Annual Report 2023

HyValue

Norwegian Centre for Hydrogen Value Chain Research

HyValue

Forskningssenter for miljøvennlig energi

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DESIGN **HALTENBANKEN**

Dear Readers

Increased use of hydrogen, produced in an energy-efficient way without CO_2 emissions, will be the foundation for a sustainable future. This is the overall goal of FME HyValue. HyValue brings together various actors in the "hydrogen family" from universities and institutes, from various industrial companies that have or will have a place in the production, transport, or use of hydrogen, and finally representatives from the public sector.

HyValue is now entering its second full year of full operation. Several of the doctoral students are on board, and the research partners have started work. Several project seminars and workshops, and not least webinars, were organized in 2023 and more will come in 2024. These arrangements are important arenas for learning, networking, and collaboration among the partners in HyValue.

Aasgeir Valderhaug
Director R&D in Elkem
Chair of the Board

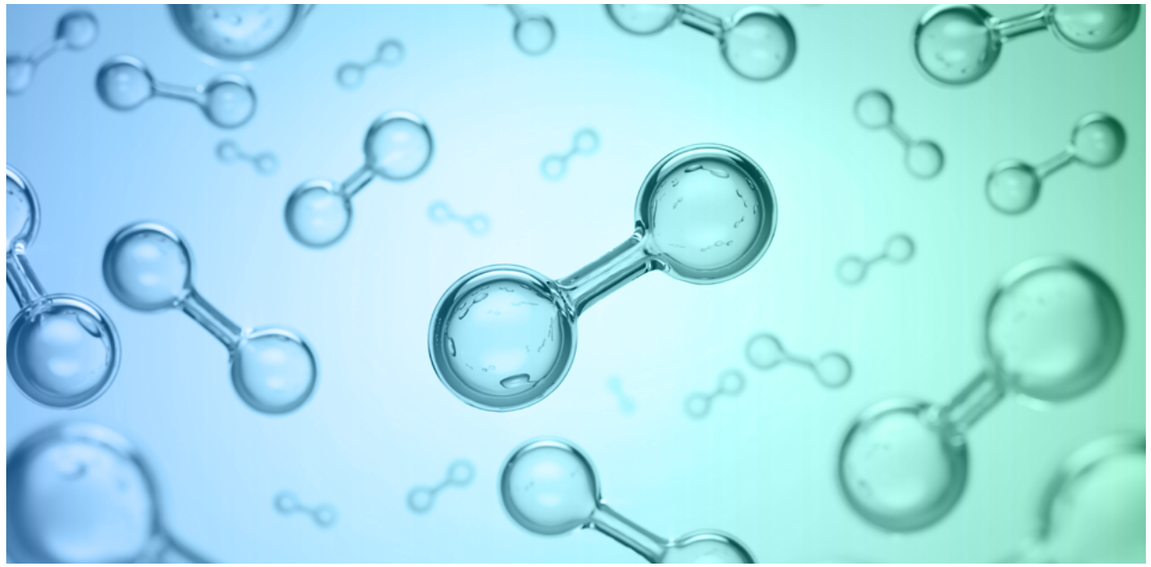
Our Ambition

Today there is an urgent need for alterntives to fossil fuels to limit global warming. Electrification on its own is not sufficient. Clean hydrogen is a candidate to help fill the remaining fuel gap, either in pure form or in more energy dense compounds such as ammonia or Liquid Organic Hydrogen Carriers.

Mature clean hydrogen production methods are today power-demanding and expensive. There is a need to find more commercially competitive emission-free hydrogen production solutions, while at the same time facilitating the implementation of hydrogen and hydrogen-based energy carriers in business and society.

In HyValue we work to build *commercially and societally sustainable hydrogen value chains*. This shall be achieved through development of technology, knowledge, and competence, bridging the gap from basic research to commercial implementation, in close collaboration with industry and authorities.

HyValue will help develop and define the role of hydrogen in reaching the goals of emission reductions by 2030 and zero emissions by 2050. We are looking forward to generating research results of critical importance for Norway, Europe, and the world.



Fionn Iversen

is the director of FME HyValue. Iversen is chief scientist in NORCE Energy and Technology. He is a doctor of materials technology and holds and M.Sc. in both applied mathematics and experimental physics. Working for more than 20 years in the research group of Energy modelling and automation, Iversen has led and taken part in development and commercialization of digitalization and physics-based automation in the industry. He has further had a leading role in NORCE efforts in the energy transition, from basic research to supporting industry efforts in technology implementation.

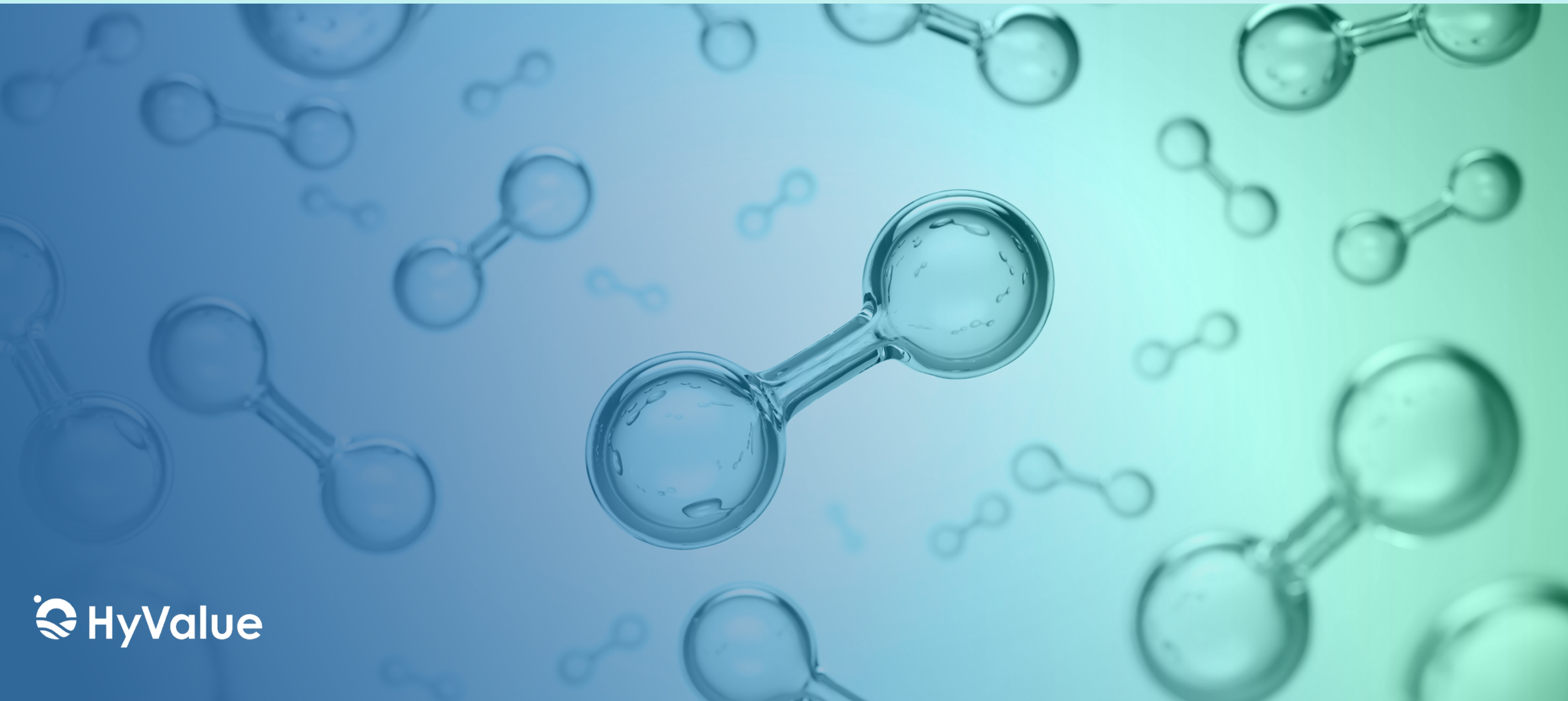
Jonas Solbakken

is the center coordinator of FME HyValue and senior researcher in NORCE Energy and Technology. He holds a PhD in Petroleum Technology from University of Bergen. His expertise is in experimental physics and research related to multi-phase flow in porous media with a specialty in CO_2 storage and enhanced oil recovery methods (EOR). Solbakken has initiated and led research projects from basic research to supporting industry efforts in various technology developments.

Velaug Myrseth Oltedal

holds a PhD in physical chemistry, and has worked as a researcher within various fields. Currently Oltedal works as an Associate Professor at Western Norway University of Applied Sciences (WNUAS). Oltedal's competence spans from nanotechnology to petroleum (drilling and wells), and green energy. Oltedal holds a certificate in Project Management from University of California. Current research interests are hydrogen, and green and renewable energy. Ongoing research activities include feasibility of hydrogen production from offshore wind, and material development for electrolyzer and fuel cell applications. Oltedal lectures in "Hydrogen technology" and leads the development of continual education courses within hydrogen technology at WNUAS. Oltedal is Deputy Director of HyValue. Here she serves as Innovation and Exploitation Manager and works to strengthen the cooperation between research institutions and industrial partners.

Research Strategy



HyValue

Overview

HyValue works to make sustainable hydrogen value chains possible through technology, knowledge and competence development.

The HyValue research centre assembles a broad cross-disciplinary consortium of national and international research partners with cutting-edge expertise in hydrogen related technical, economic, legal and societal fields of research. The centre vision is *"Achieving sustainable hydrogen value chains for a zero-emission economy"*.

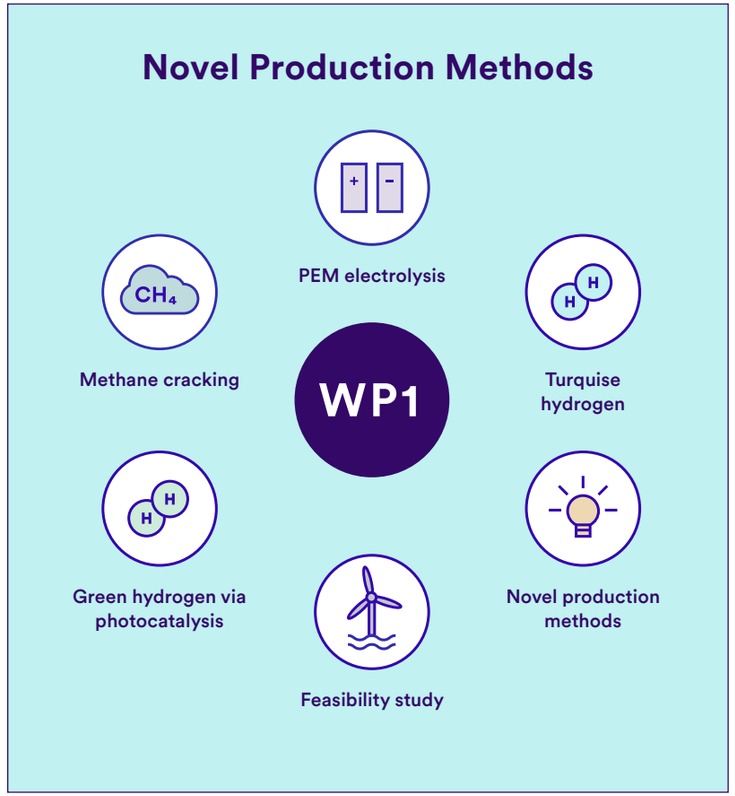
The centre research spans from studies of new, energy-efficient methods for production of hydrogen and ammonia, to how the hydrogen sector can be matured as a technical system in society. HyValue will provide new knowledge to assess and improve risk assessments for hydrogen transport systems and value chains. Equally important is our research on economic and regulatory barriers. The scientific work with the centre is organised in six work packages (WP1–WP6), where interdisciplinary collaboration is crucial to finding the right solutions.

HyValue shall

1. Significantly reduce energy loss, CO_2 emissions and cost of hydrogen and ammonia production.
2. Develop cost-efficient solutions for transport, storage and distribution of hydrogen and ammonia for export and at regional scale.
3. Solve technical challenges for transition to zero-emission economy, including maritime transport and operations and industrial production.
4. Develop novel frameworks for assessing and improving the strength of knowledge in risk assessments for hydrogen and ammonia systems.
5. Explore synergies and dilemmas between economically viable, socially inclusive, and environmentally sustainable socio-technical systems for hydrogen.
6. Identify economic and regulatory barriers and propose incentive structures to accelerate implementation of a hydrogen-based energy sector.
7. Maximise impact by communication, dissemination to stakeholders and education.

Work Package 1: Novel Production Methods

In WP1, Novel production methods, we develop new catalysts and materials beyond the state of art for the hydrogen production processes. In doing so, HyValue benefits from the team's competitive advantage in the development and use of predictive computational methods, including the sole de novo method experimentally validated in design of inorganic molecules, to reduce the time and cost of materials and catalyst discovery. Promising predictions are followed up by high-throughput synthesis and testing, further speeding up discovery. The new catalysts and materials will feed into the process-development tasks and help unleash breakthroughs in novel H_2 and NH_3 production methods.



Task 1.1
Materials for H_2 purification and catalysis

Task 1.2
Green hydrogen via photocatalysis

Task 1.3
Green ammonia via direct electrocatalysis

Task 1.4
Green hydrogen from innovative PEM electrolysis

Task 1.5
Turquoise hydrogen from methane cracking

Task 1.6
Feasibility study: offshore wind-based production of green hydrogen and ammonia

Task example

Green Hydrogen from Innovative PEM Electrolysis

Higher efficiency PEM electrolysis for green hydrogen production shall be experimental studies, addressing bubble behaviour and performance under varying g-forces and pressures. Such studies combined with development of electronic circuits for powering the electrolyser stack with inductive power transfer shall help boosting the energy efficiency to 75%. This work is lead by Jonathan Økland Torstensen of HVL.

WP1 lead

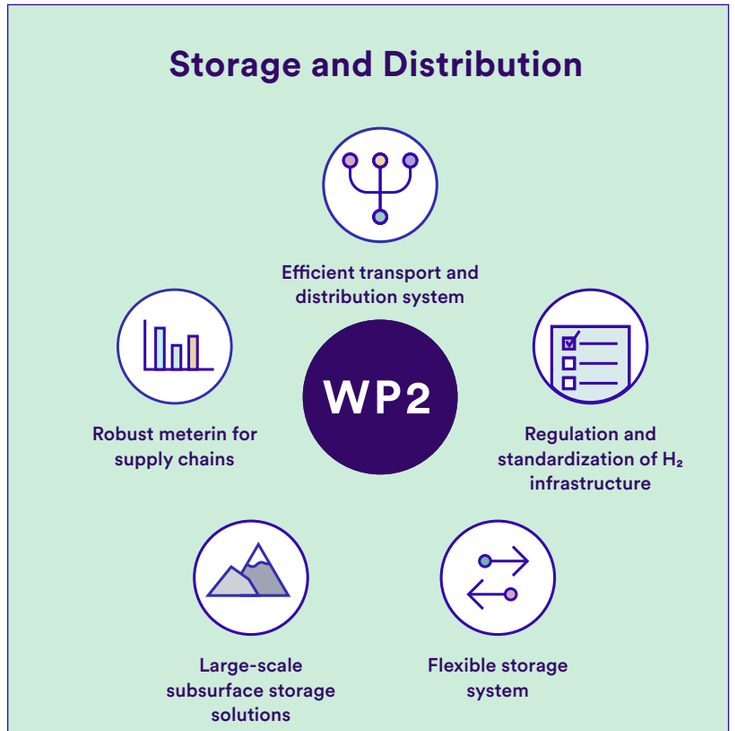
Vidar Remi Jensen is a professor at the Department of chemistry at the University of Bergen. His fields of competence are theoretical and experimental activities within synthesis and testing of (industrial or enzymatic) catalysts. Jensen is also leading the associated KSP-project, AmPep – Ammonia Production via Electrocatalytic Processes (2023–2027).

WP1 co-lead

Professor Dhayalan Velauthapillai heads the research group on Advanced Nano materials for Clean Energy and Health Applications (ANCEHA) at Western Norway University of Applied Sciences (HVL). His competence fields are experimental testing and mathematical modelling of advanced nano material with emphasis on third and fourth generation solar cells, involving hydrogen production and energy storage. Velauthapillai also leads Task 1.2 in HyValue on green hydrogen production via photocatalysis.

WP2: Efficient Transport and Distribution Systems

In WP2, Efficient transport and distribution systems, we apply a multidisciplinary approach combining technical disciplines with societal and legal sciences. Laboratory experiments will serve as a basis for process simulation and numerica models combined with equipment testing in close cooperation with vendors and end-users. Socio-technological status is combined with legal doctrinal methods, cross-industrial comparative analysis and regulation theory to address regulatory barriers for technology implementation.



Task 2.1
Efficient transport and distribution systems

Task 2.2
Robust metering for supply chains

Task 2.3
Large scale and flexible storage systems

Task 2.4
Regulation and standardization of transport, storage, and custody transfer infrastructure

Task example

Large Scale and Flexible Storage Systems

For underground reservoir storage of hydrogen, storage capacity and purity upon injection and withdrawal are evaluated, taking into account the effects of dissolution, adsorption and geochemical reactions. Understanding the impact of microbes on hydrogen in storage is also key. Nicole Dopffel of NORCE leads this work.

WP2 lead

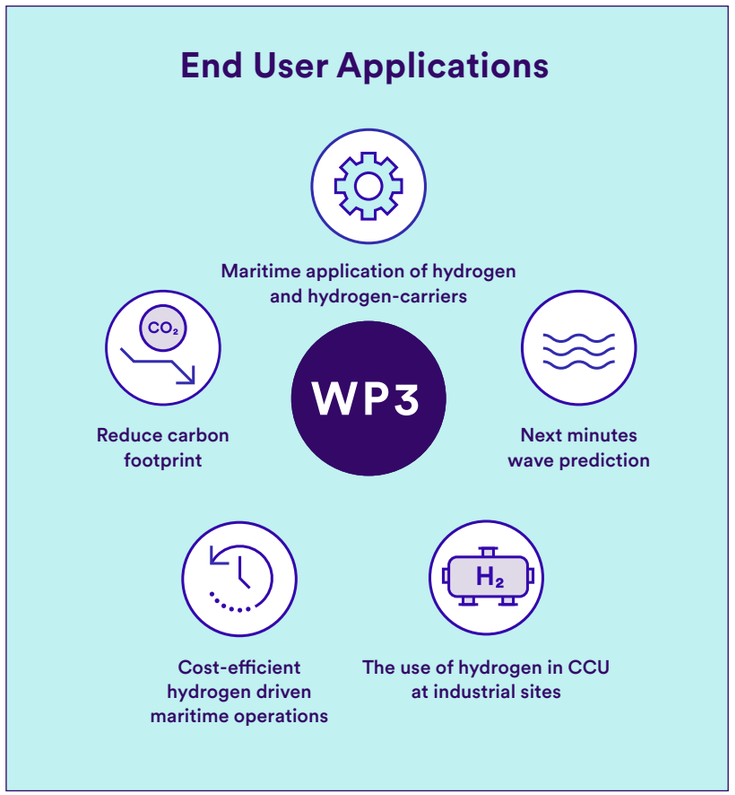
Nematollah Zamani is a senior researcher at NORCE. Zamani is specialized in numerical modelling and multiphase – multicomponent flow in porous media and holds a PhD degree in applied physics from the University of Bergen.

WP2 co-lead

Chief scientist ***Kjetil Folgerø*** works at NORCE. He has core competence within electromagnetic measurement technologies, flow measurement and uncertainty analysis of complex measurement systems. Folgerø coordinates NORCEs national and international work on measurement challenges related to custody transfer and fiscal metering of hydrogen. Folgerø also leads Task 2.1 in HyValue on Robust metering for supply chains. With relevance to hydrogen and HyValue, Kjetil also leads a work package on uncertainty analysis in the EURAMET project Metrology for the hydrogen supply chain (Met4H2), including the associated KSP-project, HyMe – Reliable metering for the hydrogen supply chain (2023–2026).

WP3: End User Applications

In WP3, End user applications, we rely on the use of tools from several engineering disciplines, together with tools from basic sciences as well as economy. Data is gathered from real life as far as possible, including input from centre user partners, and studies are performed as laboratory or computer experiments. For qualification for real implementation, the facilities of relevant Norwegian catapults, such as Catapult Future Materials and Sustainable Energy Catapult Centre, will be exploited.



Task 3.1
Cost-efficient hydrogen driven maritime operations

Task 3.2
Achieving sustainable value chains in the industry

Task 3.3
Maritime application of hydrogen and hydrogen-carriers

Task example

Cost-efficient Hydrogen Driven Maritime Operations

For cost-efficient hydrogen driven maritime operations (NORCE, MIT, NHH, SNF) next minutes wave predictions are used to maximize the vessel performance using hydrogen power plants. The most important is to reduce the load variations and optimize the control system to minimize power consumption and wear of fuel-cells, in particular at low power operation. Svein Olav Halstensen and his group work closely together with MIT on developing fast methods for calculating wave forces and vessel motions from wave data.

WP3 co-lead

Geir Nævdal is a chief scientist at NORCE with more than 25 years of research experience. His main competence areas are on solving numerical problems involving data assimilation, large-scale parameter estimation and optimization related to seismic inversion, porous media flow, well-bore flow, and more recently on medicine and batteries. Nævdal is also leading the associated KSP-project, HyEff – Energy efficient operation of hydrogen powered vessels (2022–2025).

WP3 co-lead

Jonthan Økland Torstensen is an associated professor at the Department of mechanical engineering and maritime studies at Western Norway University of Applied Sciences (HVL). Torstensen has a PhD in chemical process technology from NTNU (2019). Ongoing research activities besides teaching students and industry participants in hydrogen technology courses, includes electrolysis, pyrolysis and material science.

WP4: Safety Science and Risk

The approach for WP4, Safety science and risk, includes literature reviews, surveys and interviews, stakeholder workshops and expert panels, laboratory-scale experiments, large-scale experimental campaigns (commissioned), blind-prediction benchmark studies, risk assessment benchmark studies for hypothetical (or actual) systems, as well as intervention and case studies.

Task 4.1
Coordination and systems design

Task 4.2
Prevention and safe design

Task 4.3
Phenomena, modelling and mitigation

Task 4.4
Strength of knowledge assessments

Task 4.5
Risk communication and comprehension

Task example

Strength of Knowledge Assessments

The centre will develop and assess strength of knowledge frameworks for hydrogen and ammonia, to be applied in case and risk assessment studies. Recommendations and guidelines will be developed for practical use of the framework in risk assessments. Trygve Skjold of UiB leads the experimental investigations forming a basis for this development.

WP4 lead

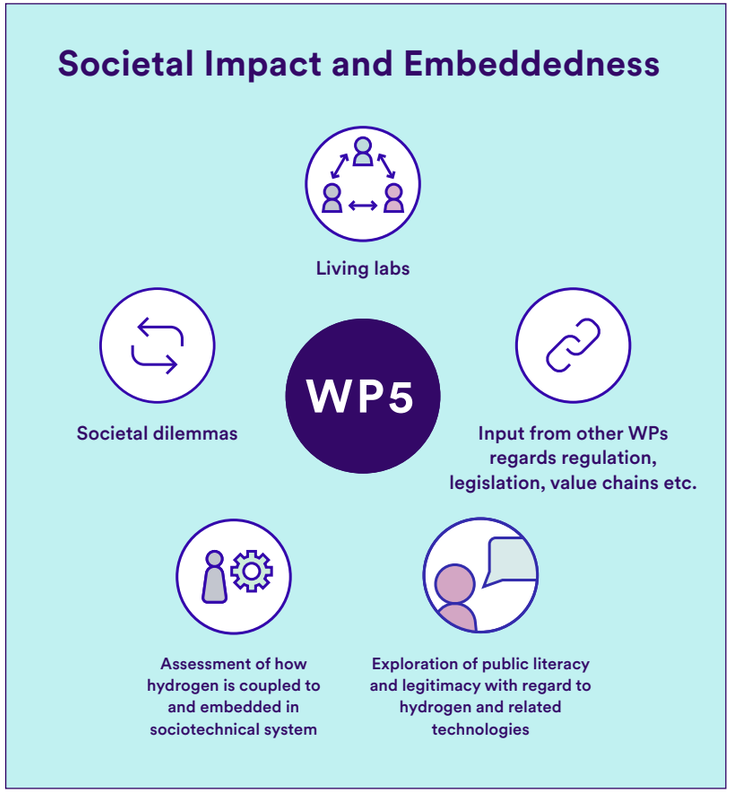
Jon Tømmerås Selvik is a professor in risk management at the Department of safety, economics and planning at the University of Stavanger. Tømmerås also holds a senior researcher position at NORCE, where he takes part in a risk management research team. His competence areas cover decision analyses and safety-uncertainties in relation to risk-based planning and operations.

WP4 co-lead

Helene Hisken is an associate professor II at the Department of physics and technology at the University of Bergen. She also works at Sweco as a safety advisor. Hisken holds a PhD in technical safety and has extensive experience in consequence model development, model validation, and analysis of results from experimental campaigns, with particular focus on gas explosions.

WP5: Societal Impact and Embeddedness

In WP5, Societal impact and embeddedness, a sociotechnical and political-economic approach is combined with institutional theory. Societal Embeddedness Level (SEL) is a valuable methodology which specifically addresses the societal conditions to be in assessed before deploying a technological innovation. Triangulation of societal science methods is essential in WP5, and important for co-creation of new and transdisciplinary insights on energy transitions towards sustainability.



Task 5.1

Assessment of how hydrogen is coupled to and embedded in various sociotechnical systems

Task 5.2

Exploration of public literacy and legitimacy with regards to hydrogen and related technologies

Task 5.3

Exploration of societal dilemmas in governing the deployment of hydrogen and other energy technologies

Task example

Exploration of Public Literacy and Legitimacy

A national survey instrument (the Norwegian Citizen Panel) will be used to study the alignment of public literacy and legitimacy in respect to politics and environment engagement, as well as in-depth (personal) and focus group interviews. Jon Kåre Skiple and Henrik Litlere Bentsen, both NORCE, will work together on the surveys.

WP5 lead

Lars Martel Antonie Coenen is professor in Innovation and Sustainability Transitions at the Mohn Centre for Innovation and Regional Development at HVL. His research interests converge around the geography of innovation. In particular, he is interested in addressing this broad set of questions on innovations related to pressing societal challenges such as climate change. Coenen is well-known internationally for his work on regional and urban innovation and his pioneering research on the geography of environmental innovation and sustainability transitions.

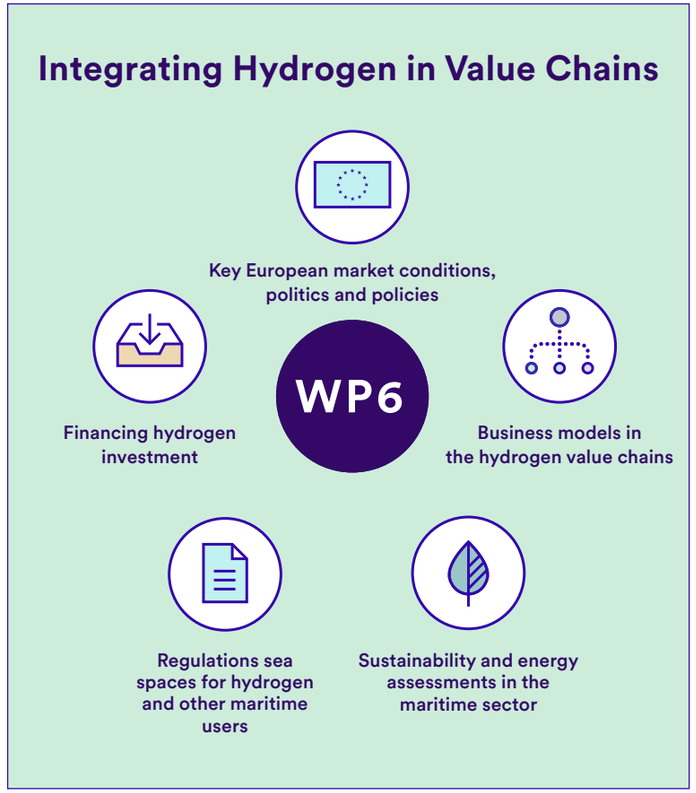
WP5 co-lead/lead 2023

Kari Kjestveit is a senior researcher at NORCE. Kjestveit has a Masters' degree in Societal Safety from the University of Stavanger. Her competence areas include qualitative and quantitative methods to assess various socio-technical systems, working life and organizational theory, including risk perceptions in society.

WP6: Integrating Hydrogen in Value Chains

In WP6, Input data from all HyValue work packages will be integrated to provide new legal, financial, political sciences and economic knowledge directed to facilitate new hydrogen value chains. We resort to modern law and institutional economics: that green innovation and business could be driven by a carbon price only, that complementary investments in value chains shape business models, regulation and finance, and that knowledge and development is geo – and agglomeration dependent.

The legal dogmatic method will be used to identify and interpret legal sources at different levels and legal issues will be discussed through law in context perspectives. Finally, we apply a double functional comparative method, in connection to other countries as well as comparing solutions found in the governance of other energy sources.



Task 6.1
A low carbon future, and business models in the hydrogen value chains

Task 6.2
Sustainability and energy assessments in the maritime sector

Task 6.3
Regulating the sea and coastal geography of hydrogen & North Sea Hydrogen-based Energy Hubs

Task 6.4
Financing hydrogen investment

Task 6.5
Contracts & strategies for commercialization of hydrogen

Task 6.6
Modelling interaction in electricity, gas and hydrogen markets

Task 6.7
European politics and policies shaping hydrogen value chain development and actor's strategies

Task 6.8
Key European market conditions: power, CO_2, gas, hydrogen and energy intensive tradable products

WP6 lead

Gunnar S. Eskeland is a Professor of Resource and Environmental Economics at the Norwegian School of Economics (NHH). Recent work on climate change has included energy sector analysis, European policy review, research on technological change and an R&D treaty. Eskeland is heavily involved in the Master's profile in Energy, Natural Resources and the Environment, with an international student body, and is directing the Energy and Climate research program.

WP6 co-lead

Ignacio Herrera Anchustegui is an associate professor at the Faculty of Law of the University of Bergen. Anchustegui leads the Research group for Climate, Energy and Environmental Law. His research interests relates to the regulation of energy markets with a special emphasis on the regulation of offshore energy, offshore wind, and new energy technologies, like hydrogen. Also, market and competition issues in public procurement and buyer power are his competence areas.

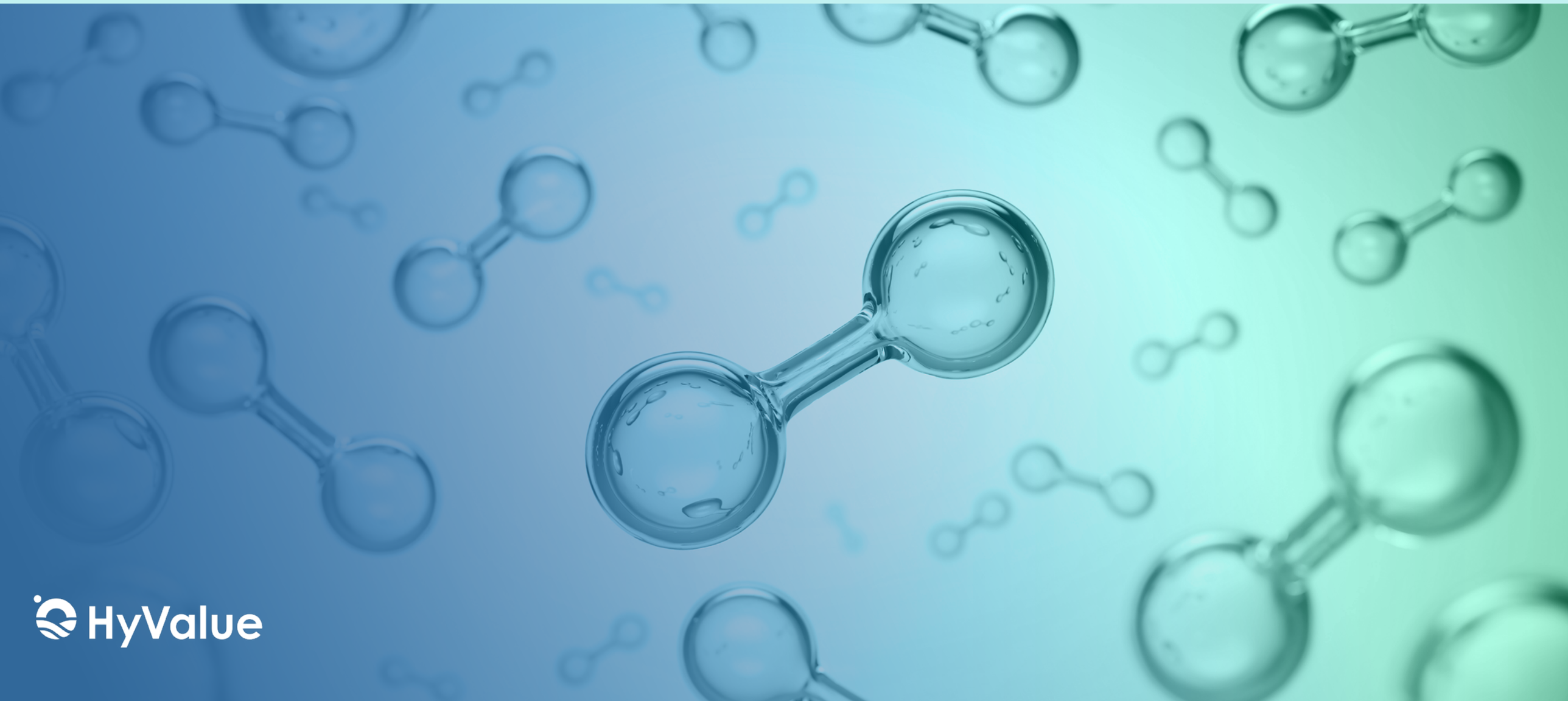
Associated Projects

FME HyValue has close ties with other projects that perform complementary research and development. Although there is no formal connection to these projects, there is close collaboration in the form of workshops and seminars. Further, higher TRL projects, such as OptHyMob, strengthen the impact of HyValue research.

PROJECT	PROGRAMME	RESEARCH TOPIC
AmPep: Ammonia Production via Electrocatalytic Processes	RCN	Development of electrocatalytic ammonia production from water and di-nitrogen. Lead by UiB.
HyMe: Reliable metering for the hydrogen supply chain	RCN	Development of knowledge, competency and methods for reliable, traceable and accurate measurements of hydrogen-based energy carriers. Lead by NORCE.
HyLife: Microbial risks associated with hydrogen underground storage in Europa	RCN	Establish microbiological models for underground storage of hydrogen with focus on microbial effects. Lead by NORCE.
MOCHyS: Microbiological Opportunities and Challenges of Hydrogen Underground Storage	RCN / CEPT	Study of mikrobiological opportunities and challenges related to unerground hydrogen storage. Lead by NORCE.
Legal-by-Design: Legal-By-Design Digital Disruption in the Circular Economy: An Exploratory Research project	EEA Grants	Cross disciplinary collaboration between Norway and Portugal with particular focus on legal aspects related to Digital Product Passport and hydrogen energy. Lead by the University of Minho, Portugal. UiB as partner.
Circularity in Decommissioning	Offshore Norge & University of Bergen, Faculty of Law	Analysis of the Norwegian rules for decommissioning of offshore infrastructure for identifying potential areas for improvement. The project has synergy with establishing a hydrogen industry in the North Sea. Lead by UiB.
HyEff: Energy efficient operation of hydrogen powered vessels	RCN KSP	Development of simulation and control methods for optimization of hybrid fuel-cell/battery vessel systems. Collaboration workshop with HyValue held in 2023. Lead by NORCE.
OptHyMob: Optimized Hydrogen Powered Maritime Mobility	RCN IPN	Twin project with HyEff under the Maroff programme. The project shall benefit from knowledge and methods developments in HyEff, further integrating solutions for trials/pilot. Lead by Corvus Energy. NORCE as partner.
GET Hydrogen: Geo-politics of the Energy Transformation: Implications of an In-ternational Hydrogen Economy	German Federal Foreign Office and Research Institute for Sustainability, Potsdam, Germany	Analysis of possibilities and challenges related to growth of hydrogen in a geopolitical perspective. Lead by FNI.

In addition to these projects, PhD candidates and postdocs collaborate across Norway through the HySchool programme, lead by the University of Bergen.

Highlights 2023



Internal Events

HyValue Days

HyValue Days, our annual two-day HyValue internal seminar, was held from 3rd to 4th of May at HVL. HyValue Days consisted of user-partner presentations on day 1. Day 2 provided an overview of status and plans for the work packages, by work package leaders.

Presented topics covered hydrogen and ammonia production, distribution and storage systems, and end user applications. HyValue days are held as a physical event and are important for dissemination to the consortium of the research being carried out, and further serves as a key contact point for all consortium partners.

Seminar on Regulatory Frameworks and Standards in Norway

FME HyValue in collaboration with FME HYDROGENi, facilitated a physical seminar in Bergen with over 70 participants on regulatory frameworks and standards for hydrogen-based energy carriers in Norway.

Aim was to outline the status with the organizations involved in Regulations, Codes and Standards (RCS) development, identify knowledge-gaps, and clarify how RCS could be used and developed further to serve as a driver for Norwegian companies in enabling full-scale hydrogen projects and applications.

The seminar participants included stakeholders from different industries developing hydrogen technology solutions, key personnel from different regulatory authorities and standard-developing-organizations. Based on the seminar's content and discussions, an article/report is in the making, with recommendations for effective and safe implementation of hydrogen in industry and society.






HyValue Research Results

The main research focus for HyValue in 2023 has been the recruitment of employees and purchase and installation of equipment for the experimentally related activities. By the end of 2023, HyValue has employed 4 PhDs and 3 postdocs in the areas of production, storage/distribution and regulations/value chain.

Ammonia Production

Ammonia is non-explosive, has almost twice the energy density of liquid hydrogen, and emerges as an attractive carbon-free energy vector. To realize ammonia's potential, its current high-energy (>400°C, >150 atm) Haber-Bosch production must be replaced by a process based on renewable electricity, dinitrogen (N_2) from the atmosphere, and water.

For decades, researchers have used nitrogenase enzymes, containing ions of so-called transition metals (in this case, vanadium, iron, or molybdenum) in their active sites, as inspiration when developing man-made catalysts, compounds that speed up chemical reactions without being themselves consumed, for nitrogen fixation and ammonia synthesis. Recently, using molybdenum-based catalysts, these efforts have resulted in the first examples of water-based ammonia synthesis at enzymatic reaction rates.

This breakthrough derives in part from the use of a chemical compound, samarium diiodide (SmI_2), to provide the electrons needed to transform dinitrogen into ammonia (NH_3). Samarium diiodide has been postulated to interact closely with both water and the molybdenum-based catalyst so as to transfer both the necessary electrons (from itself) and the protons (from water) in a highly efficient manner to the catalyst on which ammonia is formed. Using a computational model specifically developed for this challenge by HyValue researchers at UiB, the interplay between all these molecular actors is now, for the first time being described (see Figure 1). The mechanistic description is fully consistent with all experimental observations and is already being used to design catalysts and processes with improved yields of ammonia.

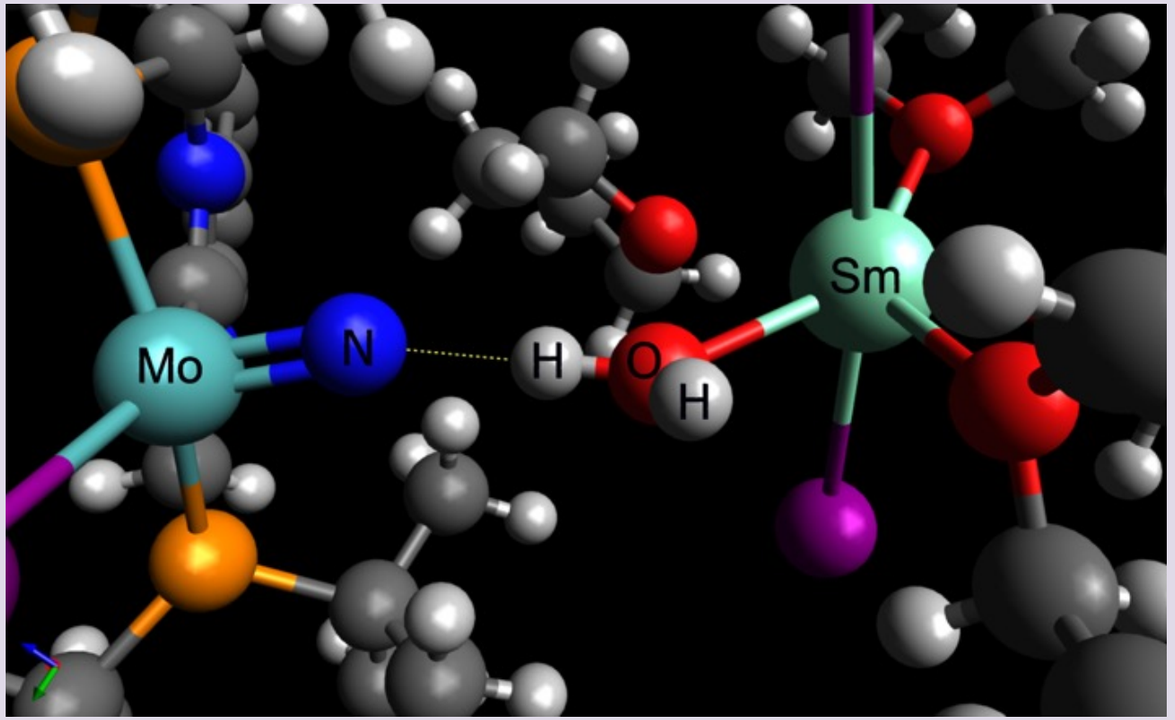


Figure 1. Interplay between molybdenum catalyst (Mo), water (H_2O), and samarium (the provider of electrons, Sm) as modelled using quantum chemical calculations: A hydrogen atom (or rather, a proton and an electron) is transferred from a water molecule (H_2O) bound to samarium (Sm) to a nitrogen atom bound to molybdenum (Mo). This reaction step (indicated by a yellow dashed line) is the first and most energy-demanding of three consecutive hydrogen transfers needed to transform the molybdenum-bound nitrogen atom into ammonia (NH_3).

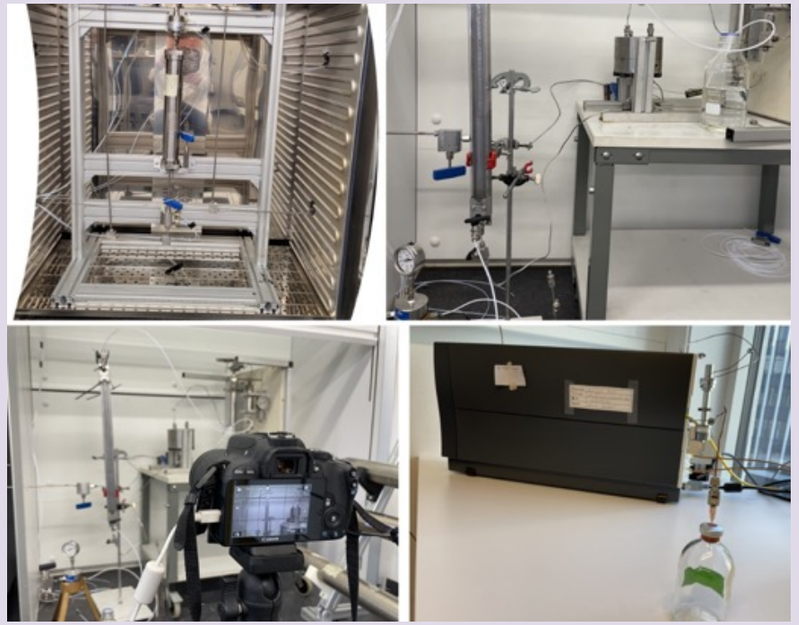
Underground Storage

One of the beneficial aspects of hydrogen as an energy carrier is that it can be stored in large-scale (TWh equivalent) quantities in the underground reservoirs. Depleted oil and gas reservoirs are potential candidates for underground hydrogen storage due to their geological stability, large storage capacity and availability of surface and subsurface injection and production infrastructure. Despite the advantages of utilizing depleted oil and gas reservoirs for hydrogen storage, it is essential to examine the challenges of hydrogen storage in these reservoirs, such as hydrogen interaction with rock and fluids in the reservoir, hydrogen trapping mechanisms as well as the recovery efficiency and quality of the back-produced hydrogen.

An experimental set-up has been established at NORCE to investigate hydrogen storage in underground reservoirs. The set-up has been used to carry out flow experiments on core samples for increased knowledge of the injection and extraction processes in the reservoir where hydrogen is stored. Such knowledge is necessary to be able to successfully store hydrogen on a large scale, which is required if hydrogen is to play a central role in the energy system of the future.

The results from experimental hydrogen displacement experiments at NORCE show generally low hydrogen saturation (hydrogen storability) in the brine saturated Berea sandstone. Severe channelling or fingering and unstable flow behaviour due to lower hydrogen density and viscosity compared to brine phase may be the reason for low hydrogen saturation in the core. The results indicate that hydrogen injection rate is an important parameter in designing hydrogen storage projects. Higher injection rates result in higher hydrogen saturation in the porous media due to higher viscous force to displace brine inside the pore structure (see figure 1.). The results from these studies have been accepted for oral presentation at EAGE-Oslo, in June 2024.

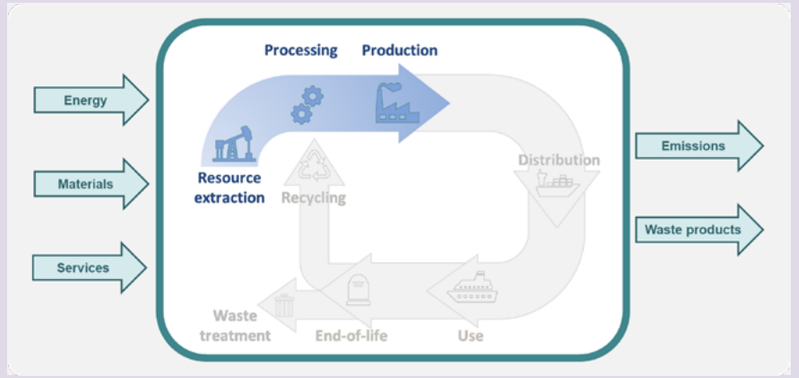
Figure 1.
Experimental set-up at NORCE for performing hydrogendisplacement experiments.



Value chain sustainability

Task 6.2 uses environmental and economic assessments, assessing value chain sustainability and avoidance of lock-in effects in unsustainable technology, including life cycle assessment (LCA). In 2023 the work has focused on finding a baseline for hydrogen production for comparison and benchmaring, and scope the possibilities for LCA on green and turquoise hydrogen production pathways. For green hydrogen literature data has been used to compile an initial LCI, and continuation will be to improve it for the electrolyser production and efficiency. For an LCA on turquoise hydrogen production a key element is if the analysis should be with system expansion including silicon.

Figure 2.
Hydrogen value chain

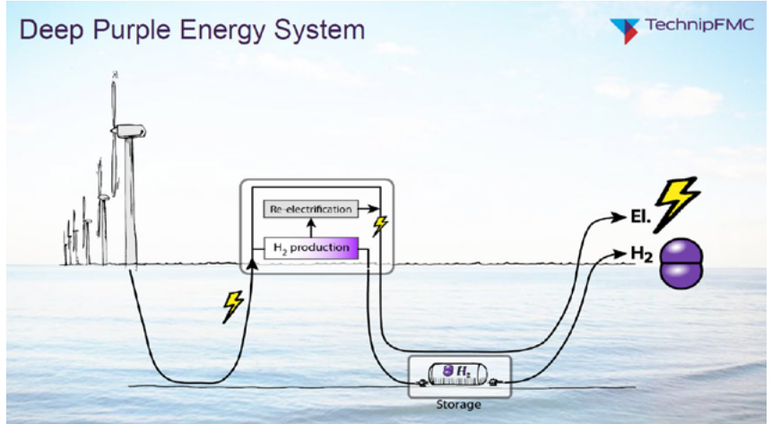


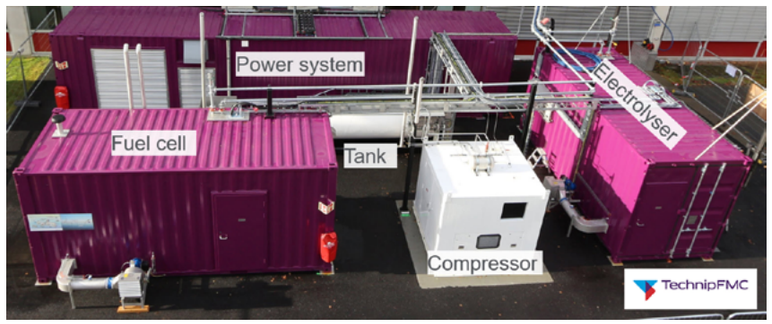
Industry Collaboration

Deep Purple™ Pilot – Webinars Series

In a four-part webinar series, TechnipFMC has been sharing technical in-sights from the Deep Purple project development for the HyValue and HYDROGENi consortia. The webinars were moderated by HyValue on behalf of our joint industry partner TechnipFMC.

The overall objective of the pilot is to demonstrate the system's ability to stabilize power to an off-grid consumer when energy origin is intermittent renewable power. The system produces hydrogen at overproduction of renewable power and stores the hydrogen for continued re-electrification to fill in the gap when renewable power production is insufficient.





Wärtsilä Workshop

On June 15th, Wärtsilä hosted a workshop at Heiane in Stord in collaboration with HYDS – Hydrogen Solutions and Sustainable Energy Norwegian Catapult Centre.

At the Sustainable Energy Testcenter, Wärtsilä is testing a large ship engine mainly running on ammonia as fuel. Wärtsilä is a frontrunner in figuring out how well ammonia can work as a fuel in maritime operations. Right next to Wärtsilä, Hydrogen Solutions (HYDS) with partners, have a 1 MW production plant of green hydrogen, a first step in producing local green hydrogen for upcoming markets in Norway, including providing hydrogen to the test facilities.

The workshop included a tour of the Energy House test facilities and a short seminar on Hydrogen use in maritime applications including use of hydrogen in Internal Combustion Engines and SOFC fuel cells.

Outreach Media/Other

Throughout 2023 the HyValue management team, work package leaders and PhD-students have presented our work and research at conferences and in the media. Here are some highlights.

Centre Deputy Velaug Myrseth Oltedal, and co-lead of workpackage one Dhayalan Velauthapillai presented HyValue in Teknisk Ukeblad. They spoke on optimising new production methods for hydrogen.

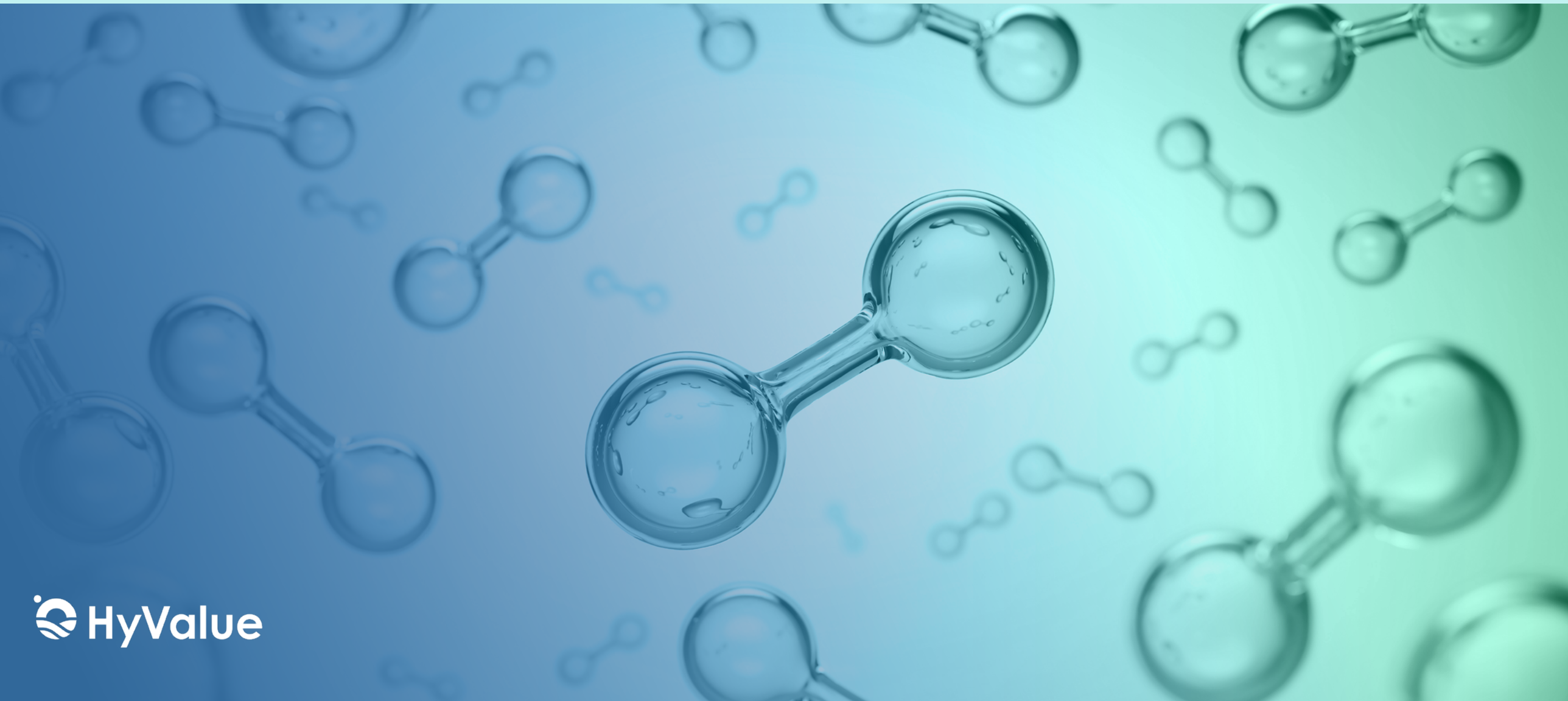
A delegation from the Western Norway University of Applied Sciences represented HyValue at the International Climate Summit in New Dehli in September. The Summit gathered 100,000 digital and physical participants to discuss sustainability through green growth.

Professor Dhayalan Velauthapillai leder laboratoriet på Høgskolen på Vestlandet og nestleder for Hyvalues fagfelt om nye metoder for å produsere grønn hydrogen. Et mål er å finne bedre nanomaterialer til elektrodene som produserer oksygen og hydrogen. *Foto: Alf Bergin*

From the left: Dhayalan Velauthapillai, Jonathan Økland Torstensen, Velaug Myrseth Oltedal og Yulia Arinicheva Skåtun.

From the Wartsila workshop at Stord looking into possible future energy solutions.

In the Spotlight



Associated PhDs in HyValue

Ingrid Marie Stuen

Affiliation | University of Bergen / HyMe

Period | 13.06.2023–12.06.2026

Supervisor(s)/Mentor(s) | Camilla Sætre and Kjetil Folgerø

Working on | Supply Chain Losses and Quality Degradation for Large-Volume Hydrogen Transport Chains

Leif Hertwig

Affiliation | University of Bergen

Period | 30.01.2023–29.01.2027

Supervisor(s)/Mentor(s) | Vidar R. Jensen, Erwan Le Roux, Giovanni Occhipinti

Working on | Transition metal catalyzed synthesis of ammonia from nitrogen and water

Jonas Himmelstrup

Affiliation | University of Bergen

Period | 01.03.2020–01.04.2024

Supervisor(s)/Mentor(s) | Vidar R. Jensen, Erwan Le Roux, Giovanni Occhipinti, Marco Foscato

Working on | Development of Novel Catalysts for Ammonia Synthesis

Torbjørn Egeland Eriksen

Affiliation | NORCE and University of Oslo

Period | 01.11.2018–31.10.2023

Supervisor(s)/Mentor(s) | Sabrina Sartori – Phd, UiO; Antonie Oosterkamp – PhD, NORCE; Truls Eivind Norby – PhD, UiO

Working on | Green hydrogen as energy storage and energy carrier in combination with offshore wind power: Production, energy management and techno-economic analysis

Shuyi Pan

Affiliation | NHH

Period | 15.08.2023–14.08.2027

Supervisor(s)/Mentor(s) | Gunnar Eskeland

Working on | Collections of research on clean hydrogen value chain and energy market

Liina Sangolt

Affiliation | Ulla-Førre Foundation founded project “Safety Culture in Green Maritime Industries” at HVL.

Period | 15.09.2022–15.09.2026

Supervisor(s)/Mentor(s) | Velaug Myrseth Oltedal, Andrés Franklin Olivares Lopez, Pawel Jan Kosinski

Working on | Hydrogen production from variable power sources

Dikshya Bhandari

Affiliation | University of Stavanger

Period | 02.01.2024–01.01.2027

Supervisor(s) /Mentor(s) | Jon Tømmerås Selvik, Eirik Bjorheim Abrahamsen and Ove Njå

Working on | Identifying and Mitigating Risks in Hydrogen Energy for Safer Integration

Post.docs. in HyValue

Roweno Johannes Ryan King Heijmans

Affiliation | NHH, Department of Business and Management Science

Thesis/project title | Designing policy to stimulate the hydrogen economy

Period | 01.09.2023–31.08.2027

Working on | theoretical economic techniques to study the design of policies to stimulate development of a well-functioning hydrogen technology and economy

Torhild Nordtveit

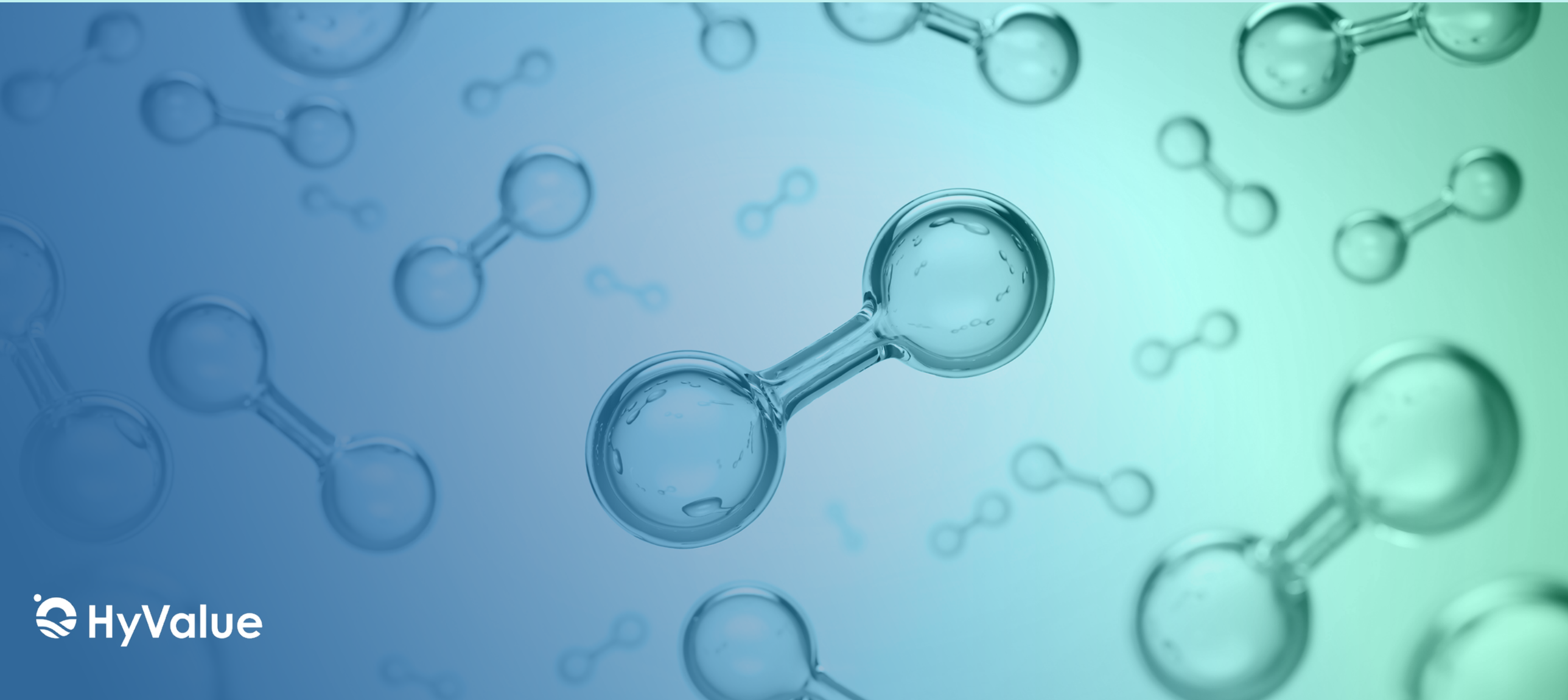
Affiliation | Faculty of Law, University of Bergen

Period | 01.08.2023–31.07.2027

Supervisor(s)/Mentor(s) | Ignacio Herrera-Anchustegui

Working on | Legal issues related to drafting and closing of contracts & Regulation of hydrogen transport at sea

International Collaboration



HyValue

International Collaboration

Centre director Fionn Iversen participated in the Annual Bilateral meeting between Norway and the United States on CCUS and hydrogen in Washington DC. The Norwegian Ministry of Energy and the Norwegian Research Council co-hosted the meeting and the goal was to discuss cooperation between the United States and Norway within carbon capture, utilization and storage and hydrogen, both blue, green and turquoise.

POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

P I K

The Potsdam Institute for Climate Impact research is an international partner in the HyValue project. In work package 6, Dr. Falko Ueckerdt and Dr. Philipp Verpoort explore the role and competitiveness of hydrogen and hydrogen-based materials from the perspective of energy systems and transformation pathways.

Dr. Philipp C. Verpoort
is a post-doctoral research scientist at PIK Potsdam and studies the role of hydrogen in the emerging green value chains of energy-intensive industrial production and basic materials.

Dr. Falko Ueckerdt
is a senior scientist and team lead at PIK Potsdam, where he is responsible for the hydrogen and e-fuels research. He also works as a guest lecturer at the Ruhr University Bochum and contributing author to two IPCC reports.

Scenarios analysis and techno-economic work

On the one hand, their work is rooted in modeling global climate change mitigation scenarios. The global integrated assessment model REMIND is the model that contributed most scenarios to the recent IPCC report. REMIND model scenarios are also informing the global finance industry about transitional trends and risks (Network for Greening the Financial System, NGFS). On the other hand, in recent years, PIK Potsdam zoomed into policy advise and scenarios for the EU and Germany. Methodologically, scenario analyses are now complemented by a strong framework allowing for techno-economic and competitiveness analyses.

Two Recent Papers in HyValue

Within the last year, Philipp and Falko published two papers that were partly funded by HyValue.

1. Impact of Global Heterogeneity of Renewable-energy Supply on Heavy Industrial Production and Green Value Chains

Accepted for publication in Nature Energy,
Preprint: DOI:10.5281/zenodo.8333736

On the path to climate neutrality, global production locations and trade patterns of basic materials might change due to the heterogeneous availability of renewable electricity. Here we estimate the “renewables pull”, i.e. the energy-cost savings, for varying depths of relocation for three key tradable energy-intensive industrial commodities: steel, urea, and ethylene. For an electricity-price difference of 40 EUR/MWh, we find respective relocation savings of 18%, 32%, and 38%, which might, despite soft factors in the private sector, lead to green relocation. Conserving today's production patterns by shipping hydrogen is substantially costlier, whereas trading intermediate products could save costs, while keeping substantial value creation in renewable-scarce importing regions. In renewable-scarce regions, a societal debate on macroeconomic, industrial, and geopolitical implications is needed, potentially resulting in selective policies of green-relocation protection.

Philipp C. Verpoort, philipp.verpoort@pik-potsdam.de

2. On the Cost Competitiveness of Blue and Green Hydrogen (with natural gas and with one another)

Access to paper: DOI:10.1016/j.joule.2023.12.004 (recently published in Joule)

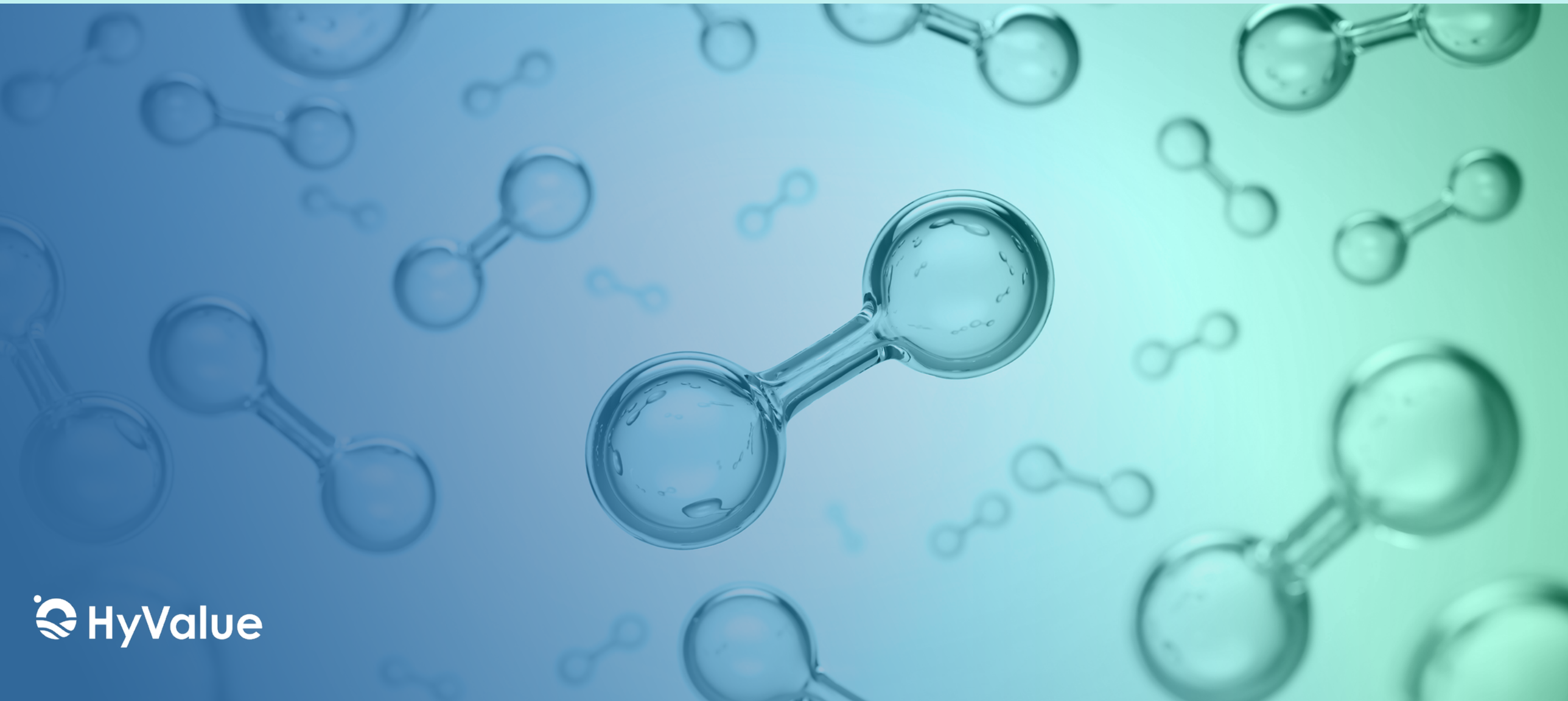
Despite the cost reductions of green hydrogen, it is uncertain when cost parity with blue hydrogen will be achieved. Beyond technology costs, electricity and natural gas prices, hydrogen’s competitiveness will be increasingly determined by carbon costs or regulation associated with its life-cycle emissions. Theoretically and numerically we demonstrate that higher residual emissions of blue hydrogen can close its competitive window much earlier than cost parity of green hydrogen suggests. In regions, where natural gas prices remain substantially higher (~40EUR/MWh) than before the energy crisis, such a window is narrow or has already closed. While blue hydrogen could potentially bridge the scarcity of green hydrogen, uncertainties about the beginning and end of blue hydrogen competitiveness may hinder investments. In contrast, in regions where natural gas prices drop to ≤15€/MWh, blue hydrogen can remain competitive until at least 2040, contingent upon achieving rigorous CO_2 capture (>90%) and negligible methane leakage rates (<1%).

Falko Ueckerdt, ueckerdt@pik-potsdam.de

Other important past papers at PIK Potsdam around the topic of hydrogen were:

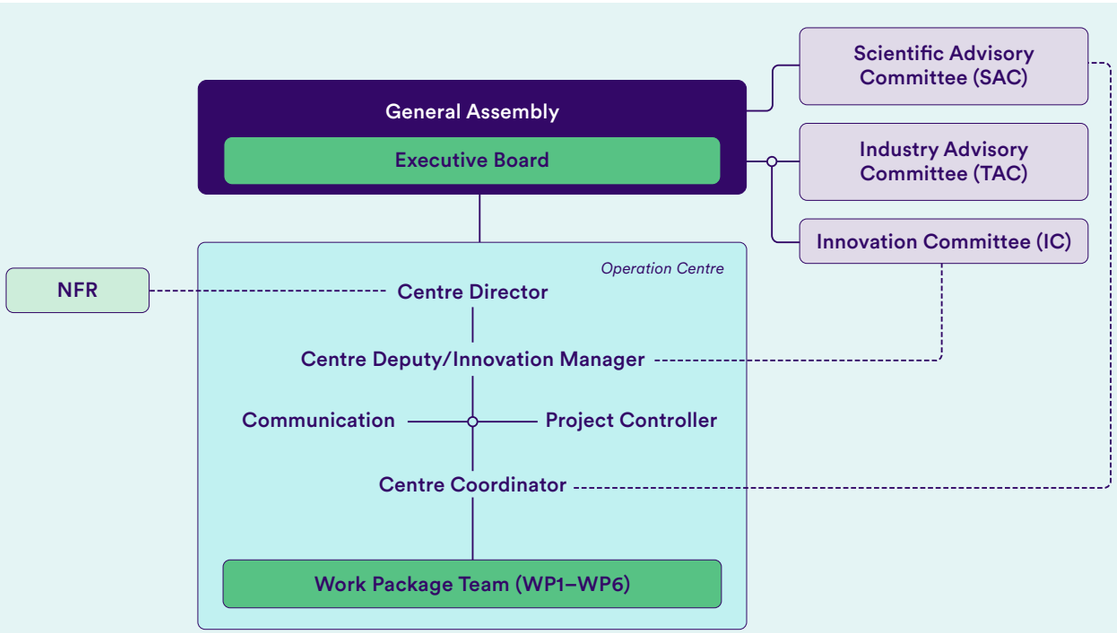
1) The potential and limitations of e-fuels (Nature Climate Change, 2021)
2) Plausible scale-up scenarios of green hydrogen (Nature Energy, 2022)
3) A German report (Ariadne project) on the polarized hydrogen debate and ways forward

HyValue Facts



Governance Structure

HyValue governing structure includes General Assembly (GA) and Executive Board (EB) and management positions: Centre Director and WP-leads. The center governance structure is further supported and strengthened by a Deputy Director, Centre Coordinator, Communication, Controller, WP-deputies and Committees to facilitate efficient project execution and good communication between the consortium partners.



Executive Board

2022+2023

BOARD MEMBER	AFFILIATION
Aasgeir Valderhaug (Chair)	ELKEM
Sylvi Høyland	Equinor
Richard Markeson	Gassco
Svein Are Folgerø	Å Energi
Victoria Griffiths	Statkraft
Ingvill Bækø	Moreld Apply
Egil Hystad	Wärtsilä
Kristine Spildo	University of Bergen (UiB)
Øyvind Midtbø Berge	Western University of Applied Sciences (HVL)
Helge Bøvik Larsen	University of Stavanger (UiS)
Leif Kristoffer Sandal	Norwegian School of Economics (NHH) & Centre for Applied Research at NHH (SNF)
Aina Margrete Berg	NORCE Norwegian Research Institute (NORCE)
Per Ove Eikeland	Fridtjof Nansen Institute (FNI)
Frants Gundersen	Institute of Transport Economics (TØI)*
Åse Slagtern	Research Council of Norway (RCN)*

*observer

Scientific Advisory Board (SAC)

Committee of experts from various research areas advising on research direction and performance.

SAC MEMBER	AFFILIATION	COMPETENCE AREA
Kees van Wingerden (Chair)	Vysus group	Safety Science & Risk
Anna Stefanopoulou	University of Michigan	Mechanical Engineering
Kim Talus	University of Finland	Energy Law
Maartje Boon	University of Stuttgart	Subsurface storage
Ranjit Koodali	Western Kentucky University	Production Technologies

HyValue Research Partners

The HyValue consortium is lead by NORCE Norwegian Research Centre supported by the Western Norway University of Applied Sciences (HVL) in centre management. HyValue comprises in total 13 leading R&D institutions in hydrogen related research, including eight Norwegian partners:

- NORCE Norwegian Research Centre (NORCE)
- Fridtjof Nansen Institute (FNI)
- Institute of Transport Economics (TØI)
- Norwegian School of Economics (NHH)
- Centre for Applied Research at NHH (SNF)
- Western Norway University of Applied Sciences (HVL)
- University of Bergen (UiB)
- University of Stavanger (UiS)

and four international partners:

- Forschungszentrum Jülich (FZJ), Germany
- Massachusetts Institute of Technology (MIT), United States of America
- Netherlands Organisation for Applied Scientific Research (TNO), Netherlands
- Potsdam Institute for Climate Impact Research (PIK), Germany

The research partners have world-leading competence in hydrogen related technical-economic-legal-societal fields of science with extensive analytical, modelling, simulation, and experimental capabilities. The research institutions are all strategically committed to the scope of HyValue and they provide multi-disciplinary expertise and skills needed to carry out the ambitious research programme of HyValue including materials science, catalysis and chemical processes (UiB, UiS, HVL), porous media, biogeochemistry, underground storage (NORCE, UiS, TNO), fluid dynamics, pipeline transport, measurement science, metering research (NORCE, UiB, TNO), optimization (NORCE, MIT), safety risk assessment (UiB, UiS, FZJ), societal research (NORCE, TNO), economics and finance, LCA, value chain analysis, political science, law, energy systems (FNI, NHH/SNF, TØI, UiB, TNO, PIK).

HyValue User Partners

The centre user partners represent leading national and international industrial firms as well as key public partners. HyValue undertakes long-term research at low technology readiness levels (TRL) to support and enable the hydrogen energy transition, while also committing to short-term research at high TRL to address bottlenecks and research gaps identified by the centre user partners, thereby stimulating innovations and spillovers in the short term. Further, a set of user cases from the industry serve as catalysts to connect the centre academic and user partners and enhance relevance of the research activities.

The user partners cover the whole hydrogen value chain, on the technical part from engineering *(Moreld, TechnipFMC, Hy2Gen, Greenstat, Hydro)* to consultants / service providers *(PWC, Gexcon, Kongstein, EY)* to technology, equipment *(Corvus energy, Alma, Wärtsilä, EoneE, TECO2030, SEID, Hexagon, BARTEC)* and sensors *(Justervesenet, Sick)* providers, together with test facilities for maturing technology *(METCENTRE)*. Power companies as electricity providers and system operators *(Statkraft, Å Energi)*, and energy companies *(Equinor, Shell)* as investors and infrastructure owners drive the shift, with producers and distributors *(HYDS, Westgass, Gassco)* making the hydrogen available. Process industry *(Elkem)* enables circular economy. Industrial parks *(Greenspot Mongstad)*, harbours *(Florø Hamn)*, municipalities, and county councils *(Haugesund, Stavanger, Øygarden, Kristiansand, Vestland and Rogaland)* are key stakeholders with respect to use-cases. Ship agency *(GAC)* together with maritime authorities *(Norwegian Martime Authority, Norwegian Coastal Administration, Norwegian Ocean Industry Authority)* provide the link to shipping, while clusters *(Atheno, Maritime Cleantech, GCE NODE, VIA, Energy Transition Norway, Ocean Hyway Cluster)* provide connectivity with a broader field of stakeholders. Law firms *(Hjort and Schjødt)* support regulations and contracts development, central for achieving the energy shift. Finally, our public science centre partner Vilvite provides a strong link to public dissemination.

Publication Highlights & Key Figures

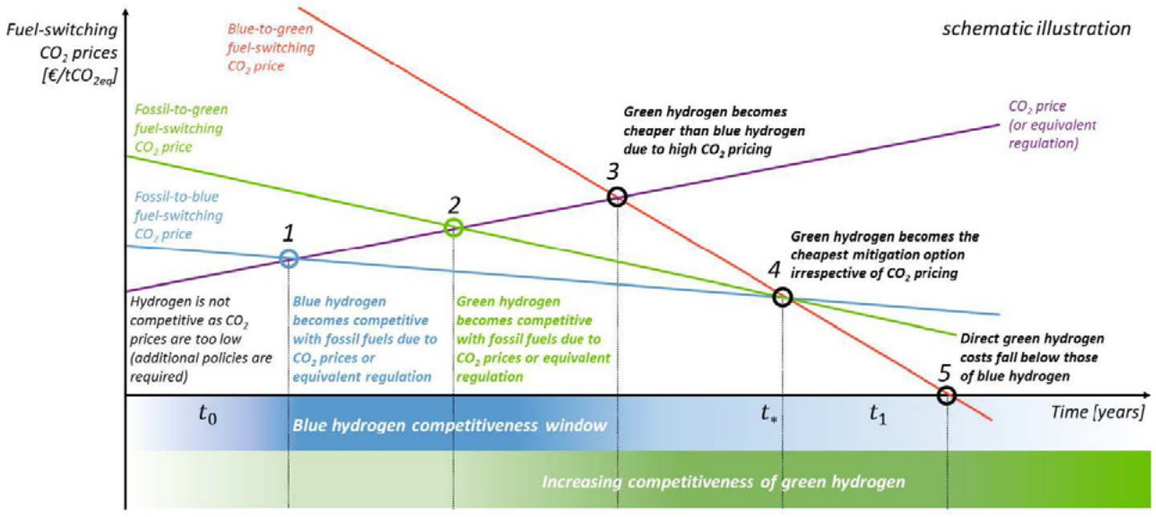
Selected Publication Highlights

Skjærseth, Jon Birger; Eikeland, Per Ove; Inderberg, Tor Håkon Jackson; Larsen, Mari Lie
Norway's Internal and External Hydrogen Strategy. *2023, 21 ss.*

Ueckerdt, Falko; Verpoort, Philipp; Anantharaman, Rahul; Bauer, Christian; Beck, Fiona; Longden, Thomas; Roussanaly, Simon Nathanael
On the Cost Competitiveness of Blue and Green Hydrogen. *SSRN Electronic Journal 2023, s. 1–39*

Oosterkamp, Antonie; Egeland-Eriksen, Torbjørn
State of the art for transport systems for hydrogen-based energy carriers. *Internal Report 2023*

Himmelstrup, Jonas; Jensen, Vidar Remi
Enabling Molecular-Level Computational Description of Redox and Proton-Coupled Electron Transfer Reactions of Samarium Diiodide. *Journal of Physical Chemistry A 2023 (1089–5639)*



KEY FIGURES – PUBLICATIONS	2022–2023
Journal Publications	3
Published conference papers	1
Books/book chapters	2
Reports/thesis	6
Popular science presentations & In media	47

For further details on publications, please visit hyvalue.no

KEY FIGURES – USED BUDGETS*	2022–2023
Host Institution (NORCE)	12 587
National Research Partners	13 995
International Research Partners	846
Industry Partners	4984
Public Partners	964
Total amounts	**33 376**

*Financial figures in 1000 NOK

KEY FIGURES – FUNDING*	2022–2023
Research Council of Norway	8 021
Host Institution (NORCE)	3 040
National Research Partners	7 210
International Research Partners	451
Industry Partners	13 690
Public Partners	964
Total amounts	**33 376**

*Financial figures in 1000 NOK

HyValue
hyvalue.no

HOST INSTITUTION

NORCE
Norwegian Research Centre AS

Postboks 22 Nygårdstangen
5838 Bergen
norceresearch.no

HyValue NORCE Forskningssenter for miljøvennlig energi