



POSITION PAPER

HySpeedInnovation

A JOINT ACTION PLAN
FOR INNOVATION AND UPSCALING
IN THE FIELD OF WATER
ELECTROLYSIS TECHNOLOGY

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A JOINT ACTION PLAN FOR INNOVATION AND UPSCALING IN THE FIELD OF WATER ELECTROLYSIS TECHNOLOGY

- on the challenge of rapidly **upscaling** the **production capacity** for clean (carbon-free) hydrogen
- on the particular role for Europe's Research and Technology Organisations (RTOs) to play, in conjunction with universities and other R&D intensive organisations.
- on concrete opportunities for improving our shared innovation ecosystems and research infrastructure, especially around
 - **Materials, components** and **electrochemical stack development**
 - **System performance** and **data sharing**
- and thereby shaping the conditions for rapid upscaling and **commercialisation of water electrolysis systems.**



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FOREWORD

In this new era of energy transition, Europe expects profound changes to achieve a climate-neutral Europe by 2050. In addition to the support and development of renewable energies in Europe over the last decades, hydrogen is now recognised as a new player at the service of the environment and the economy.

Renewable electricity is expected to play a vital role in decarbonising the EU's energy consumption. However, it will not do it all through direct electrification, or battery solutions. Hydrogen, as a versatile energy carrier and chemical feedstock, offers advantages that unite all of Europe's energy resources —renewables, nuclear, and fossil fuels— and enables innovations in energy production and end uses that can help decarbonise the most energy intensive sectors of our economy.

The potential of hydrogen is being recognised worldwide, with strategies, plans and investments by government and industry ramping up in many countries, in particular in Europe. The recent European hydrogen strategy sets out an ambitious vision of how Europe can turn clean hydrogen into a viable solution to decarbonise different sectors over time, identifies the challenges to overcome and provides a concrete policy framework for the European Clean Hydrogen Alliance to develop an investment agenda and a pipeline of concrete projects.

Over the past decades, owing to a continuous European support to research, development and innovation, hydrogen technologies have transitioned from highly specialized applications to commercially available products. However today renewable and low-carbon hydrogen are not yet cost competitive compared to fossil-based hydrogen. To fulfil the increasing demand for clean hydrogen, scaling up hydrogen production (6 GW of electrolysis by 2024 and (2x) 40 GW by 2030) and building up hydrogen infrastructure are necessary.

Fostering cross-border RD&I collaboration and supporting a European RD&I ecosystem approach along strategic value chains is the only solution to face this kind of challenge today. Bring innovations from the lab to our everyday life to support the society is the essence of RTOs in particular by closely cooperating with industries, large and small, as well as public actors. Hydrogen Europe Research thus welcomes this initiative of RTOs contributing to a rapid upscaling of a European electrolysis industry towards a zero-emission society.

Laurent Antoni

President of Hydrogen Europe Research

ENDORSEMENTS

This paper is approved by the following research institutes:



LIST OF TERMS / ABBREVIATIONS

AE	Alkaline Electrolyser
AEM(E)	Anion Exchange Membrane (Electrolyser)
BoP	Balance of Plant (components of the electrolysis system)
BPP	Bipolar Plate (key component of electrolysis stack)
CCM	Catalyst Coated Membrane = MEA
EI	Education Institutions
MEA	Membrane-Electrode-Assembly = CCM
PC	Private Companies
PCC (E)	Proton Conducting Ceramic (Electrolyser)
PEM (E)	Proton Exchange Membrane (Electrolyser)
R&I	Research and Innovation
RTO	Research and technology organization
SO (E)	Solid Oxide (Electrolyser)
Stack	Electrochemical reactor of the electrolyser
TRL	Technology Readiness Level
WE	Water electrolysis

EXECUTIVE SUMMARY

Industrialisation of water electrolysis (WE) technologies is considered a critical step for the large-scale implementation of clean hydrogen and deep-decarbonisation of our society. Moreover, Europe is strongly positioned to capture the economic value of the growing markets associated with clean hydrogen production. At the same time, the timeline set by the energy transition now requires a more coordinated effort. More cooperation across national and regional boundaries is required to prevent fragmentation of efforts while leveraging existing assets and fortifying our frontrunner position.

This challenge is also being addressed by industry representatives, as it becomes clear from the EU industry association Hydrogen Europe calling for a Pan-European concerted effort for its 2x40 GW initiative.

With this HySpeedInnovation Joint Action Plan, we as Europe’s RTOs propose to rally behind that call with state of the art innovation support through mobilisation of our (shared) research infrastructure, independent expertise, next generation technologies and facilities for testing, validation and monitoring. This is an absolute prerequisite to reach climate neutrality by 2050 or preferably earlier.

Three sets of opportunities to accelerate the developments for upscaling of WE technologies have been identified that call for a joint action plan.

These opportunities are: (i) Connecting Hydrogen labs; (ii) Setting clear performance standards; and (iii) Monitoring performance of subsidized pilots. For each opportunity, concrete steps have been identified that fall within the responsibilities of Europe’s RTOs (Figure I).

HySpeedInnovation how research institutes can help accelerate industrialization of water electrolyser production

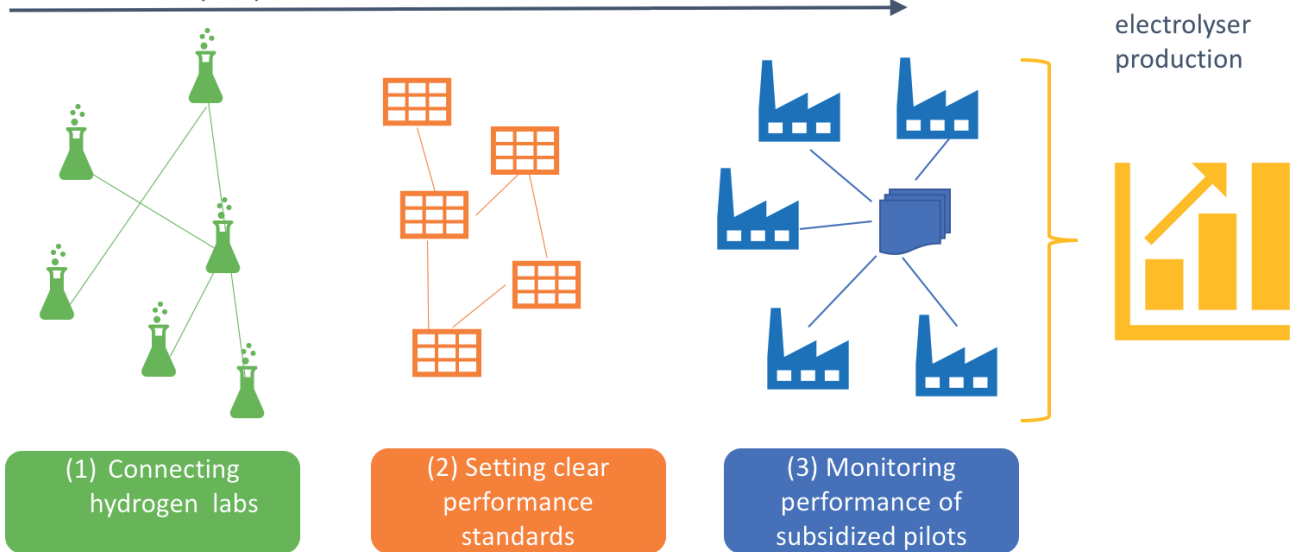
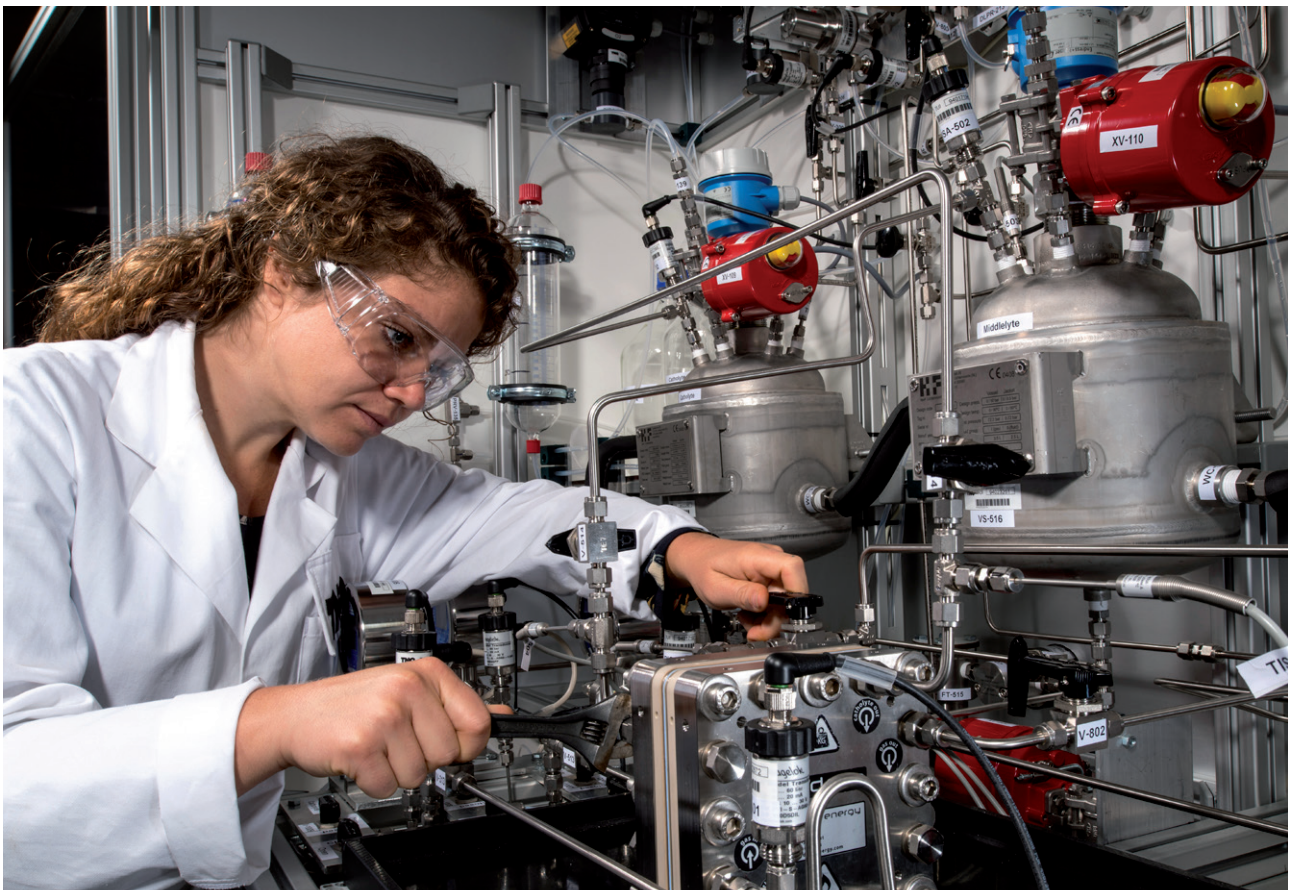


Figure I: Opportunities for joint action.

To achieve these objectives, European RTOs call for support from national governments and EU policy makers on the following topics:

- An EU funded programme aimed at facilitating the establishment of a coordinated EU infrastructure enabling to use / share water electrolysis testing facilities with improved data sharing across RTOs, developed and supported by leading national governments.
- An EU funded programme aimed at developing harmonized performance, safety, sustainability and quality standards setting international minimum requirements for (components of) electrolyzers, e.g. as materialised in tender specifications.
- The implementation of an Open Access policy for sharing aggregated data and learnings. Governments should make sharing of data and learnings of all subsidised research, demonstration and deployment projects mandatory.

However, for each opportunity, some requirements will have to be met that lie outside of direct RTO influence. It is here that the responsibility of policy makers on the national and EU levels is required to facilitate the proposed effort.



1. INTRODUCTION

The global challenge of climate change forces governments, businesses and knowledge organisations all over the world to mobilise behind carbon-reducing innovations, e.g. large-scale renewable energy implementation and electrification. The capacity to economically produce, store, transport and use clean (carbon free) hydrogen as part of a renewables centred energy system is widely considered an enabler, if not a requirement, of such developments.

At this time, despite a promising outlook, water electrolysis technology is not sufficiently mature to fit that purpose. An enormous challenge lies ahead in upscaling currently available technologies to GW-scale factories required to drive forward the energy transition.

For Europe, this challenge is reflected in the European Green Deal, which puts renewable hydrogen produced by electrolysis high on the political agenda. The European Hydrogen Strategy sets a target for 6 GW installed electrolyser capacity by 2024, and 2x40 GW by 2030 (40 GW in Europe and 40 GW in neighbouring countries) producing respectively 1 and 10 million tonnes of hydrogen annually. Tens of billions of euros are promised as a stimulus for this development. Several hydrogen strategies from European member states also have quantified targets for electrolysers according to their National Hydrogen Strategies looking at 2030 horizon, e.g. 6.5 GW in France, 5 GW in Germany, 3-4 GW in the Netherlands 1 GW in Portugal and 4 GW in Spain.

Box 1: How much is a GW?

One GW is comparable to the power of:

- A large offshore wind park (meaning hundreds of MW-scale wind turbines)
- One internet data center (although they may use up to 5 GW)
- Electricity consumption of all households in 5-10 large cities

To put things into perspective, a 1 GW electrolyser plant can produce 150,000 tonnes of carbon-free hydrogen per year. For comparison, this corresponds to the use of about a million fuel cell vehicles a year. An industrial petrochemical cluster typically uses hundreds of kilotonnes hydrogen per year, so that would require multiple Gigawatts of installed electrolyser capacity.

In the last five years, governments on various levels have already started to allocate large budgets to R&D activities, yielding a diverse landscape of research activities, pilots, even demonstrations focusing on semi-commercial applications. Europe, in particular owing to the Fuel Cell and Hydrogen Joint Undertakings, has developed into a global frontrunner in the field of water electrolysis (WE) technology.

At the same time, the timeline set by the energy transition now requires a more coordinated effort. The authors of this paper claim that more cooperation across national and regional boundaries is required to prevent fragmentation of efforts and leverage on the currently existing assets and built-up frontrunner position.

This challenge is also stressed by industry representatives, as it becomes clear from the EU industry association Hydrogen Europe calling for a Pan-European concerted effort for its 2x40 GW initiative.

With this HySpeedInnovation Joint Action Plan, we as scientists at Europe's RTOs propose to rally behind that call with state of the art innovation support through mobilisation of our (shared) research infrastructure, independent expertise, next generation technologies and facilities for testing, validation and monitoring. This is an absolute prerequisite to reach climate neutrality by 2050 or preferably earlier.

The purpose of this paper is to articulate the understanding of the European research community and to call out to more RTO's and other knowledge institutes across Europe, for a joint approach on a series of specific challenges related to electrolyser development and especially upscaling. Based on a series of conversations and meeting of minds, involving key experts from five RTOs, three sets of opportunities have been identified to accelerate the developments for upscaling of WE technology through a joining of efforts, in synergy with the next Clean Hydrogen for Europe partnership. For each opportunity, we identify concrete steps to be taken. However, for each opportunity, some requirements will have to be met that lie outside of direct RTO influence. It is here that we call on the responsibility of policy makers on the national and EU levels, to facilitate the proposed effort.

This paper is structured as follows:

1. Challenges of upscaling:

specifying where critical challenges are for rapidly reducing system costs and improving performance of water electrolysis systems;

2. Role of RTOs:

referring to the critical challenges, RTOs are well positioned to accelerate developments and foresee potential dead-ends;

3. Opportunities for joint action:

a set of concrete opportunities for cross-national cooperation in service of rapid upscaling of water electrolysis technology.

*Accelerate the developments
for upscaling of WE technology*

2. CHALLENGES OF UPSCALING

Electrolysis is not a new technology: Alkaline electrolysis was used from the 1920s to the 1960s to produce hydrogen for fertilizer production before being eclipsed by hydrogen produced from natural gas.

Still, water electrolysis globally accounts for less than 0.1% of dedicated hydrogen production and the total European production capacity for electrolyzers is currently below 1 GW per year.¹ Scaling up to multiple GWs in 2030 depends on the scaling up of manufacturing capacity and on bringing down the costs of water electrolyzers.

Also, the growth of electrolysis capacity should go hand in hand with decarbonisation of industry and clean electricity production.

¹ European Commission 2020. *A hydrogen strategy for a climate-neutral Europe*. Brussels, 8.7.2020 COM(2020) 301 final



Box 2: Currently available water electrolyser technologies**Alkaline Electrolysers**

Alkaline electrolysis is the most mature electrolyser technology with several large-scale plants operated for decades. Alkaline electrolysers operate at ambient or elevated pressure, they use little or no precious/expensive materials in their construction and are well suited for large-scale applications. But they suffer somewhat from low dynamic response and large footprints. These disadvantages must be overcome for the integration with renewable energy systems.

PEM Electrolysers

Proton exchange membrane (PEM) electrolysers have existed since the 1960s when introduced in the NASA space programme by General Electric and have mostly been used for small-scale applications. PEM technology has gained momentum in the last decade, with several multi-MW installations now under construction.

These electrolysers are the most compact and dynamic and deliver hydrogen under pressure, which makes it suitable for storage and handling.

Solid Oxide Electrolysers

Solid oxide electrolysis (SOE) is a less mature technology, for which pioneering work started in the 1960s. There are very few demonstrated commercial SOE plants so far, but the first multi-megawatt plant is planned to be installed in 2024 (MULTIPLHY project). SOEs have the potential to reach higher conversion efficiencies compared to Alkaline and PEM electrolysis due to favourable thermodynamics at higher temperatures where a larger part of the energy needed for the process of water splitting can be supplied as heat instead of electrical energy, making it attractive to couple SOE systems to industrial processes with excess heat available.

Proton Conducting Ceramic Electrolysers

Proton conducting ceramic electrolysers (PCCE) are intrinsically different to SOEs in that the transported species is hydrogen rather than oxygen. The proton conducting ceramic electrolyte enables the production of compressed, dry hydrogen with no further purification needed. PCCE have the same favorable thermodynamics as SOEs, but are currently a less mature technology with only a handful of smaller scale demonstrators being operated.

And more ...

Several other technologies exist, especially aimed at combining features of e.g. PEM and Alkaline, or SOE and PEM so as to overcome the most important shortcomings of one or the other. It is beyond the scope of this paper to go into such details. Suffice to say that RTOs and universities, especially in Europe, are very active in this field and occupy a frontrunner position.

Multiple electrolysis technologies exist (see Box 2). For all available technologies, severe bottlenecks have yet to be solved to enter the GW scale. Importantly, there are challenges related to the current market conditions and the way supply chains are currently organized. Regardless of the electrolyser technology, the following main challenges can be identified:

R&D challenges

- Generally speaking, **designs are to be improved (on the stack level) to handle more power (higher current density), improve efficiency and enable larger stack sizes without using too much (costly and/or scarce) materials**, all while guaranteeing the integrity of the system and a high efficiency over a sufficiently long lifetime.
- Key areas for innovation, on the **cell-level**, are the catalysts, electrodes, porous transport layer and membranes/separators. Here, a balance needs to be found between **costs / material** use and component **performance / durability**. Striving for efficient utilisation and possibility of recycling of materials is especially relevant for PEM and SOE systems, where scarcity of certain raw materials, e.g. Iridium, Platinum, rare-earth elements pose a serious hurdle for upscaling. With respect to the latter, it is crucial to develop solutions for recycling and substitution, especially in the context of large-scale implementation.
- A **GW scale** electrolyser plant will consist of several hundred individual electrolyser stacks which potentially can or must be individually controlled. Developing control and operational strategies for such plants is of high importance. For such systems as a whole, optimized set-up and balance-of-plant (BoP) components and sub-systems are to be developed, integrated and optimized for specific application contexts. Here, lessons are to be learnt and shared that will feedback into further component, sub-system and system eco-design.
- In the pursue of improved stack technologies towards the 2030 goals, it is extremely challenging to predict the effect of emerging electrolyser materials, components and new electrolyser designs on GW scale electrolyser plants **operating under highly dynamic conditions and under offshore conditions**.
- Water Electrolyser systems are currently manually **assembled**. Large scale deployment requires low-cost, efficient, and durable stack modules which are easily integrated into larger electrolyser systems fulfilling upstream and downstream process requirements. Such **automated manufacturing** is yet to be designed. For the components (cell level) as well as for the integrated stacks (the core of the electrolyser), a large opportunity for cost reduction lies in automated manufacturing. Part of the challenge here is that there is currently no standard product. Moreover, it is currently undecided for which components and technologies such as automated manufacturing are feasible.
- Due to the current state of the field, where various designs are being developed and assembled piecemeal, there is a lack of **harmonized technology standards, test protocols** and **well-defined benchmarks**. This hampers a fair comparison of products, the system cost decrease and also R&D advancements across organisations. After all, markets also requires regulations, codes, and standards to function well. As mentioned by the IEA, the trade will benefit from international standards and Europe has to be a frontrunner in standardisation to keep its technology leadership.²

²« The future of Hydrogen » IEA, 2019



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Supply Chain challenges

- The **electrolysis industry is currently dominated by very few large companies** such as Siemens, thyssenkrupp, Hitachi, Hydrogenics-Cummins, ITM Power, Areva H2Gen, McPhy or Sunfire. These system-integrators work closely together with a relatively small community of suppliers. Most are SME like McPhy, Areva, Hygs, h-tec, NEL, Teledyne, Plug Power, etc. Roughly, half of all the electrolyser manufacturers are located in Europe, and their component suppliers are mostly European as well. Still, in the face of the upcoming challenge of upscaling, the industry remains too small and activities are fragmented and poorly optimized.
- For obvious reasons, the **current manufacturers protect their IP** and keep their suppliers closed. The drawback here is that innovative newcomers, even potentially innovative suppliers, have a hard time working their way into this market (market barriers at the entrance). This puts a brake on the dynamics of innovations that are needed to accelerate developments towards second and third generation-technologies.
- Generally speaking, technological knowledge and expertise about electrolysers is fragmented across a broad range of actors, with lots of small entrepreneurs holding an enormous potential for innovation, but **lacking a shared direction and common frame of reference**. Potential supply chain partners are often unaware of each other's existence, let alone their needs and capabilities. This is true within European countries, but even more so on an international level. Such lack of transparency limits the potential for mutual learning and seriously hampers the necessary coupling between various kinds of knowledge, for instance on automated manufacturing, electrochemistry, power electronics, plant optimization, to name but a few.
- All of this is exacerbated by a looming uncertainty concerning the various available technologies and their designs (e.g. PEM, Alkaline, SOE). The **lack of a standardized product and clear use cases** create uncertainty for downstream players, e.g. companies looking to invest in automated production lines, especially for components (where high volume manufacturing seems most feasible) and stacks. Although it should also be stated that such design variety has its merits, for instance in creating a broad possibility space with numerous options now in development and potentially serving a variety of markets.

Market and System challenges

- Perhaps the most significant issue to tackle is the **lack of a sufficiently large market for CO₂-free hydrogen**. Despite manifold ambitions and targets, from policy makers and industry alike, there are no market incentives in place that justify large volume production. This is largely the result of a market failure when it comes to pricing of CO₂.
- The other big system challenge is the **availability of a sufficient amount of low-carbon and renewable electricity**. In the coming decade, renewable energy sources may prove to be relatively scarce, making the business case for large scale electrolysis highly dependent on government stimuli.
- Related to the previous topic, is the fact that the contribution of electrolysis technologies to carbon reduction will largely depend on the fit **within a broader energy system**. On the short term, a large-scale electrolyser may not be the optimal route for allocation of scarce renewable electricity, while on the long term these systems are simply necessary to meet the set targets. This requires walking a fine line where upscaling of low-carbon and renewable electricity goes hand in hand with the upscaling of electrolysers and their applications.
- Infrastructure decisions, both for hydrogen gas and high voltage powerlines, have to hold pace with the roll-out of electrolyser capacity.
- A regulatory framework also needs to be in place that helps in reducing the costs of carbon-free hydrogen as compared to fossil based hydrogen.

*Europe has to be a frontrunner
in standardisation to keep
its technology leadership*

3. ROLE OF RTOs

When it comes to innovation, Europe is a global leader in electrolysis technology. This is clear, for instance, from patent data and from the simple fact that most of the industry leaders are currently located in Europe. Yet, when implementation and especially upscaling, are at stake, there lies a serious challenge in maintaining and exploiting this position. With respect to these challenges, RTOs and other research institutes have a key role to play.

RTO's and other research institutes actively contribute to solutions on all fronts, ranging from low-TRL laboratory stage R&D at the level of materials, component development and prototyping to high-TRL near-industrial demonstrations. And also providing services and support to industries (e.g. assembling and testing platforms or pilot lines, activities in regulation, codes & standards activities), looking for avenues of commercialization on the basis of their R&D portfolio. With respect to market creation and 'system building', relevant for the non-technical challenges, RTOs play a role in such activities as vision building, techno-economic-socio-environmental analyses, policy advice or even more hands-on efforts aimed towards influencing shared innovation hubs / supporting (regional) innovation (eco)systems.

To illustrate the central role of RTOs, it is interesting to look at the Cordis database that contains information on all EC funded innovation projects. A data search for 'electrolysis projects' makes very clear that RTOs are central to research and innovation, especially in terms of centrality (being well connected to various partners) and in terms of bridging (connecting various parts of the innovation (eco)system).

Figure 1 shows the relative importance of RTOs (red circles) in terms of their position in the EU ecosystem. Generally speaking, RTOs play a key role in bridging the gap between academia and industry.

A further analysis, for each electrolyser technology, of specific 'collaboration networks' makes clear that around PEM electrolysis RTOs can be considered 'bridging actors' that link one part of network to another (see Figure 2).

This is also the case for SOE projects, although the network, and number of projects, is relatively smaller.

For Alkaline, the network is smaller and the role of RTOs is less prominent as here the technology maturity leads to the industries being more in the lead.

Please refer to the graduation thesis of Safwan Shurieh for a more elaborate analysis of EC funded innovation projects: <https://repository.tudelft.nl/>



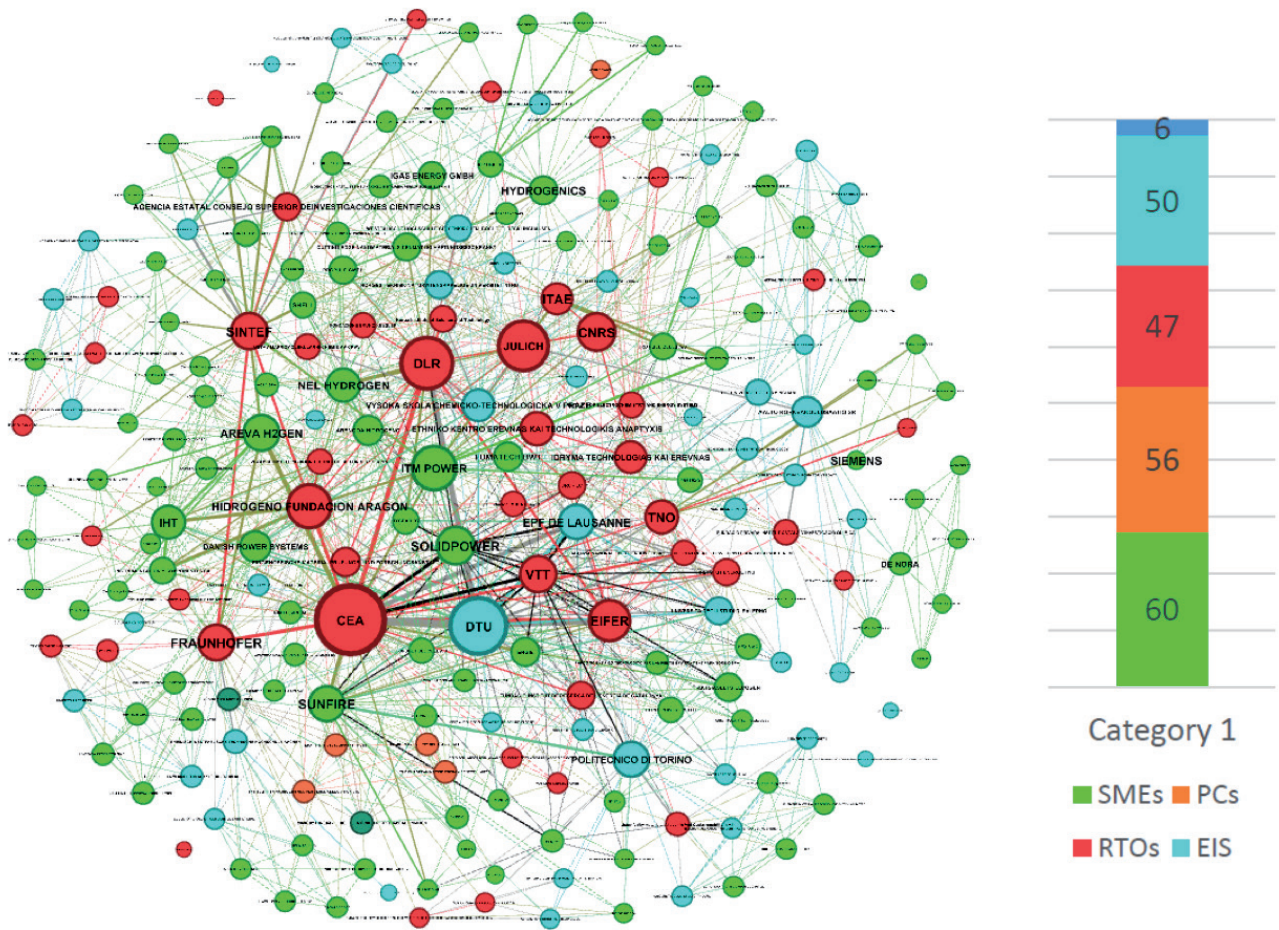
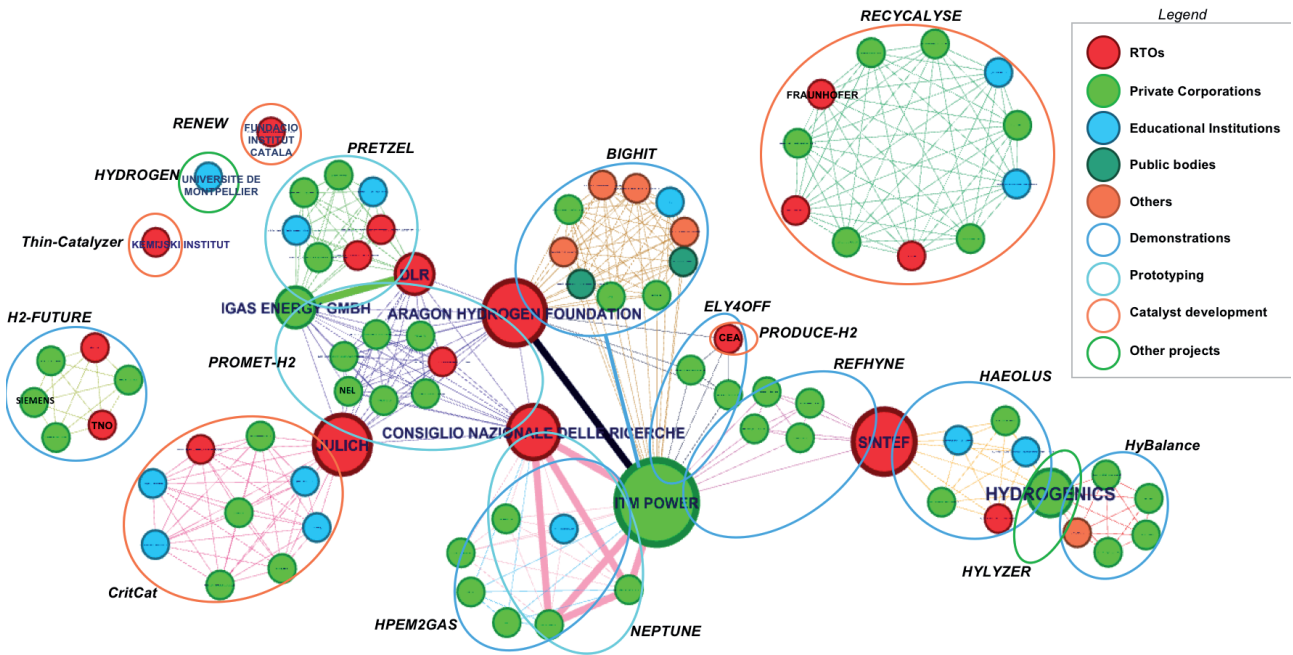


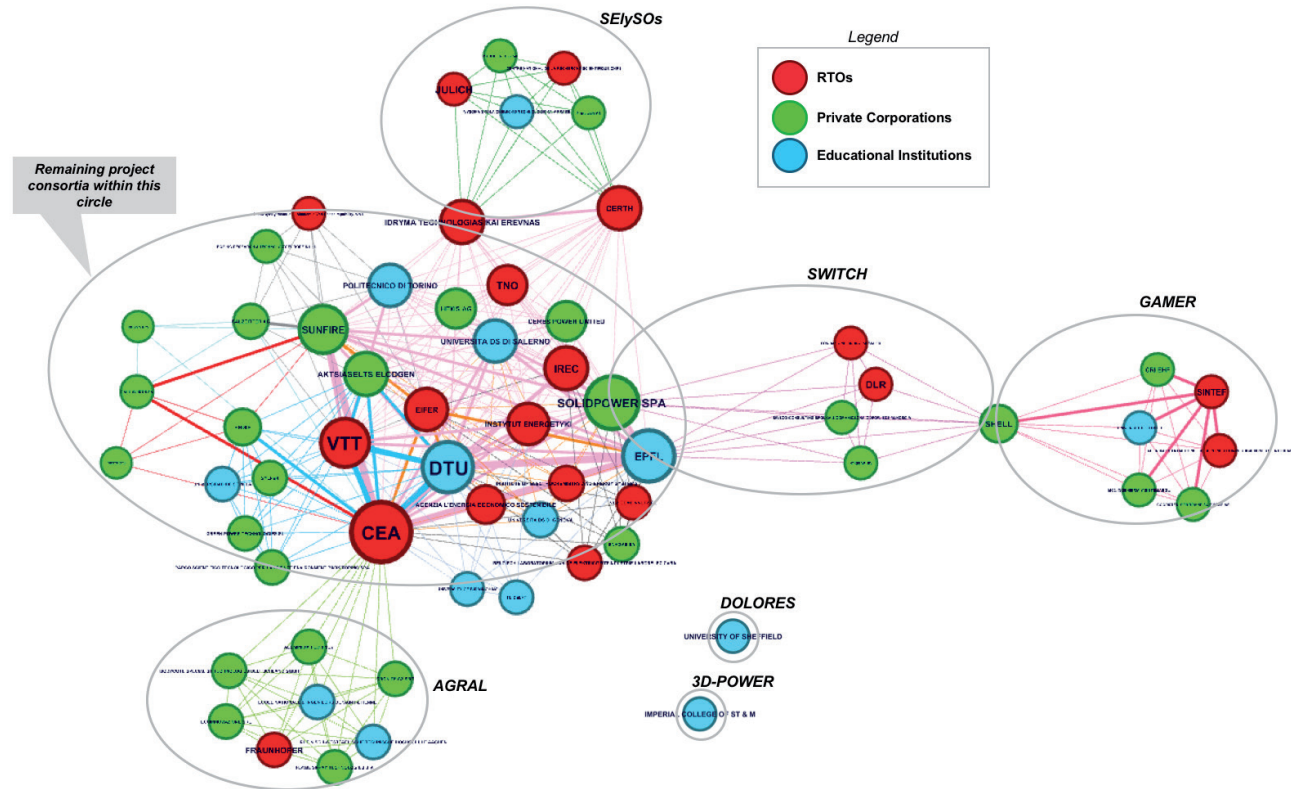
Figure 1: Network of organizations involved in FP6, FP7, H2020 electrolysis related R&D. 70 electrolysis related projects (from 2003 to-2019). The nodes i.e., circles represent organizations and thenode size represents number of partnerships, which is based on projects they have been involved in. Lines (and their thickness) imply partnerships in the projects (with a thicker line representing multiple instances of partnerships). SOURCE: Safwan Shurieh, 2020 (TNO / TU Delft).

RTOs play a key role in bridging the gap between academia and industry

PEM



SOE network



Alkaline network

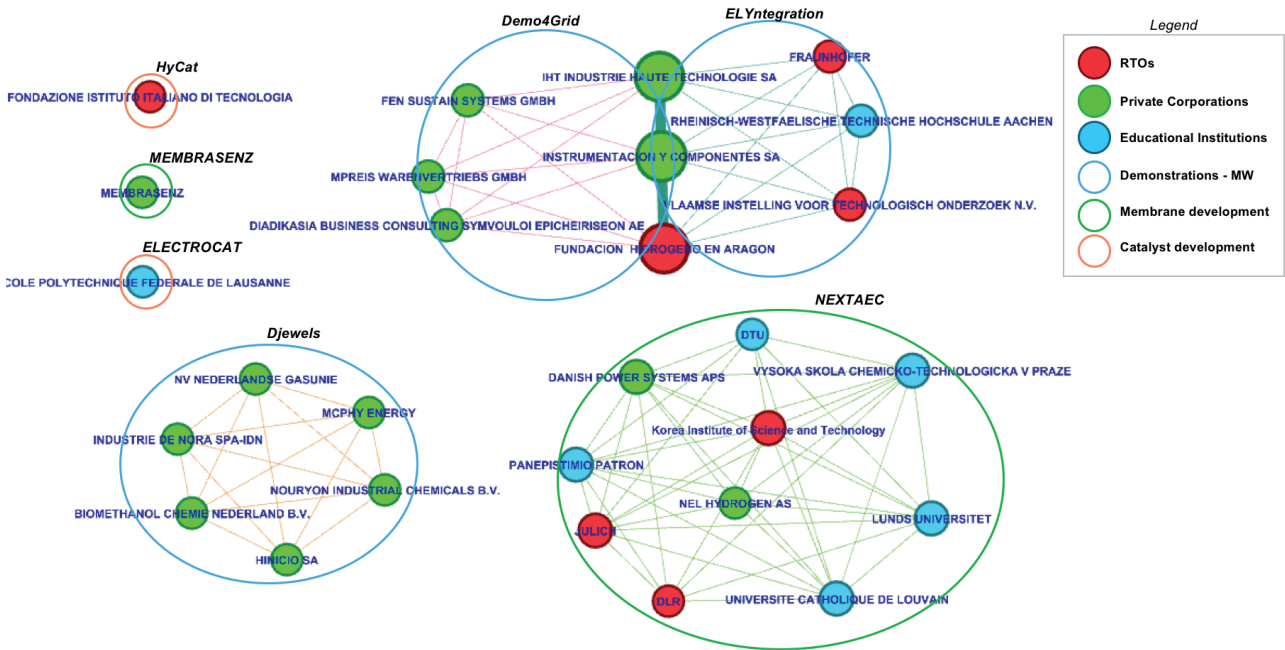


Figure 2: A specific view of the PEM electrolyser network (top) shows how RTOS (red), even though relatively few in numbers, act as bridging actors between project consortia. Similar analysis was done for SOE (middle) and Alkaline (bottom). SOURCE: Safwan Shurieh, 2020 (TNO / TU Delft).



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To provide some concrete insights in the on-going activities of RTOs involved in electrolysis development, please refer to [Appendix 1 and 2](#) which provides a basic overview of current focusarea's for the authors involved with this initiative as well as a number of other RTOs active in the field.

4. OPPORTUNITIES FOR JOINT ACTION

With the challenges provided in Section 2 as an urgent call for action, and with the strengths portrayed in Section 3 as a broad basis for solutions, this section presents a proposal for a shared effort. Based on a series of conversations and meeting of minds, involving key experts from five RTOs, with additional input from experts, three sets of opportunities have been identified to accelerate the developments for upscaling of WE technology. For each opportunity, concrete steps have been identified (Figure 3) to take that fall within the responsibilities of Europe’s RTOs (and other research organisations).

HySpeedInnovation how research institutes can help accelerate industrialization of water electrolyser production

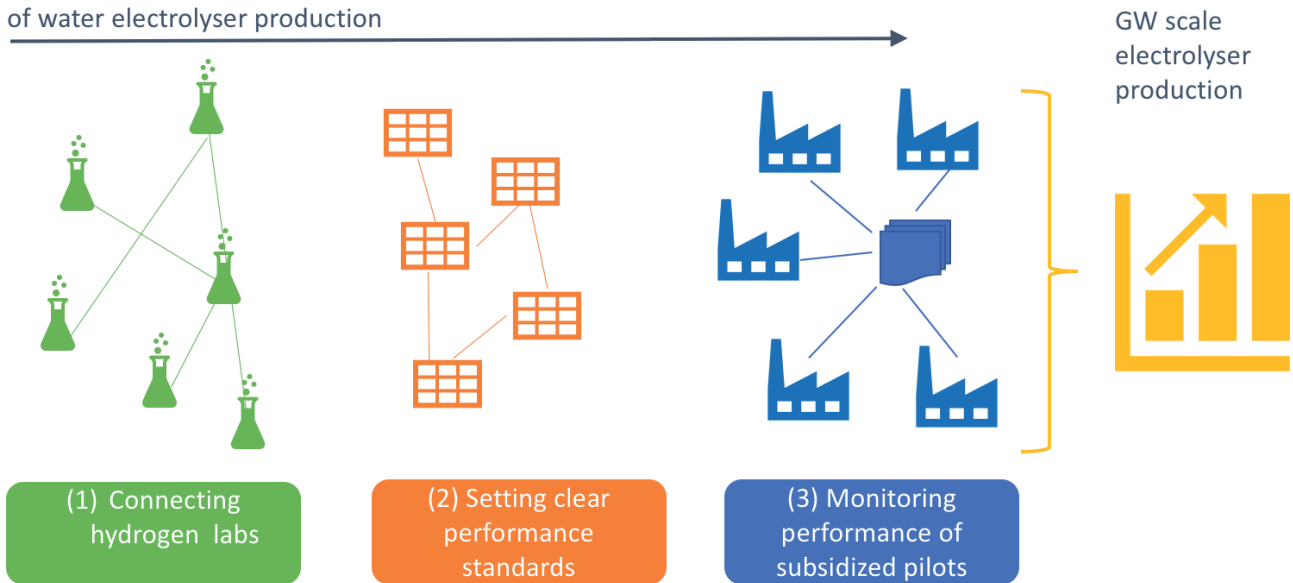


Figure 3: Opportunities for joint action.

For each opportunity, concrete steps have been identified to take that fall within the responsibilities of Europe’s RTOs. However, for each opportunity, some requirements will have to be met that lie beyond the direct influence of RTOs. It is here that we call on the responsibility of policy makers on the national and EU levels, to facilitate the proposed effort.

(1) Connecting hydrogen labs

Challenge: Laboratory activities and infrastructure are currently insufficiently aligned. This results in a sub-optimal capacity for learning. Also, if industry activities ramp up, due to rising market demand, the EU capacity for performance testing and validation will soon be scarce. Finally, for the more expensive lab assets, it is crucial to align investments and jointly accelerate the supply chain of material, component and system suppliers for electrolysers.

Solution: The approach here is to work towards a shared R&D infrastructure for testing and validation by aligning and connecting lab and R&D infrastructure, e.g. pilot lines. This way we can improve the accessibility, effectiveness and impact of Europe's R&D capacity. The benefit is that European industries gain access to a broad basis of support for testing, validation and benchmarking. This helps new high-tech companies in their product development and enables them entering the electrolyser supply chain. Also, large investments in key demonstrator facilities, for higher TRL, become more viable.

Joint action(s):

- Develop a shared reference database concerning assets, equipment, testing protocols, parameters, Key Performance Indicators.
- Enlarge impact of national labs by sharing references on the performance of components and stacks for comparison.
- Organise Round Robin testing to align and harmonize methods and results.
- Exchange programme for personnel.
- Involve industry and their labs (especially also SMEs).

Needs: A funded programme aimed at improved data sharing across RTOs, developed and supported by leading national governments and/or EC.

(2) Setting clear performance standards for the European market

Challenge: Performance data are of limited access and availability should be improved. To enable the meaningful comparison of performance evaluations across laboratories, there is a need to harmonize performance standards, testing protocols and testing hardware. This is not just a challenge for purposes of research and innovation, but it is also related to the possibility of fair market competition within Europe and globally. Clear performance standards may strengthen the position of companies with a unique selling point for high quality, durable and sustainable solutions.

Solution: To set up performance standards that provide direction to the development of materials, components and electrolyser systems. In addition to the testing protocol proposed by JRC for EU harmonised polarisation curve test method for low-temperature water electrolysis (EUR 29182 EN, 2018), these should be targeted at:

- Quality: efficiency, durability, costs, hydrogen purity, other key metrics.
- Sustainability: to help incentivize limited use of scarce materials, and extra focus on a circular design and recycling strategies.
- Safety: to have a clear reference for safety requirements.

Joint Action(s):

- Agree on minimum requirements for Quality, Sustainability, Safety.
- Agree on associated measurement protocols.
- Develop harmonized test protocols, e.g. Accelerated Stress Test methods, to enable accurate and efficient measurement of electrolyser performance over long duration and cyclic operation.
- Lobby for shared quality standards for EU regulated procurement programmes.
- Involve industry and their labs (especially also SMEs).
- Involve manufacturers, customers, other stakeholders (e.g. fire brigade).

Needs: Governments should set requirements for minimum quality standards, including but not limited to long-term durability, e.g. as materialised in tender specifications. These should demand high quality in terms of various dimensions (also safety, circularity, performance, sustainability). Not solely focusing on costs.

(3) Monitoring performance of subsidized pilots

Challenge: Availability of detailed data on the performance of electrolysers is crucial for speeding up innovation. This is of critical importance for system developers themselves, but also component and material developers in the supply chain.

As the first large scale green hydrogen pilots will be heavily subsidised by both European and national governments, we argue that data sharing of the electrolyser and system performance should be a prerequisite to accelerate the market and innovations.

Solution: The European Commission could put the JRC in a position, as an independent actor, to gather and aggregate all data. RTOs can provide a data structure and methodology for aggregating and processing the data.

RTOs can then play a role in systematically processing and analysing the anonymized aggregated data from subsidized pilots / demonstration projects according to the FAIR principles (cf. <https://www.nature.com/articles/sdata201618>).

This has successfully been done in the US through the DoE hydrogen program.

Joint actions:

- Develop a database containing detailed performance data from the first large electrolyser systems.
- Develop methodologies by which data / critical insights can be aggregated and shared without influencing markets and competition. For example, data on electrolyser performance, efficiency, durability.
- Find a way to collect non-technical learnings, e.g. relevant process features. For example by conducting cross-project workshops to share non-technical learnings'
- Start a discussion on which data can be accessed? And on FAIR data / formats.

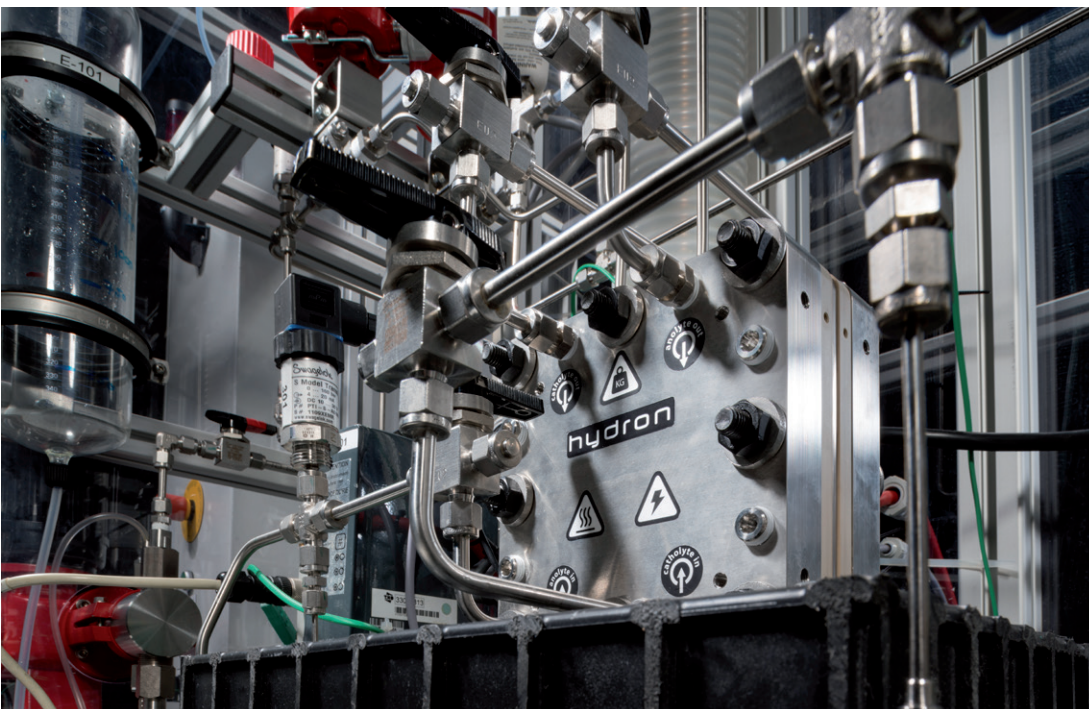
Needs: Governments, EU and member state levels should make sharing of data and learnings of the subsidised research, demonstration and pilot projects mandatory and would propose JRC as an independent actor for the creation and the coordination of a data safe house with Open Access policy for sharing aggregated data and learnings

5. THE WAY FORWARD / DEMANDS

It has been established that there is a critical role to play for Europe's RTOs, in the upscaling and industrialisation of WE systems.

There lies great opportunity in a series of strategic joint actions, aimed at cooperating, aligning and generally making optimal use of existing research and innovation infrastructure.

In order to leverage our current positions in support of a strong and well-aligned shared innovation ecosystem, European RTOs believe that strategic cooperation is required on topics around 'linking up laboratories', 'establishing shared quality standards' and 'organizing ways of sharing aggregated data and learnings around pilot lines and demonstration projects'.



TNO en fotograaf Eric de Vries

In order to do this well, European RTOs call for support from national governments and EU policy makers on the following topics:

- An EU funded programme aimed at facilitating the establishment of a coordinated EU infrastructure enabling to use / share water electrolysis testing facilities with improved data sharing across RTOs, developed and supported by leading national governments.
- An EU funded programme aimed at developing harmonized performance, safety, sustainability and quality standards setting international minimum requirements for (components within) electrolysers, e.g. as materialised in tender specifications.
- The creation of an Open Access policy for sharing aggregated data and learnings. Governments should make sharing of data and learnings of all subsidised research, demonstration and deployment projects mandatory.

Appendix 1: RTOs and their relative technology focuses

Organisation	Core topics	PEM	Alkaline	SOE	AEM	Remarks
CEA	Top player on SOE. Strong IP position. Integrated approach, involving industrial stack B12 manufacturers, component and cell suppliers. Focus on cost reduction and industrialisation (MRL). Roadmap: 80kW 2021, 300kW 2023. Active on MEA fabrication and PEM cells and stack testing.					Including modelling tools, LCA, eco-design and recycling.
CIEMAT	Focus on catalysts, electrode fabrication and cell design Active on MEA fabrication using electrospray deposition PEM testing and validation, design of portable systems Microstructural and electrochemical characterization of components					Capacity for systems integration. Socio-economic studies including LCA
DLR	DLR is the key player in development and application of fuel cell technology for mobility (road, rail, sea, air). A special emphasis of DLR research is placed on electric flight. DLR covers the complete value chain from hydrogen production over storage and distribution to stationary and the mentioned mobility applications.					
FBK	Key EU player on SOE with relevant link to industry Strong competence on SOC reversible systems and co-synthesis processes (Ammonia) Joint labs with industry. Technology validation and testing on most of the key electrolysis technologies. Competence on AEM, with dedicated test benches on technology					Numerical simulation. Dynamic modelling connected with design of control strategies and logics. Focus on materials, components, system integration and advanced controls.
FC Jülich	R&D on PEM, Alkaline and SOE. Focus on transforming electrocatalysts, materials and components for cells, stacks and systems Active on AEM electrolysis for water and CO2 Unique expertise in thin-film fabrication and infrastructure for cell and stack durability testing.					
Fha	Design, development and implementation of BOP design and cost optimization. High pressure testing; Standardized testing protocols for electrolyzers to perform electricity grid services Capacity for systems integration. Experimental validation of results obtained by modelling. Socio-economic studies.					Recently planning and organizing capacities and infrastructures to foster hydrogen technologies and aligning Europe research. Research lines are in expansion towards AEM electrolyzers.
Fraunh. IFAM	Dedicated to Alkaline Electrolysis, also AEM. Focus on material science and technology to support industry in a.o., the following key areas: Recyclable materials and production technologies, integration of sensors, electrode fabrication, cell design. Testing capabilities cm2 – 0,5 m2 electrode size.					Fraunhofer is connected through Hydrogen Network
Fraunh. IPT	As an institute for production technology, Fraunhofer IPT deals with questions of component production for PEM electrolyzers and fuel cells.					
Fraunh. ISE	Top player on PEM. Coordinator in Hydrogen Europe. Provides solutions to manufacturers based on integrated approach. Know-how on producing components for purposes of customer tailored testing & validation. Work closely together with industry.					Focus on system integration. Including modelling tools, LCA, etc. Know-how on Manufacturing Fraunhofer is connected through Hydrogen Network
HyCenta	Integrated approach & developments on cell, stack and system level supported by different simulation models Focus on system integration, BoP components, controls and testing, Close connection to industry and implementations					Testing capabilities: up to 150 kW
IREC	Top player on SOE. Also working on PEM catalysts. Integrated approach involving cell and stack manufacturers Focus on materials and new manufacturing pathways Testing and validation capabilities at cell and stack level.					Specialized know-how and facilities on advanced manufacturing.

Organisation	Core topics	PEM	Alkaline	SOE	AEM	Remarks
SINTEF	<p>Top player on PEM.</p> <p>Integrated approach, involving stack manufacturers, component and MEA suppliers.</p> <p>Focus on solutions that can be implemented on large scale. E.g. not using scarce materials.</p> <p>IP position on Tubular Proton Ceramic Electrolyser.</p>					<p>Does not work on membranes / diaphragms</p> <p>Specialised Know-how on Production planning / Design of Production Facilities/ Manufacturing</p>
Tecnalia	<p>Focus on component level: MEA (catalyst, membrane, coatings)</p> <p>Experience on Alkaline electrolysis</p> <p>Capabilities on power electronics for coupling with renewables</p> <p>Capabilities on recycling of critical materials.</p>					<p>Focus on key components for cells and stacks</p> <p>Focus on power electronics for coupling with renewable energy</p> <p>Strong in recycling of critical raw materials, e.g. relevant for PEM</p>
TNO	<p>Focus on component level (e.g. MEAs) prototyping in combination with modelling, testing and validation</p> <p>Active in Automation, Manufacturing Technologies.</p> <p>Application / System Integration in combination with Modelling, Testing and Validation.</p> <p>Close collaboration with industry. On technology issues and business / supply chain / ecosystem support.</p>					<p>Capability for testing ranges from cm2 to m2 / MW-scale</p>
ZSW	<p>Focus on AEL from materials to system integration and monitoring in the MW-class</p> <p>PEM and AEM concept studies</p> <p>Innovative electrolysis reactor concepts</p>					<p>Electrolyzer testing capabilities from small single cells to 500 kW Stacks</p> <p>Electrolysis block and system design experience.</p>

Appendix 2



CEA is a Research and Technology Organization of 16,000 employees, covering fundamental to technological research to help resolve the main EU challenges (low carbon energies, defence, information and healthcare technologies). The Laboratory for Innovation in New Energy Technologies (LITEN, 950 people) is fully dedicated to the program of new technologies for renewable energy and energy efficiency. On hydrogen technologies and in particular on electrolysis, the research field covers cells developments, electrochemical characterization from button cells to stacks and systems, supported by microstructure advanced characterization, diagnostic and modelling, as well as techno-economic and life cycle assessment. A 700 m² lab is dedicated to SOFC/SOEC electrochemical tests, from button cells to stacks and systems, equipped with different fuels (H₂, CH₄, CO₂, CO). Button cells, short stacks and large stacks (up to 20 kWel) test benches are available, one being pressurized. They are used for performance and durability tests. A prototype of an integrated SOFC/SOEC system is operational. CEA is involved in various national and EU research and demonstration projects related to hydrogen production and/or fuel cells and their integration with renewable energy and the electricity grid.



DLR is the key player in development and application of fuel cell technology for mobility (road, rail, sea, air). A special emphasis of DLR research is placed on electric flight. DLR covers the complete value chain from hydrogen production over storage and distribution to stationary and the mentioned mobility applications.



The two **Fraunhofer** institutes Fraunhofer ISE and IFAM belongs to the German Fraunhofer Society which is the largest organization for applied research in Europe.

Fraunhofer ISE works in the field of hydrogen technologies and water electrolysis since more than 30 years. Current research work focus on PEM technologies, either for fuel cells and electrolysis and comprise fundamental investigations of cell components as MEA and PTLs, degradation mechanisms, cell and stack design, CCM manufacturing, cost models and reduction strategies and system integration....Fraunhofer IFAM specializes in Alkaline and AEM electrolysis, thus, avoiding any precious metal catalysts. IFAM develops materials and production technologies, mainly for electrocatalysts and electrodes, and conducts cell as well as stacks tests under realistic operation conditions. Moreover, accelerated stress protocols are developed to shorten the R&D phase.



Fraunhofer IPT: As an institute for production technology, Fraunhofer IPT deals with questions of component production for PEM electrolyzers and fuel cells. For this purpose, IPT develops processes for the production of PTLs and bipolar plates, processes and special machines for the production of MEAs as well as processes and plant engineering for the automated assembly of electrolyser components. In addition to process- and plant-related research questions in the field of forming and coating processes, the IPT develops solutions for quality assurance using digital methods.



The Foundation for the Development of New Hydrogen Technologies in Aragón (FHa) is a private non-profit organization promoted by the Regional Government, other public bodies and private companies. Over the last seventeen years, the FHa has been supporting the regional strategy for the uptake of hydrogen and fuel cell technologies, publishing the Hydrogen Master Plan in Aragón (2007-2010, 2011-2015 and 2016-2020), and showcasing the whole hydrogen chain from production to the efficient use. The facilities include hydrogen production means (PEMWE as well as AWE), storage, dispensing at 200 and 350 bar and ultimately the use in fuel cells, including hydrogen-powered vehicles.



HyCentA Research GmbH is the only extra-university research institution in Austria exclusively concerned with hydrogen technologies. Since its foundation in 2005, HyCentA is performing R&D projects in an international network with industry and academia regarding production, distribution, storage and application of hydrogen. The fields of expertise include research, engineering, simulation, testing and education of hydrogen technologies like electrolysis, gaseous storage systems, fuel cells, refuelling, measuring and safety systems. HyCentA is operating a modern research infrastructure with highly qualified staff at the facilities of Graz University of Technology. The research infrastructure consists of the real gas high pressure test stand up to 1000 bar, electrolysis test stand, the hydrogen refuelling infrastructure for 350 and 700 bar, two flexible test cells for components and systems, and the fuel cell system test bench which enables comprehensive investigations of fuel cell systems up to 160 kW in a virtual environment simulating dynamic operation and real ambient conditions.



IREC is a public research institution under the trust of different governmental and private organizations which include leading energy companies such as ENDESA, NATURGY and ENAGAS. IREC is founder member and stakeholder of the Knowledge and Innovation Community for Sustainable Energy (KIC Innoenergy). IREC's mission is to contribute to the sustainable development of our society by generating research of excellence, building new technologies and ensuring universal access to abundant, inexpensive and sustainable energy. On hydrogen production by water electrolysis, IREC has a dedicated team and world-class facilities for developing SOE cells and stacks beyond the state of the art. IREC has developed SOE proprietary technology and possess testing facilities up to 10kW.



Institute for Sustainable Process Technology (**ISPT**) is an independent foundation. We believe that radical change can be achieved through technological innovation and cooperation. As an active and open innovation platform for sustainable process technology we connect stakeholders from different sectors and disciplines. At ISPT, industry, SMEs, scientists and governmental bodies find the inspirational and trusted environment where they can optimally work together to stimulate breakthrough innovations.



The **Forschungszentrum Jülich** ("Jülich Research Centre") is a member of the Helmholtz Association of German Research Centers and is one of the largest interdisciplinary research centers in Europe. The transition to a sustainable energy system requires the deployment of new, efficient technologies for the conversion of greenhouse-gas-free secondary energy carriers produced from renewable energy sources. The IEK-14 is at the forefront of these efforts. In collaboration with national and international partners from research and industry, we develop solutions for mobile, portable, and stationary applications, and conduct research into using liquid energy carriers as fuels as well as producing and using them in an efficient, environmentally compatible manner. In addition, we work on groundbreaking innovations for electrochemical conversion systems for the direct generation of hydrogen, syngas, and power by means of electrolysis, co-electrolysis, and fuel cells. The electrochemistry electrolysis department covers areas in electrochemistry related to the synthesis of nanostructures, fuel cells and electrolyzers testing, development of novel characterization methods, and fabrication of electrodes and thin films.



SINTEF is an independent non-profit multidisciplinary contract research organisation that performs research and development for national and international industry and public sector. SINTEF main offices are located at Trondheim and Oslo in Norway. SINTEF staff is about 2000 from 75 nationalities. SINTEF has a high level of activity in connection with Horizon 2020. As of October 2020, SINTEF successfully coordinated 57 projects in H2020 and participated in an additional 218. The EU has in H2020 awarded SINTEF a total of EUR 148.5 million in funding. SINTEF has research activities on PEM and alkaline electrolyzers including AEM as well as high temperature proton conducting electrolyser. The activities range from development of operational and investment strategies for large scale electrolyser plants to catalyst and component development for beyond state of the art. SINTEF is the host of the Norwegian national infrastructure on fuel cells and electrolyzers which includes test stations for single cells and stacks up to 10kW and is planning expansions towards larger Power-to-X infrastructures. SINTEF has a long track record in organizing and aligning research infrastructures in Europe, e.g. through the ECCSEL ERIC.



TECNALIA RESEARCH & INNOVATION is a private, independent, non-profit applied research centre of international excellence. Legally a Foundation, TECNALIA is the leading private and independent research and technology organisation in Spain and one of the largest in Europe. In the field of electrolysis, TECNALIA has experience on Alkaline-type electrolyzers, in particular, on the development of key components for the cells and stacks, e.g. membranes, electrodes, etc. In addition, TECNALIA has experience on Power electronics that is required for coupling the electrolyzers with renewable energy. Moreover, TECNALIA has strong background on recycling of different critical raw materials, that will be needed for large-scale implementation of some of the electrolysis technologies, such as PEM.



TNO is an independent research organization. TNO connects people and knowledge to create innovations that boost the competitive strength of industry and the well-being of society in a sustainable way. This is TNO's mission and it is what drives the over 3,200 professionals in their work every day. TNO is one of the leading applied research institutes in the field of hydrogen. More than 15 research departments spread over 5 units are collectively working on innovations along the entire hydrogen value chain from production to infrastructure, storage and final applications. TNO is involved in over 50 hydrogen related projects in 2020 only. From developing new materials for PEM and SOE in our Faraday lab, test on industrial scale up to 2.500 cm², 250 KW in the Hydrohub and in our new power2X fieldlab Rotterdam. We work on pre-feasibility and engineering studies for large scale deployment in project such as NorthH2 and the Gigawatt project. We identified over 150 high tech companies in the Netherlands who are, or are becoming, active in the hydrogen supply chain for developing novel materials, components and new manufacturing technologies. With our facilities it is possible to speed up the R&D process and time to market for the industry.



VTT Technical Research Centre of Finland is a fully state-owned Research and Technology Organization (RTO) and operates under the mandate of the Ministry of Economic Affairs and Employment. Among the key research areas today are clean hydrogen, P2X, and fuel cells from single components to complete systems. VTT's hydrogen research supports the industry in its product development by maintaining a large selection of research facilities, modelling tools and know-how encompassing different technologies throughout the entire business chain. VTT maintains an extensive hydrogen laboratory infrastructure. They include several SOFC/SOEC stack test rigs and component test stations with high developed automated control systems, catalyst/adsorbent test station, and hydrogen purity analysis equipment. VTT has a thermally self-sustainable 12 kW SOEC system suitable for steam and co-electrolysis. In addition, VTT has a mobile unit for Fischer-Tropsch synthesis and methanation, which can be combined with different electrolysis technologies.



The Solar Energy and Hydrogen Research Center Baden-Württemberg (**ZSW**) is one of the leading institutes for applied research in the fields of photovoltaics, renewable fuels, battery technology and fuel cells as well as energy system analysis. Approximately 280 scientists, engineers and technicians are currently working in the three ZSW laboratories in Stuttgart, Ulm and Widderstall. Besides R&D in Photovoltaics and system analysis, ZSW is actively pursuing research and development work for high power water electrolyzers in its Stuttgart laboratories. Further activities are in design and monitoring power to X technologies as well as industrial electrolyzer sites. ZSW's range of competencies at its Ulm laboratories covers the entire value chain of batteries and fuel cells: from modeling and simulation of electrochemical processes, synthesis and characterization of active materials, optimization of components and technologies for their serial production to the demonstration of prototypes. State-of-the-art test facilities enable comprehensive testing, evaluation and qualification of components and systems in terms of performance, service life and safety.