntl certification bodies)	Deploy (industry)	Report (ISSB)
Assessment of sustainability attributes of hydrogen	Regulation of sustainability attributes	Certification systems	UN SDGs delivery	Reporting & disclosure standards

Cross-cutting topics include guidelines for qualifying hydrogen as low carbon/renewable
- e.g. creating a repository of the emerging thresholds, hydrogen definitions and potential 'corridors'

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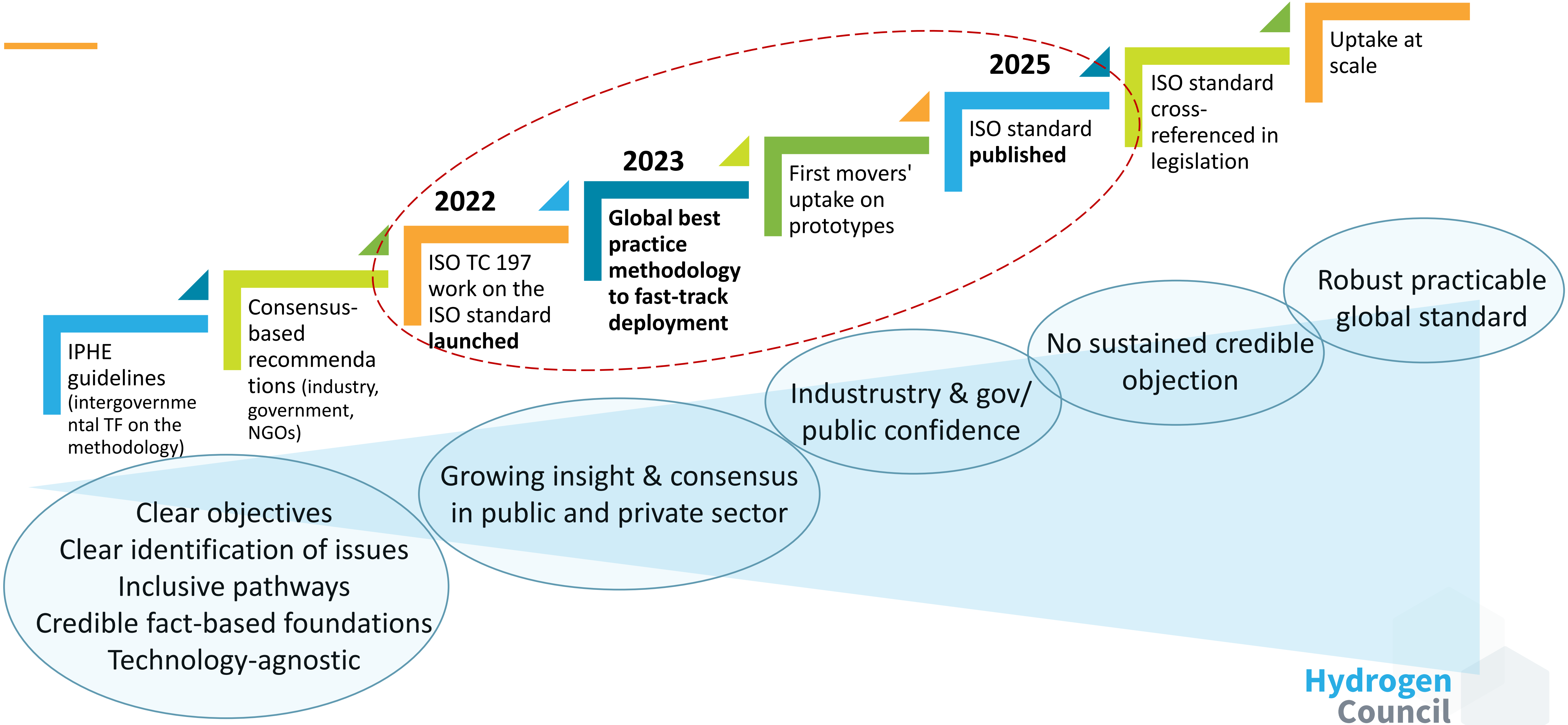
Equivalence foundation for trade: an ISO standard methodology for assessing the GHG footprint of H2



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Hydrogen certification: puzzle solving

1 Keep the pieces in order

2 Keep the pieces on purpose

3 Build consensus with constructive action

A roadmap for robust tradeable certification systems for hydrogen: challenges and mitigation measures

CHALLANGES

Divergence between purposes of certification systems (compliance/ disclosure)	→	Market fragmentation	→	Lack of fungibility of certificates/ barriers to cross-border trade

MITIGATION MEASURES

Map out the landscape: certification systems/ pilots; policies and standards	→	Mutual recognition / fungibility	→	**A roadmap & a check list** for certification systems to support cross-border trade

Focus on practical solutions to foster global cross-border trade

Hydrogen Council

Roadmap for robust tradeable certification systems for hydrogen: joining forces with international partners

April 2022: **Roadmap project launched by the Council**

May 2022: **Advisory Board to the study project formed and launched** (with experts from IEA, IRENA, H2Global, WEF, WBCSD)

Collaboration with IRENA on G7 recommendations

COP 27: roadmap presented

IEA Hydrogen TCP Task on certification launched & led by the Council

Hydrogen Council's ongoing initiatives

Insights into materials sustainability	• Materials sustainability - a favourable attribute of hydrogen systems
Advancing system thinking on hydrogen	• Modelling hydrogen integration at system level (power- gas - liquid fuels) revealing tangible resilience, reliability and cost-efficiency benefits
Towards a global hydrogen market	• Dynamic model optimising global hydrogen trade flows, considering macro-economic trends
A roadmap for robust tradeable certification systems	• Solutions for mutual recognition of emerging hydrogen certification systems to foster global cross-border trade

Hydrogen Council

Hydrogen Valleys

An opportunity to foster large-scale deployment of clean hydorgen bringing the costs further down

1. Champion the deployment of **demand-pull meansures, such as quotas and targets, in end use sectors across the valleys** within the next two years

2. Unlock the cost-efficiency and optimisation benefits of **an integrated approach to hydrogen deployment** (beyond the heavy industry – in transport and buildings)

3. Maximise **social value** through close cooperation with local communities

Hydrogen Council

THANK YOU

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Hydrogen Council

Hydrogen end to end materials challenges

Clean Hydrogen Mission R&I Workshop

Robert Sorrell

Hydrogen Challenge Lead, Royce Institute

The blueprints provide insights into UK research needs; starting with Production

- Green hydrogen production (via electrolysis) at Terawatt-scale (TW) levels is critical to widescale hydrogen deployment in a 2050 timescale, as described in the Henry Royce Institute (Royce) Materials for End-to-End Hydrogen report published in 2021.
- Royce in consultation with businesses, research technology organisations (RTOs), and universities to build a comprehensive picture of current UK electrolysis capabilities and complete the gap analysis to identify areas for future funding.
- This blueprint provides, for the first time, a comprehensive view of the UK electrolysis capabilities to inform future spending plans in this area.
- We expect the blueprint to be refined further as we continue to receive feedback and as the hydrogen sector evolves.

The first step was to identify UK Electrolysis Needs

Scope	**Electrolysers:** PEM water, Alkaline water, Solid Oxide Water and AEM water
Scale up & Electrolyser Testing	Meet efficiency, potential scalability to 1TW , durability, recyclability and carbon footprint targets
PEM Electrolysis	Iridium free or low iridium catalysts / Develop new conductive and stable materials for current collectors, porous transport layers and catalyst support / Contaminants – mitigate impact and scale up away from pure water
Alkaline Electrolysis	Improve sluggish HER & OER kinetics through catalyst development
Solid Oxide Electrolysis	Improve electrode and electrolyte materials
AEM Electrolysis	Improve membrane stability and conductivity and catalyst activity
Monitoring	On line techniques enabling real time measurement of reaction progression, impact impurities, and degradation pathways impacting ageing

ROYCE

The existing electrolysis facilities and programmes were then identified

Capability Areas	Scale up & Electrolyster Testing	PEM Water Electrolysers	Alkaline Water Electrolysers	Solid Oxide Electrolysers	AEM Water Electrolysis	Monitoring
Universities	UCL Imperial	UCL Imperial Oxford Southampton Cambridge Manchester Met Strathclyde	Loughborough	Imperial Oxford St Andrews	Surrey Newcastle	UCL Imperial Oxford Warwick
Businesses	Johnson Matthey Ceres Power ITM Power	Johnson Matthey ITM Power	Johnson Matthey INEOS AFC Energy	Johnson Matthey Ceres Power	AFC Energy	Johnson Matthey ITM Power Ceres Power
RTOs	NPL	NPL	NPL	NPL		NPL

ROYCE

From the analysis we could map the UK electrolysis capabilities to the needs

Capability Areas	Catalyst Discovery	In-silico Design	Stability Measurement	Catalyst & Electrode Scale up	Membrane Production & Scale up	Test Rigs	Analytical Techniques
UCL	Partial Match		Partial Match	Partial Match		Partial Match	Partial Match
Imperial	Moderate Match	Moderate Match	Partial Match	Partial Match	Partial Match	Partial Match	Partial Match
Manchester			Partial Match				Partial Match
Liverpool	Moderate Match	Moderate Match					
Oxford	Partial Match	Partial Match		Partial Match		Partial Match	Partial Match
Newcastle					Partial Match		Partial Match
Manchester Metropolitan	Partial Match		Partial Match			Partial Match	Partial Match
Cambridge	Partial Match					Partial Match	Partial Match
Surrey					Moderate Match	Moderate Match	Partial Match
Southampton	Partial Match		Partial Match	Moderate Match		Partial Match	Partial Match

Capability Areas	Catalyst Discovery	In-silico Design	Stability Measurement	Catalyst & Electrode Scale up	Membrane Production & Scale up	Test Rigs	Analytical Techniques
Glasgow	Partial Match						Partial Match
Strathclyde	Partial Match						Partial Match
Warwick	Partial Match						Moderate Match
Nottingham	Partial Match	Partial Match		Partial Match	Moderate Match		Partial Match
Birmingham	Partial Match				Moderate Match		
Loughborough	Partial Match						Partial Match
Bath	Partial Match						Partial Match
St Andrews	Partial Match				Partial Match		Partial Match
Exeter	Partial Match						Partial Match
Coventry				Partial Match		Partial Match	

Partial Match   Moderate Match   Strong Match

ROYCE

The analysis identified areas to build on/gaps to address in the R&D production landscape

The blueprint highlighted specific capability areas to address, seeded by an initial £5m investment;

- Provision of multiple electrochemical test cells (single to part stack)
- Development of an intelligent electrode design facility
- Provision of membrane scale up facilities

Royce UK Hydrogen Electrolysis Blueprint

Materials Testing was highlighted as key priority by the community – mapped UK testing needs

Temperature Pressure	<-253 to -50°C ~1 bar	-50°C to Ambient 100 to 700 bar	Ambient to 300°C 100 bar	300 to 1200°C 1 to 300 bar		
Application	Aerospace, heavy duty transport, storage: scale/mobile	Gas transmission and distribution, production (electrolysis), heavy duty transport, gaseous storage, purification	Aerospace, industrial, domestic fuel switching, internal combustion engine			
Testing Scenarios	Store/dispense liquid hydrogen, Spillage e.g. wings	Gas T&D pipelines, valves, seals, compressors (100 bar) Production cathode, anode, catalyst and membrane storage HD mobile and large-scale tanks (700 bar)	Combustion: domestic gas burners, industrial, gas turbines, refractory linings, finished goods			
Mechanical Testing	Tensile strength, shear, compression	Fracture toughness	Fatigue & fatigue crack growth	Creep	Hydrogen permeability	Ductility
Materials Systems	Metals and alloys	Polymers	Ceramics	Composites	Coatings	

The existing testing capabilities and facilities were identified

Capability Areas	<-253 to –50°C ~1 bar	-50°C to Ambient 100 to 700 bar	Ambient to 300°C 100 bar	300 – 1200°C 1 to 300 bar	Mechanical Testing	In-silico Testing
Universities	Bath Southampton Manchester Birmingham Bristol Oxford	Bath Brunel Bristol Southampton Birmingham	Bath Brunel Bristol Southampton Birmingham Manchester	Birmingham Bath Oxford Manchester	Bath Brunel Bristol Southampton Manchester Imperial Swansea Oxford	
Businesses	Airbus GKN	National Grid NGN Teer Coatings	National Grid NGN Teer Coatings		National Grid Airbus GKN	National Grid Airbus GKN
Testing Houses	Element DNV Composite Test & Evaluation Ltd Rina Tech UK Ltd Rtech Materials TUV Sud	Element DNV Composite Test & Evaluation Ltd Rina Tech UK Ltd Rtech Materials	Element DNV Finden Ltd Pacson Valves TUV Sud LBBC Baskerville	Lucideon Group Ltd	Element DNV Composite Test & Evaluation Ltd Finden Ltd LBBC Baskerville Lucideon Group Ltd Rina Tech RTECH	Element DNV
RTOs	STFC UKAEA NCC NPL TWI	HSE TWI NPL UKAEA	HSE TWI NPL NCC UKAEA	STFC UKAEA TWI	TWI NPL NCC STFC	TWI NPL NCC STFC UKAEA

The current capabilities vs. the needs could be mapped for UK testing

Capability Areas	Cryogenic testing	High pressure 50 to 300°C testing	High temperature testing	Non-destructive testing & characterisation	Mechanistic studies	Sensors	Accelerated ageing
Bristol	Moderate Match	Partial Match	Partial Match	Moderate Match			
Bath				Partial Match			
Manchester		Partial Match	Partial Match	Partial Match			
Southampton	Strong Match						
Oxford	Partial Match			Partial Match	Partial Match		
Birmingham	Partial Match	Partial Match	Partial Match				
Bangor	Partial Match	Partial Match	Moderate Match	Partial Match			
Swansea		Partial Match		Partial Match			
Cranfield	Partial Match	Partial Match	Partial Match	Partial Match			
Cambridge					Moderate Match	Partial Match	Partial Match
Brunel	Partial Match		Partial Match	Partial Match			
Imperial			Partial Match	Partial Match			

Partial Match   Moderate Match   Strong Match

ROYCE

This identified areas to build on/gaps in the UK testing R&D landscape

The blueprint highlighted specific capability areas to address, seeded by an initial £5m investment;

- Mechanical testing facilities to address industrial end use scenarios
- Accelerated ageing facilities combining physical and in silico approaches to predict material lifetimes
- Complete development of a publicly accessible hydrogen materials database
- Publish assessment of current UK hydrogen materials testing capabilities

Royce UK Hydrogen Testing Blueprint

ROYCE

Next steps

- Define required UK investment to support the remaining priorities in the **strengthening of the base** and **addressing the gaps** areas referenced in the electrolysis and testing blueprints
- Submit funding bids to address testing blueprint priority areas and leverage further funding from BEIS, EPSRC, Innovate UK and the private sector
- Develop comparable blueprints for end use, distribution and storage
- Complete talent pipeline assessment to support materials blueprint delivery
- Explore opportunities for international collaboration

ROYCE

Launch of R&I Working Groups

- The Clean Hydrogen Mission is launching two new working groups and is currently inviting interested parties to join.
  - Production working group – contact Madhu Madhavi madhu.madhavi@beis.gov.uk
  - Storage and Distribution working group – contact Trevor Rapson trevor.rapson@csiro.au
- The end-use application Working Group is up and running.
  - To join- contact Pete Devlin peter.devlin@ee.doe.gov