HyScaling

Public end report

August 2024

RVO project nr. MOOI 42010
MOOI regeling 2020: Industrie, Toepasbaar maken van waterstofproductie vanuit elektriciteit

Institute for
Sustainable
Process Technology

TNO innovation for life

Project: HyScaling

RVO project nr. MOOI 42010

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Het project is uitgevoerd met Topsector Energie subsidie van het Ministerie van Economische Zaken en Klimaat, uitgevoerd door Rijksdienst voor Ondernemend Nederland. De specifieke subsidie voor dit project betreft MOOI-subsidie ronde 2020.

1) Goal, starting points and partners

Goal of the project and starting points

The need to produce green hydrogen as a feedstock and as energy carrier is large and urgent in The Netherlands. Nowadays, hydrogen is made from natural gas (a fossil fuel) by steam reforming. Green hydrogen can be made by electrolysis of water.
However, to make the large amount of hydrogen which is needed, the capacity for producing electrolysers must be enlarged. Moreover, costs of producing hydrogen, using electrolyzers must be strongly reduced.
To address these challenges, 29 innovative companies, SMEs, RTO's have joined forces in the Hyscaling project.

The specific objective of HyScaling is to achieve 25-30% cost reduction for levelized cost of hydrogen compared to the state-of-the-art at the beginning of the project by bringing the HyScaling innovations to full implementation and roll-out by 2030. In HyScaling novel hardware, low-cost manufacturing processes, optimized integrated system designs and advanced operating and control strategies are developed that all contribute to the overarching target.
HyScaling aims also to establish a Dutch electrolyzer industry e.g. community. More than half of the consortium partners aim to enter the market by making their innovations into products.

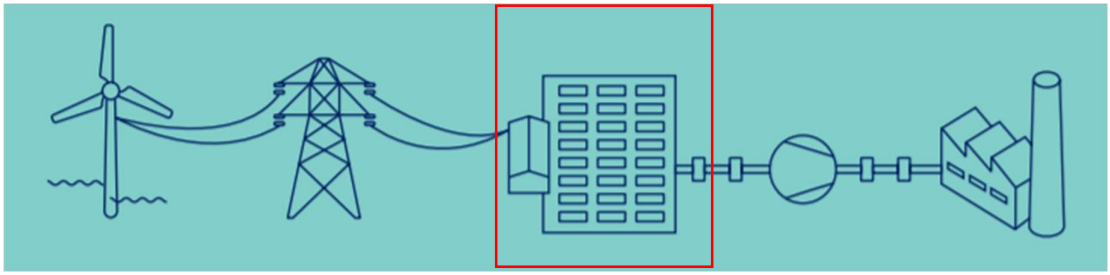


Figure 1: Schematic presentation of steps between green electricity and application of hydrogen; electrolysis is in the middle.

The HyScaling work and deliverables are organized following 6 main result areas:

1. **Use cases** – 4-5 use cases are fully expanded, with scope, technology baseline and cost-models to assess progress beyond state-of-the-art and cost reduction potential.
2. **Component and stack performance optimization** – identification of the best performing innovative components and materials for alkaline and PEM electrolysis – focused on performance, lifetime and manufacturability.
3. **Advanced Alkaline Electrolyzer development** – use-case focused optimized novel components, stack designs for increased manufacturability and innovative system designs reaching 25% lower cost of hydrogen in 2030.
4. **Advanced PEM Electrolyzer development** – novel membranes, electrodes, catalysts for higher performance and durability, advanced stack and system designs leading to a 30% lower cost of hydrogen in 2030.

5. **Validation @scale** – performance and scalability of innovations demonstrated in full-stack prototypes for alkaline and PEM at TRL 6.
6. **Action Plan** – analysis of public support, human capital, legal barriers and identification of robustness of the supply chains and business cases result in *Action Plans* towards full roll-out and implementation by 2030.
    - Characterization procedures and accelerated stress tests to address a lack of benchmarking tests for electrolyzer components
    - Development and testing of a kW range alkaline stack and an alkaline stack suitable for large-scale
    - Experimental validation of selected novel PEM components tested in an available full-scale PEM test stack

Project duration

Start project: 11. June 2021
End date: 1. July 2024

Project partners

1. Stichting ISPT (penvoerder (secretary)) - *Amersfoort*
2. Brabantse Ontw. Mij.. - BOM Business Development & Foreign Investments B.V.- *Tilburg*
3. Borit N.V. – *Geel (B)*
4. Brainport Development NV - *Eindhoven*
5. Danieli Corus B.V. – *Velsen-Noord*
6. Delft IMP (Powall) - *Delft*
7. DotX control Solutions BV - *Haarlem*
8. EnTranCe, Centre of Expertise Energy, Hanzehogeschool Groningen - *Groningen*
9. Vereniging FME - *Zoetermeer*
10. Frames Group BV / Plug Power – *Alphen aan den Rijn*
11. Fraunhofer Institute IPT – *Aachen (D)*
12. GreenbergTraurig LLP - *Amsterdam*
13. HyCC B.V. - *Amersfoort*
14. IHI Hauzer Techno Coating B.V. - *Venlo*
15. Ionbond Netherlands B.V. - *Venlo*
16. MAGNETO Special Anodes B.V. - *Schiedam*
17. MTSA Technopower B.V. - *Arnhem*
18. MX Polymers B.V. *Wageningen*
19. SALD B.V. - *Eindhoven*
20. Stichting S-ISPT - *Amersfoort*
21. Teijin Aramid B.V. - *Arnhem*
22. TNO – *The Hague, Amsterdam, Delft, Petten*
23. TU Eindhoven - *Eindhoven*
24. TU Delft - *Delft*
25. VDL Energy Systems B.V. – *Almelo*
26. Veco BV - *Eerbeek*

27. VONK EUA B.V. - *Zwolle*
28. VSL B.V. - *Delft*
29. ZEF B.V. - *Delft*

The advisory board of the Hyscaling project gives high-level guidance and feedback. The members are: Randolf Weterings (Port of Rotterdam), Ulco Vermeulen (Gasunie), Anne Mieke van der Werf (InvestNL), Jelle Blekxtoon (FME), Ad van Wijk (TU Delft), Mark Boneschanscher (TU/e), Michèlle Prins (Natuur & Milieu).

2) Results, Obstacles and perspectives for application

Project activities and schedule are presented in Figure 2.

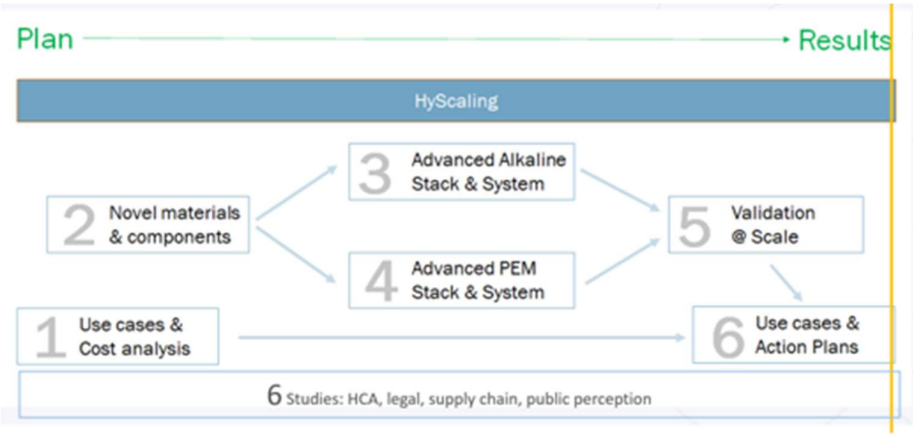


Figure 2: Schematic presentation of HyScaling work packages in sequence of executing.

In the first project year, technology activities focused on further exploration of possible innovations in the electrolyser technology, both alkaline and PEM. It resulted in: a) the set-up of a framework (use cases and models) to evaluate innovations, b) aligned test methods, c) positive test results of innovations.

In the second project year laboratory tests were executed for the innovations. Results were compared with performance of agreed reference materials. Exchange of knowledge and discussions about test results, material costs, life time expectations, reliability of stack components, interactions between system components led to improved system designs for 50 kW units AWE (VDL) and PEMWE (MTSA) and for a small AWE unit (ZEF).

Focus in the third project year was on validating innovations at scale, preferably in test systems between 50 and 500 kW, and on building improved stacks and systems.

The first study report was published in December 2022: Roadmap of the measuring requirements for green hydrogen production by electrolysis. Other study results followed, see list of publications in chapter 5.

More specific results are described in next chapters. It should be underlined here that the overarching project goals have been achieved:

- Tests and calculations show that the improved small AWE system meet the price reduction goal.
- A community of Dutch electrolyser industry parties has been formed and many HyScaling partners are contributing in several ways, see chapter 4.

Results

- Innovations PEMWE stack technology:
  - Setting up accelerated stress tests (AST) for PEMWE components (TNO)
  - New MEA-concept including PFAS free membrane (Teijin)
  - Dot-coating technology proven, with improved performance (Ionbond)
  - Alternative approach to optimize catalyst application in coating in MEA has successfully been applied and tested, in potential leading to strong reduction (3x) of for example Iridium use per GW (Powall)
- Innovations AWE stack technology:
  - Substrates with higher surfaces successfully applied and validated in a large test bed, in potential leading to higher performance compared to reference materials (VECO)
  - New coatings successfully applied and validated in a large test bed, in potential leading to higher performance compared to reference materials (Magneto)
  - Application of innovative ALD-technology for putting precious metals on electrodes proven at lab-scale (SALD)
- Innovations PEMWE systems:
  - Optimization of the balance of plant for a PEMWE with their own test system as starting point and worked out improved design (MTSA)
  - Optimized operation strategies for fluctuating power sources (TNO), taking into account:
    a) membrane degradation, influenced by hours of operation and by total amount of start and stops;
    b) performance effects by splitting stacks in groups with sequential switching or not and apply a total parallel approach
  - Optimized process control approach reducing the bandwidth in which a stack is operated. It leads to an overall better stack performance (DotX control)
- Innovations AWE systems
  - Development and patenting of new type of hydrogen sensor. Typical for this sensor are its reliability and low costs (ZEF)
    It enables ZEF to produce high quantities of hydrogen in a safe way.
  - Small AWE unit based on improved design has been built and tested.
    ZEF has reviewed all choices within their electrolyser system, fed by Solar power, and calculated the cost reduction potential by applying these new choices and producing their system in high quantities.
    Calculations show that the levelized costs of hydrogen, produced by the ZEF electrolyser system, is more than 25% cheaper than the reference case.
  - VDL has built and tested its own electrolyser system, 50 kW, based on improved design, making use of insights in AWE project team.
  - A vision document has been set up for autonomous hydrogen plant (ISPT)
- Study results
  - Roadmap of the measuring requirements for green hydrogen production by electrolysis
  - Potential cases for electrolysis as solution for grid congestion

- The public perception of green hydrogen in The Netherlands
- Next steps towards autonomous hydrogen production. Varieties of industrial policy: the case of upscaling electrolyser manufacturing in Flanders and Germany.
- Report on the EU Carbon Border Adjustment Mechanism (CBAM)
- HyScaling Use cases (internal)
- HyScaling Action Plan (internal)

It is expected that many technical findings in the project will be part of future electrolyser systems.

Obstacles

The challenges of a system change: The introduction of hydrogen as feed-stock and energy carrier is part of the energy transition, which requires innovations, but is in itself a system change. This system change includes all aspects of our society. For many aspects, which are also relevant for the use cases in this project, as pricing, trading conditions, industry policies and regulations, permitting requirements, availability of infrastructure and standardization no reliable information was available at the moment of executing the project and for 2030. Consequently, the techno-economic evaluation of the use-cases was limited. However, because the found limitations reflect the struggling of actors in the field, insights and derived importance of certain aspects will support decision making during the energy transition.

It was foreseen that technological innovations would be tested in the systems at the MW Test Center at ENTRANCE / Hanze Hogeschool. Unfortunately, commissioning of both systems were delayed and testing at full scale for the Hyscaling project had to take place in other systems.
For PEMWE team the system of MTSA was available in spring 2024. Components at which coating technology of Ionbond was applied, have been tested in this system.
The AWE team made use of the large test bed at TU Eindhoven. Results with this test bed can easily be translated to real systems.

Perspectives for application

Figure 3 shows the supply chain for electrolyser systems. Everyone will recognize, based on this figure, that electrolyzer systems are complex and that a promising innovation in one step needs to be proven as attractive in the whole system.

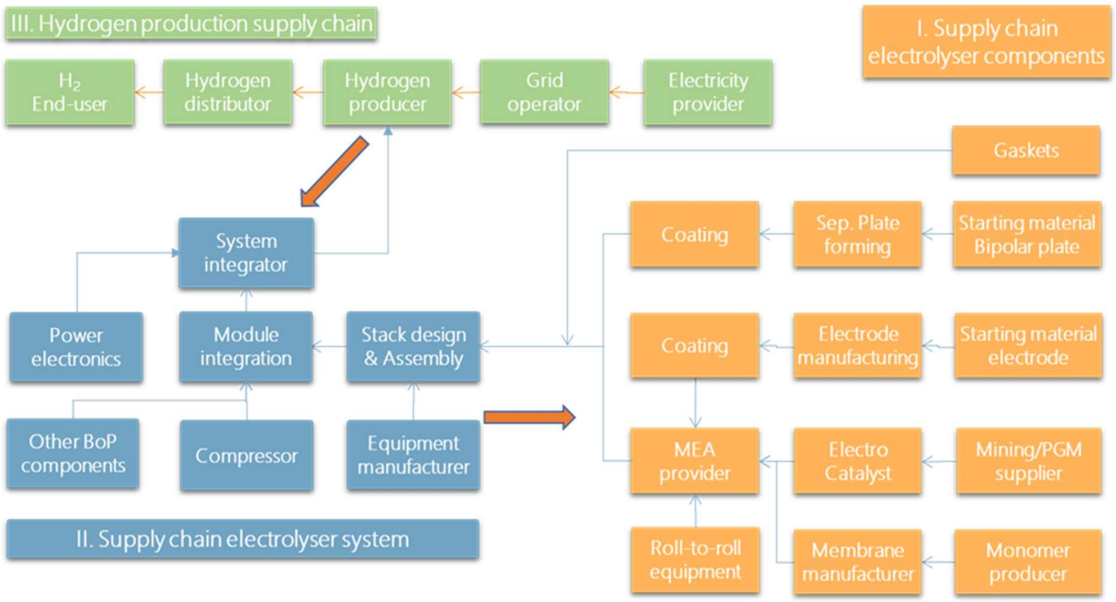


Figure 3: The Supply Chain overview for delivery of Electrolyzer systems from (I) Components to (II) Systems to (III) Hydrogen delivery to end-user. This example is for the PEM supply chain, alkaline supply chain is largely the same.

Fraunhofer IPT has successfully developed a calculation model in which the cost reduction of innovations and production optimization can be determined.

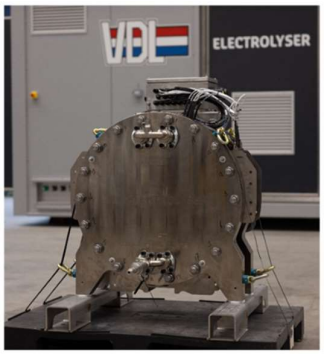
Many innovations of suppliers studied in the HyScaling project will be further optimized and tested in R&D projects already started or starting soon.
Hydrogen production companies have their requirements on costs, reliability, performance and life time. Based on first reports and calculations, using the model of Fraunhofer, it seems that 2nd and 3rd generation stack technologies have good chances to become competing for 1st generation stack technology.

Suppliers have worked out action plans to ensure steps are taken towards introduction of their technology in future electrolyzer systems.

ZEF has successfully tested the new design for a small AWE unit as developed in this project. From technical point of view their product has a very good perspective of being introduced and successfully applied in the future chain of energy carrier production.

Z E F
Zero Emission Fuels

VDL Groep B.V. has developed a roadmap for its activities in electrolyser systems, partly based on the successes from this project. It is difficult to look into the future, but given the fact that VDL can work on electrolysers both as an OEM and / or as a supplier, there is a good chance that this company with its industrialization experience will become an important player in this field.



Plug Power took over Frames, which participated in this project, in the first year of this project. It created the possibility for suppliers to connect to an OEM of PEMWE systems. Plug Power contributed itself to the use case and business case studies in the project, leading to useful insights for all parties involved.

VONK is already a commercial player in the world-wide electrolyser systems community. Studies done in this project related to system optimization show the possibilities and need to optimize and standardize power electronics.

3) Contribution of the project to the MOOI Goals

The project directly contributes to the MOOI Goal for industry: To develop cheaper, climate-neutral and / or circular products, processes and services that will lead to a first market application in one of the industrial sectors in the Netherlands that is significant for the climate objective by 2030 at the latest.

More specific it contributes to the subgoal: Making hydrogen production from electricity on a GW_e -scale applicable and enable its integration into production processes as feedstock and fuel for industrial processes, and its integration into the energy system.

4) Spin-off of the project within and outside the sector

An eco-system for a community of Dutch electrolyser suppliers is formed.

Many partners have contributed to the Dutch National Hydrogen Program, especially on the topic electrolyser systems manufacturing industry.

Many partners have extended their activities in the field of water electrolysers and are participating in other research and development projects or in demonstrations:

- 3 projects in Dutch subsidy Groeifonds NXTGEN HIGHTECH
    - ZEF + consortium
    - Phoenix Alkalina (VDL + consortium)
    - Gen3 Electrolyzer 16 partners (AWE, PEM, AEM, SOE, CO_2)
- HyPro – Work Package 1 GroenvermogenNL

Many industrial partners are expanding their activities to the commercial market.

VDL Hydrogen Systems B.V. has been founded. The company has strongly broadened its activities in the field of water electrolysers, partly based on insights gathered during this project.

VONK has introduced the brand name Neya for their standardized power electronic units and is setting up a new production site in Europe.

5) Publications about the project

Public reports presenting project results

I. van Waveren, T. (2022, 22 June). Progress 1st year HyScaling project. Institute for Sustainable Process Technology. https://ispt.eu/publications/progress-1st-year-hyscaling-project/
II. Baldan. A., de Groot, A., Workamp, M., & Persijn, S. (2022, 5 December). Roadmap of the measuring requirements for green hydrogen production by electrolysis, Institute for Sustainable Process Technology. https://ispt.eu/media/Hyscaling-Roadmap-of-the-measuring-requirements-for-green-hydrogen-production-by-electrolysis.pdf
III. Jansen, N., & Dowling, R.A. (2023, 24 March). Potential cases for electrolysis as solution for grid congestion, TNO. https://repository.tno.nl/islandora/object/uuid%3A491e3ff1-9109-4ae9-af0e-54c3f20ca27a
IV. Van Waveren, T. (2023, 7 August)). Progress 2nd year HyScaling project. Institute for Sustainable Process Technology. https://ispt.eu/publications/progress-2nd-year-hyscaling-project/
V. Jilderda, M., Reinders, R. (2024, 28 May) Next steps towards autonomous hydrogen production, Institute for Sustainable Process Technology. https://ispt.eu/publications/next-steps-towards-an-autonomous-large-scale-hydrogen-plant/
VI. Klösters, M. (2024, 9 July) The public perception of green hydrogen in The Netherlands, TNO https://ispt.eu/publications/the-public-perception-of-green-hydrogen-in-the-netherlands/
VII. Campbell – Johnston, K., Suurs, R., Groot, de A., (2024, 15 July) Varieties of industrial policy: the case of upscaling electrolyser manufacturing in Flanders and Germany, TNO https://ispt.eu/publications/varieties-of-industrial-policy-the-case-of-upscaling-electrolyser-manufacturing-in-flanders-and-germany/
VIII. Bodeliers, M., Hardy, R., (2024, 15 July) Report on the EU Carbon Border Adjustment Mechanism (CBAM), Greenberg Traurig Amsterdam https://ispt.eu/publications/report-on-the-eu-carbon-border-adjustment-mechanism-cbam/

Other publications may follow.

Webinars

1. HyScaling webinar: Exploring Technological Developments in PEM and Alkaline Water Electrolysis: https://ispt.eu/news/ispt-hyscaling-webinar/
2. HyScaling webinar 2: Economic and Public Aspects of Green Hydrogen Production: https://ispt.eu/news/hyscaling-webinar-2-economic-and-public-aspects-of-green-hydrogen-production/

Articles and news flashes

1) ISPT Project page: https://ispt.eu/projects/hyscaling-establishing-a-dutch-electrolyzer-industry/
2) ISPT News 1 July 2021: https://ispt.eu/news/hyscaling-green-hydrogen-as-an-economic-perspective/
3) TNO-website: https://www.tno.nl/nl/aandachtsgebieden/energietransitie/roadmaps/co2-neutrale-industrie/waterstof-voor-een-duurzame-energievoorziening/optimalisatie-productieproces-waterstof/waterstofproductie-het-economisch-perspectief-nederlandse-maakindustrie/

4) TNO-website: https://www.tno.nl/nl/aandachtsgebieden/energietransitie/roadmaps/co2-neutrale-industrie/waterstof-voor-een-duurzame-energievoorziening/optimalisatie-productieproces-waterstof/waterstofproductie-het-economisch-perspectief-nederlandse-maakindustrie/
5) Voltachem news: https://www.voltachem.com/news/hyscaling-establishing-a-dutch-electrolyzer-industry-for-the-next-level-of-green-hydrogen-production
6) Agro-Chemie: https://www.agro-chemie.nl/nieuws/tno-en-ispt-bouwen-aan-duurzame-waterstofketen/
7) Danieli Corus. (2021, 2 July). Green hydrogen as an economic perspective. Danieli Corus. https://www.danieli-corus.com/news/2021/07/02/danieli-corus-joins-hyscaling-consortium
8) Kiemt: https://www.kiemt.nl/nieuws/sleutelrol-met-hyscaling-programma/
9) MTSA website: https://www.mtsa.nl/nl/hyscaling-green-hydrogen-as-an-economic-perspective/
10) Alles over waterstof: https://allesoverwaterstof.nl/hyscaling-project-gaat-voor-duurzame-en-goedkope-waterstof/
11) Presentation Andreas ten Cate, seminar Energy Port Zeeland (25 november 2021): https://www.pc-nsp.com/nl/nieuws/380-webinar-grensoverschrijdende-samenwerking-in-de-wind-in-zicht
12) Publication Learning Communities: https://chemistrynl.com/wp-content/uploads/2022/02/Overzicht-stand-van-zaken-rond-Industriele-Learning-Communities_Sept2021.pdf
13) Spaans, C. (2021, 2 September). Nederland exportland voor elektrolysers – 'Maar dan moeten we wel gas geven!'. Innovation Origins. https://innovationorigins.com/nl/nederland-exportland-voor-elektrolysers-maar-dan-moeten-we-wel-gas-geven/
14) ISPT. (2023, 9 May). Electrolysis as a potential solution for congestion management. Institute for Sustainable Process Technology. https://ispt.eu/publications/electrolysis-as-a-potential-solution-for-congestion-management-use-case-study/
15) ISPT (2022, 23 May) MAGNETO: "Applying new technologies to contribute to the energy transition" https://ispt.eu/news/partner-in-the-picture-magneto/
16) ISPT, (2022, 18 August) Teijin: "The biggest challenge is changing human-behaviour" https://ispt.eu/news/teijin-the-biggest-challenge-in-the-energy-transition-is-changing-human-behaviour/
17) https://www.hightechnl.nl/energy/agenda/electrolysis-rd-acceleration-hyscaling-project-and-beyond/
18) https://www.tno.nl/en/newsroom/2022/10/breakthrough-electrolyser-development/
19) https://www.ipt.fraunhofer.de/en/projects/hyscaling.html
20) https://allesoverwaterstof.nl/hyscaling-project-gaat-voor-duurzame-en-goedkope-waterstof/
21) https://brainporteindhoven.com/nl/ondernemen-en-innoveren/cases/hyscaling-groene-waterstof-als-economisch-perspectief
22) https://research.hanze.nl/nl/projects/hyscaling
23) https://netwerk.wijzijnkatapult.nl/detail/2271/hyscaling/netwerk/
24) https://www.tno.nl/nl/duurzaam/co2-neutrale-industrie/schone-waterstofproductie/waterstofproductie-maakindustrie/
25) Recap of the ISPT Hydrogen conference 2023: Hydrogen Conference: what challenge are we currently facing? https://ispt.eu/news/ispt-industrial-hydrogen-conference-2023-learn-invest-and-time-for-action/
26) ISPT (2024, 19 February) https://ispt.eu/news/verlaag-de-kosten-van-waterstofproductie-door-investeringen-in-nieuwe-meetapparatuur/
27) ISPT (2024, 23 July): https://ispt.eu/news/hyscaling-advancing-green-hydrogen-in-the-energy-transition/

ISPT regularly posted updates about HyScaling project activities on Linked-In.

ISPT and TNO organized the event 'Electrolysis R&D acceleration: HyScaling and beyond' on the 5th of June 2024. During this event several results of the HyScaling project were presented.