

WaterstofNet

# Hydrogen Research in Flanders

Overview of Hydrogen related activities  
at Flemish knowledge institutes



Status January 2024



# 1 Introduction

Hydrogen is high on the EU agenda as one of the pillars of the climate policy and recognized as an essential building block to realize climate neutrality by 2050. Also, in Flanders & Belgium, hydrogen is a hot topic, with the 'Hydrogen vision'<sup>1</sup> of the Flemish government as starting point for further development and roll-out of H<sub>2</sub> - technology in our region. In the industry the interest in hydrogen keeps on growing, which is clearly shown by the growth of the *Waterstof Industrie Cluster* (WIC), that has developed into a network of around 180 members of which about 150 are located in Belgium.

Flanders boasts considerable expertise in the field of hydrogen, with a number of important technology players globally recognized for their products and expertise. However, to sustain our leading position and continue to play a role in this rapidly evolving ecosystem, it is important to bring our research competences to the required level to feed and support our industry.

In our Flemish knowledge institutes several research groups are active in hydrogen related domains that are very relevant for the further development and scaling up of the hydrogen technology. We have a large diversity in topics, covering the whole value chain and comprising both experimental research and modelling activities.

Given the large number of topics, distributed over many diverse groups, WaterstofNet – as a knowledge platform and facilitator for hydrogen in Flanders - has taken the initiative to make an overview of the relevant research groups in a comprehensive publication for Flanders.

The first catalogue 'Hydrogen Research in Flanders' was published in the beginning of 2022<sup>2</sup> and a year later an updated version was released<sup>3</sup>. This catalogue provides an overview of the most relevant research groups, categorized by their focus area in the hydrogen value chain (production, storage, transport, use of hydrogen & general hydrogen topics) and the type of research (material or process development & modelling).

This new document is an update of last year's catalogue, retaining the same structure and content, while incorporating new data and topics. We hope this catalogue can be a practical guide for both research groups and industrial technology developers, facilitating the search for certain skills and expertise in the field.

The ultimate goal of this overview is to stimulate collaboration among knowledge institutes and industrial partners, allowing for the identification of knowledge gaps and opportunities for new research topics.

The WaterstofNet team  
January 2024

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<sup>1</sup> Mededeling aan de Vlaamse regering, Vlaamse Waterstofvisie "Europese koploper via duurzame innovatie"  
<https://www.vario.be/nl/nieuws/vlaamse-waterstofvisie-%E2%80%98europese-koploper-duurzame-innovatie%E2%80%99>

<sup>2</sup> [https://www.waterstofnet.eu/\\_asset/\\_public/WIC/WaterstofNet-Hydrogen-research-in-Flanders.pdf](https://www.waterstofnet.eu/_asset/_public/WIC/WaterstofNet-Hydrogen-research-in-Flanders.pdf)

<sup>3</sup> [https://www.waterstofnet.eu/\\_asset/\\_public/Publicaties/WaterstofNet\\_Hydrogen-Research-in-Flanders-2023\\_final.pdf](https://www.waterstofnet.eu/_asset/_public/Publicaties/WaterstofNet_Hydrogen-Research-in-Flanders-2023_final.pdf)

## 1.1. Content & structure

With the SRIA program, the European Union has proposed a research agenda that delineates various topics for hydrogen research, as shown in Figure 1.

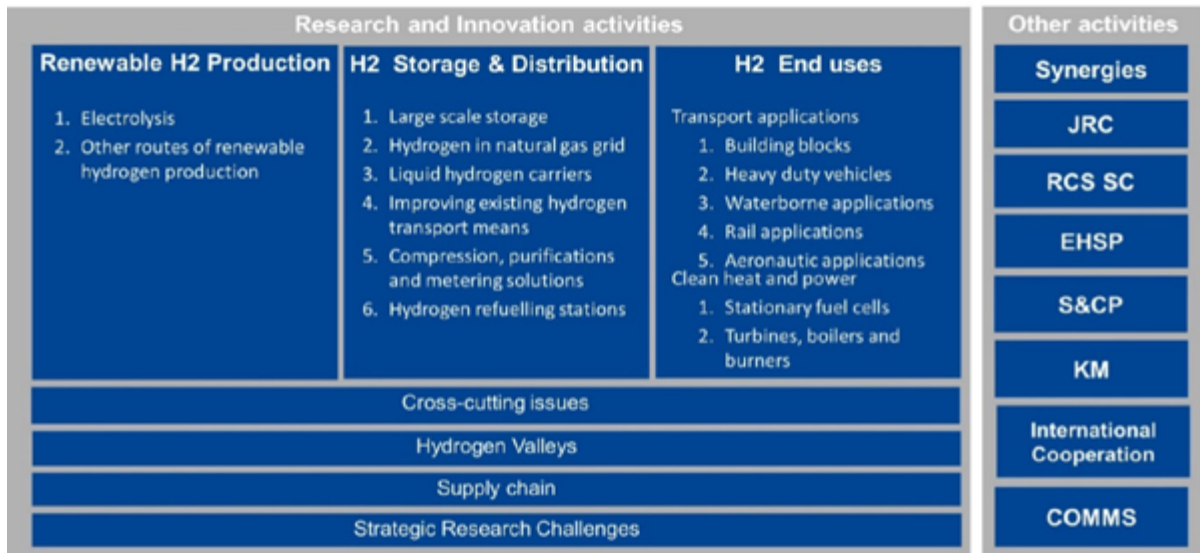


Figure 1: SRIA-program EU. It divides the topics of hydrogen research.

The most common method to produce green hydrogen involves the separation of water into hydrogen and oxygen via electrolysis using electricity from renewable energy sources like wind and solar energy. Numerous research institutions are active in further optimization of existing technologies such as Alkaline (AEL) and Proton Exchange Membrane (PEM) Electrolysis or exploring less conventional types of electrolysis such as Anion Exchange Membrane (AEM) or high temperature Solid Oxide (SO) Electrolysis. For instance, ELCAT (a research group from UAntwerpen) is committed to advancing flow electrolyzers encompassing all previously mentioned technologies, focussing on electrochemical reactor engineering and steering electrocatalysis away from the typical high-cost catalysts. Similarly, VITO possesses substantial expertise in the development and testing of both types. At the same time, the DUeL research group at UAntwerpen develops membraneless alternatives, while VIVES Hogeschool investigates further system optimization for integrating green hydrogen production into the energy landscape.

These electrolyzers rely on high-cost catalysts such as platinum (Pt), iridium (Ir) or ruthenium (Ru). The LADCA research group at UAntwerpen designs heterogeneous catalysts for in-situ hydrogen production while the COCOON group at UGent researches Atomic Layer Deposition (ALD) of electrocatalysts. COMOC at UGent is internationally renowned for developing amongst others, novel porous materials and heterogeneous catalysts. At the UHasselt, the DESINe research group delves into the intricacies of catalyst design and synthesis for hydrogen and oxygen evolution reactions within PEM electrolyzers. Typically, these PEM electrolysis cells are integrated into stacks, forming what is known as a membrane electrode assembly (MEA). The group of Electrochemical Engineering at IMO-IMOMEK undertakes membrane electrode assembly (MEA) preparation, which are part of an electrolysis cell. They also

<sup>4</sup> Strategic Research and Innovation Agenda



optimize and conduct extensive research into the lifespan and polarization characteristics of PEM electrolyzers. Moreover, IMEC focuses on developments in solid electrolyte materials and membranes, aiming for reduced resistance, thickness and gas crossover. They strive to create new thin electrodes with substantial surface area and porosity, achieved through controlled and ordered nanostructures, ultimately enhancing ionic conductivity. This innovation aims to increase current density, thereby enabling thinner MEAs for improved electrolyser performance. The EELAB & Lemcko research groups at the UGent investigate integration aspects of the electrolyser with the electrical grid, i.e. flexibility and support for power generation grids, while the Electrical Energy Applications group from KULeuven is evaluating hydrogen as storage for the electrical distribution grid.

Beyond water electrolysis, various alternative technologies exist to produce hydrogen. SolHyd, a spinoff of COK-KAT at KU Leuven produces innovative hydrogen panels that directly produce renewable hydrogen from air and solar energy using catalysts without noble metals. At the UAntwerpen, the research group PLASMANT actively explores the utilization of plasma to convert CH<sub>4</sub> and NH<sub>3</sub> into H<sub>2</sub>. Also, COK-KAT from the KULeuven, in collaboration with ElectrifyHy and PLASMANT seeks innovative ways to crack green ammonia into hydrogen.

Another method involves photoelectrochemical splitting, wherein water is split using semiconductor materials converting solar energy into chemical energy (hydrogen). The DUeL research group at Uantwerpen and both the research groups Materials for Energy Applications and DESINe at UHasselt investigate this technology. Moreover, these research groups explore photocatalytic water splitting using catalyst instead of semiconductors. Meanwhile the HyMaD and OOE research group at UHasselt are developing hybrid perovskite for application in photoelectrochemical cells. The LCT research group at UGent conducts primary research of hydrogen production, intertwining this focus with research of other e-fuels such as methanol, methane and ammonia.

Hydrogen, due to its nature, requires specific storage methods. It can either be stored in pressurized tanks or bonded with chemical substances such as ammonia or liquid organic hydrogen carriers (LOHC). The INCAT research group at UGent develops NaBH<sub>4</sub> as a carrier for hydrogen. The ElectrifyHy research groups focus on designing dehydrogenation units and test rigs for these LOHCs. When a carrier is used to transport or store hydrogen, a separation method is required to extract the hydrogen from the carrier. Following this, through purification, highly pure hydrogen remains. This purification is one of the main focusses of the Chemical Engineering research group from the VUB, but also from the PaInT research group. The ARCLATH consortium (COK-KAT & NMRCoRe, KU Leuven; CMM & COMOC, UGent; LADCA & DUeL & EMAT, UAntwerpen; Chemical Engineering, VUB) develops hydrogen storage solutions based on H<sub>2</sub> hydrates confined in porous materials. Also, the Centre for Molecular Modelling at the UGent is designing materials for hydrogen storage.

An alternative involves storing hydrogen as a gas in underground rock salt caverns, explored by the research groups New Materials/iR at KULeuven or in underground porous rock layers (e.g. aquifers), as studied by PProGress at UGent.

When opting for the pressurized tanks, designing pressurized vessels becomes essential. The MMS research group at the UGent studies the vessel design, stress calculation and Non-Destructive Testing (NDT) of thick-walled composites. The LMSD & CMG research groups at the KULeuven focus on cylindrical components and dome-like end caps, investigating low- and high-pressure vessels for storage in liquid and gaseous state respectively. Von Karman Institute for Fluid dynamics applies its expertise in computational fluid dynamics to liquid hydrogen transport and application. In addition to technical aspects, ensuring the safety of hydrogen storage requires comprehensive exploration, an area investigated by the FLOW research group at VUB.



Hydrogen as a fuel offers three different pathways. The first involves its utilization in internal combustion engines, an area of expertise of the FLOW research group at the VUB. They investigate the combustion dynamics of  $H_2$  and  $H_2$ -based carriers, such as ammonia. Similarly, the LowCarb research group at KU Leuven utilizes experimental and numerical methods to characterize alternative fuel combustion. Additionally, VIVES Hogeschool possesses expertise in internal combustion engines and specializes in dual fuel technology, particularly in diesel-hydrogen systems. The UGent based research group Transport Technology has extensive experimental and numerical expertise in internal combustion engines: it has been investigating hydrogen engines since 1992 and methanol engines since 2009, both in single fuel as dual fuel configurations.

The second option involves employing fuel cells, which is an additional area of expertise of VIVES Hogeschool. They investigate the use of these fuel cells in an integrated system. VITO contributes to the development and testing of these fuel cells. On the other hand, the Chemical Engineering group at VUB performs computational fluid dynamics (CFD) modelling to optimize the flow field design within fuel cells. Moreover, the MMS group at UGent specializes in designing and simulating fuel cell stacks, contributing to advancing fuel cell technology. The Precision Manufacturing group at Sirris investigates ultrashort pulsed laser texturing which can potentially increase the specific surface area of fuel cell electrodes, thereby increase the efficiency. Lastly, the TME (M-group) division at KU Leuven examines hybrid drone propulsion systems with fuel cells.

A third pathway would be using hydrogen as both fuel and feedstock in energy-intensive industries where full electrification is not feasible anymore as they effectively need to substitute fossil fuels as feedstocks with hydrogen in their production routes. One of the research focuses of the ESIM research group is to investigate the future potential demand for renewable hydrogen in energy-intensive industrial sectors in North-West Europe following the emission reduction targets based on EU fit for 55 or Renewable Energy Directive.

Beyond technological considerations, the economic facets of hydrogen implementation are equally pivotal. Several research groups such as EVERGi from VUB and ESIM from KU Leuven concentrate on modelling, designing and optimizing techno-economic solutions. They delve into the intricate balance between technology and economics in various hydrogen-related applications, while also assessing European and national policies related to hydrogen. More specific for ESIM, they are focussing on analysing and designing a cost-effective and feasible future renewable hydrogen infrastructure encompassing production options, transmission networks and storage units in both Belgium and neighbouring countries. This involves identifying potential hydrogen hubs, supply zones, offshore corridors, demand areas, and storage locations. Moreover, VITO and KU Leuven developed various techno-economic models, which aid in assessing and strategizing the economic viability and potential of different hydrogen technologies. Similarly, the STEN research group at UGent also assessed e-fuels with an LCA while also investigating the resource footprint and efficiency. The LCT research group at UGent utilizes its knowledge of catalysts, kinetics, reactor and process design to evaluate the economic aspects of hydrogen and other e-fuels. The geopolitical aspects of hydrogen are an area of expertise for the Ghent Institute for International and European Studies, while the Centre for Sustainable Development at UGent conducts political analysis and socio-technical evaluation. The Centre of Environmental & energy law at UGent are specialized in certification of hydrogen and green molecules.

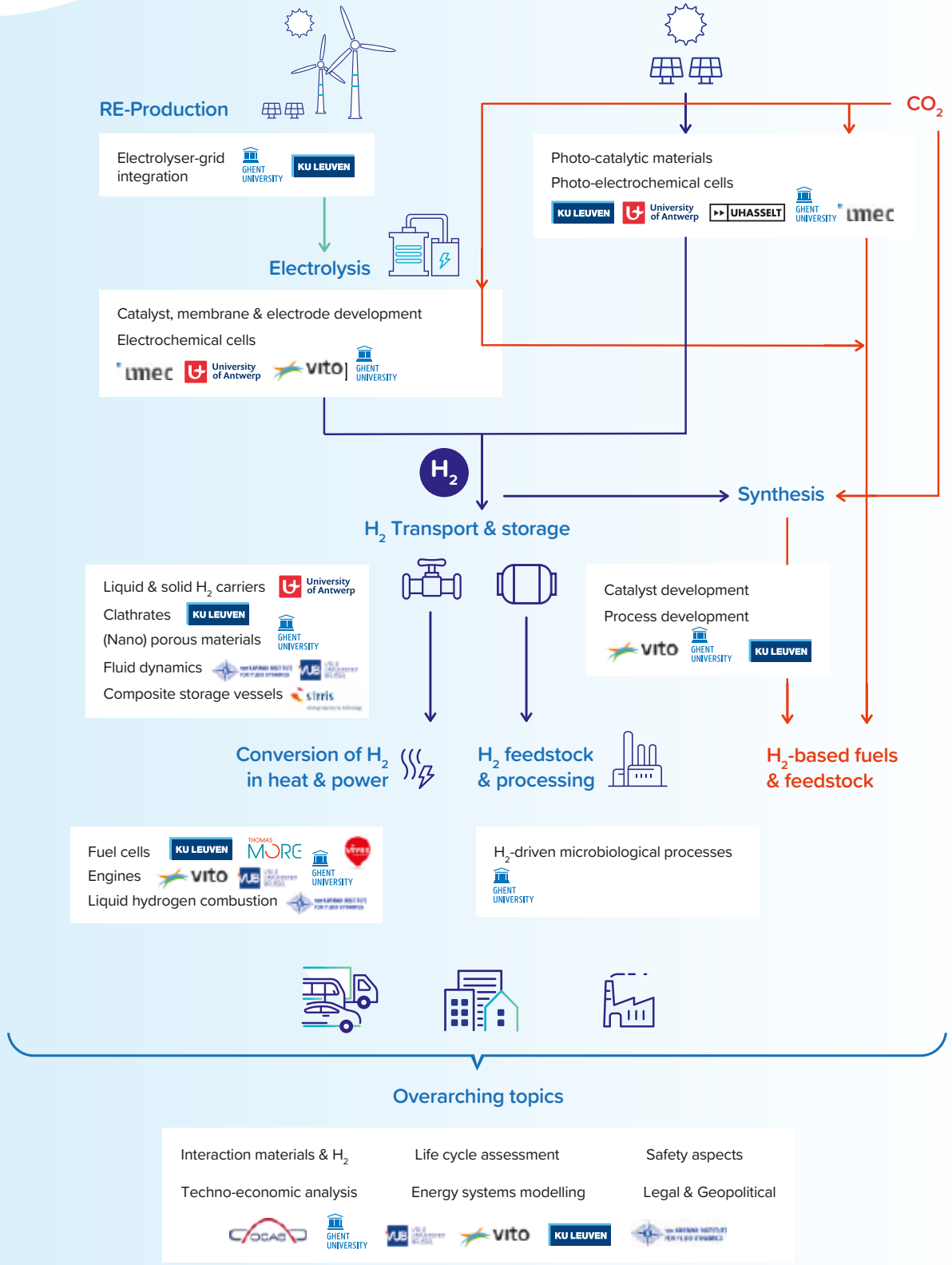


Hydrogen can also play a pivotal role in microbiological processes. The research group CMET at UGent is actively exploring microbial hydrogen metabolism, aiming to produce microbial protein, bioremediate pollutants and enhance nutrient removal for improved potable water quality.

Lastly there is the main R&D of hydrogen, like the work of the Soete Laboratory at UGent. They focus on researching the impact of hydrogen on mechanical properties of steel and roller bearings. Similarly, the MACH & SURF research groups at VUB delve into the interactions between hydrogen and steel, approaching it from a surface-oriented perspective. OCAS boasts a comprehensive expertise in R&D, particularly in understanding the interplay between hydrogen and materials, assessing the impact of hydrogen on material performance and elucidating the behaviour of materials in the presence of hydrogen. Moreover, the research group Sustainable Materials Science at UGent has garnered international recognition for its expertise in developing advanced experimental methodologies specifically tailored to studying hydrogen embrittlement.



# Academic H<sub>2</sub>-related research Flanders





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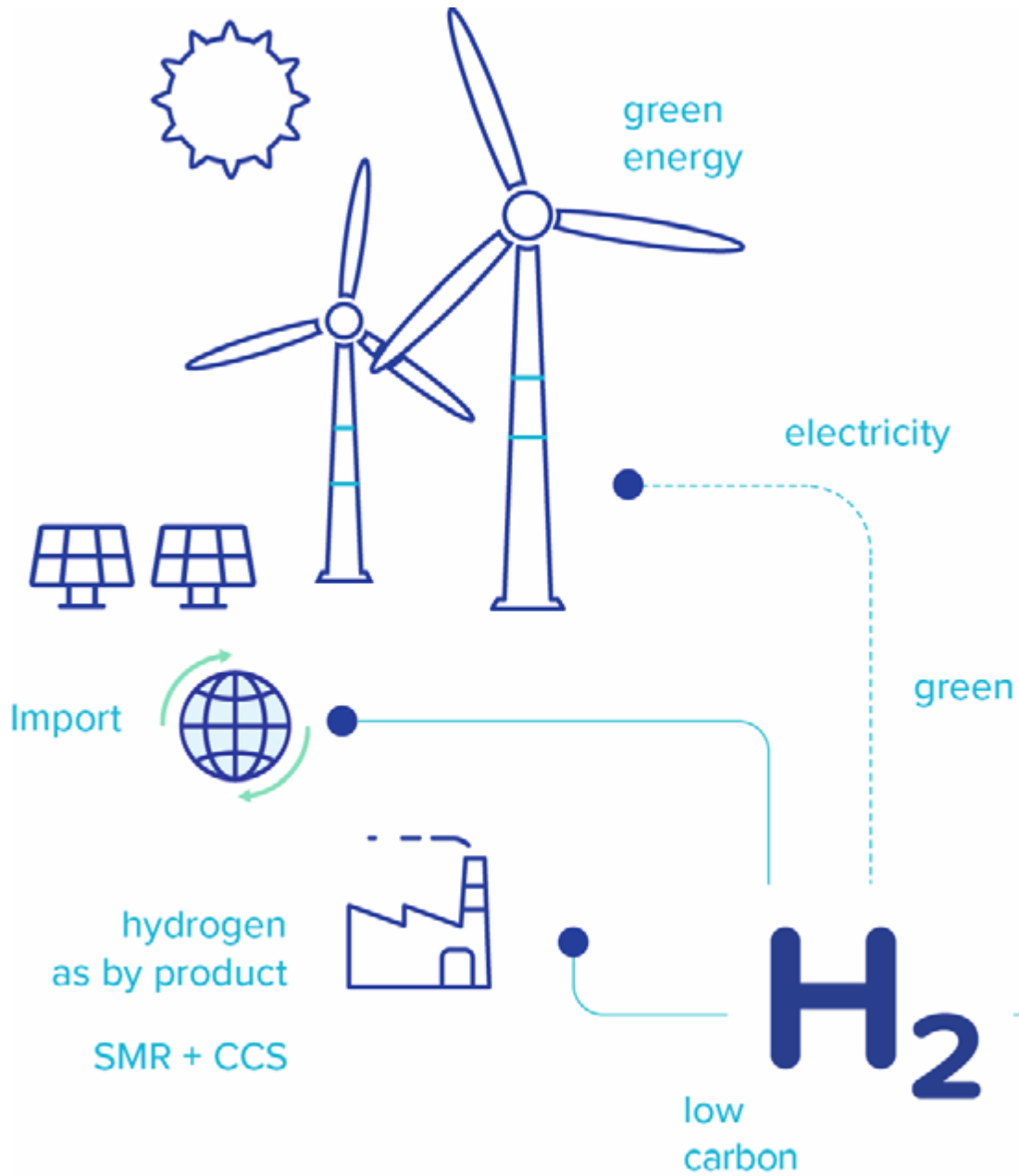


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### 3. The research

#### 3.1. Production, transport & storage



### 3.1.1. IMEC

## Energy Department

### IMEC

#### General expertise of the research group

In the area of energy research imec is active in the whole value chain from basic material research up to the system level. It spans applications from energy generation (Silicon, perovskite and tandem PV cells and modules), energy storage (solid state batteries), energy conversion (power to molecules or electrolysis and fuel cells) and energy systems. For this research, imec builds on its expertise in (semiconductor) electrochemistry, novel materials (electrodes, catalysts, electrolyte), surface functionalization, design of interfaces, various thin film deposition technologies. Imec also has expertise in characterization of relevant material properties at interfaces and in bulk, and of PV-cells and modules, batteries, electrolyzers and fuel cells.

#### Specific hydrogen- related expertise & research topics

- Development of new solid electrolyte materials and membranes with lower resistance, lower thickness and lower gas cross-over.
- Development of new thin electrodes with very large surface area and porosity for ionic conductivity based on controlled and ordered nanostructures to increase current density for thinner MEA.
- Development of novel catalysts and related deposition technologies for higher efficiency and durability
- Realization of membrane-electrode assemblies (MEA) as basic component for electrolyzers
- Upscaling of all the previous to scales which are industrially relevant
- Study of dynamic behaviour as input for technology-aware modelling
- Integration of PV-elements with electrochemical cells
- Next generation electrolyser using steam or water from the environment (humidity)

#### Available equipment/tools:

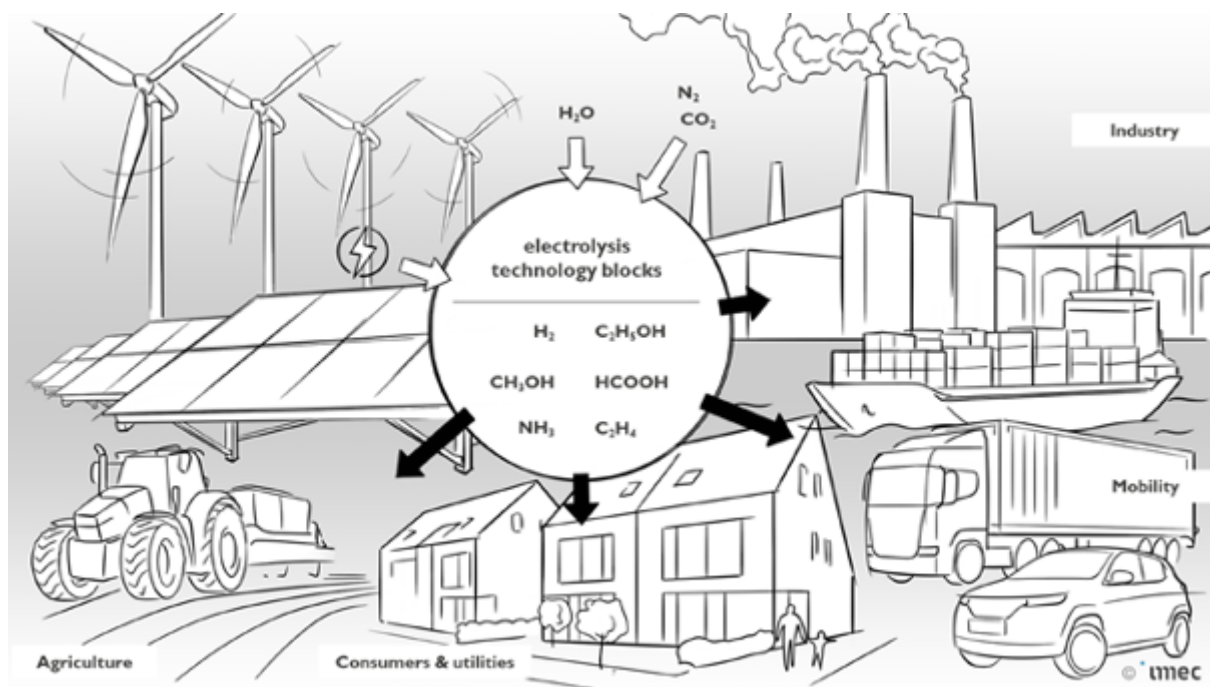
- Plating and anodization equipment for sizes up to 200 mm
- Thin-film deposition (sputtering, atomic layer deposition, physical evaporation)
- Printing and coating equipment (small size)
- Sol-gel synthesis and analysis
- Ionic conductivity and ionic coupling measurements
- Electrochemical equipment for analysis, synthesis, and characterization
- Single stack electrolyser test cells

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- H<sub>2</sub>-Mhytic – Blauwe Cluster – VITO, imec, UGent: Hydroxyl Exchange Membrane based electrolysis
- PROCURA – ETF – imec, Vito, KUL, VUB, ULiège, WaterstofNet: PV-EC demonstrator and system modelling



Imec's vision is that the electrolysis technology blocks under development have a wide application in conversion of (green) energy to molecules, including CO<sub>2</sub> Capture and Utilization. The following graphic illustrates that point.



### Main relevant publications

- “Combining High Porosity with High Surface Area in Flexible Interconnected Nanowire Meshes for Hydrogen Generation and Beyond” Stanislaw Zankowski and Philippe M. Vereecken, ACS Appl. Mater. Interfaces, 2018, 10 (51), pp 44634–44644; DOI: 10.1021/acsami.8b15888
- Nanotechnologie: hoe een voetbalveld in een blikje frisdrank onze toekomst kan veranderen | VRT NWS: nieuws (<https://www.vrt.be/vrtnws/nl/2019/03/12/nanotechnologie-hoe-een-voetbalveld-in-een-blikje-frisdrank-onz/>)
- “Redox Layer Deposition of Thin Films of MnO<sub>2</sub> on Nanostructured Substrates from Aqueous Solutions” S.P. Zankowski, L van Hoecke, F Mattelaer, M de Raedt, O. Richard, C. Detavernier, P.M. Vereecken, Chemistry of Materials, 31(13):4805-4816 (2019). IF 9.89.
- “Enhanced Photocatalytic Activity of Nanoroughened GaN by Dry Etching” W. J. Tseng, D. H. van Dorp, R. R. Lieten, B. Mehta, P.M. Vereecken, and G. Borghs, ECS Electrochemistry Letters, 2 (11) H51-H53 (2013).
- “Synthesis of large area carbon nanosheets for energy storage applications”, D. Cott, M. Verheijen, O. Richard, I. Radu, S. De Gendt, S. Van Elshocht, and P.M. Vereecken, Carbon 58, 59–65 (2013); <http://dx.doi.org/10.1016/j.carbon.2013.02.030>.

### Contact persons:

- Philippe Vereecken (technical)
- Jef Poortmans (strategic)
- Bart Onsia (business)

### 3.1.2. KU Leuven

## *Oppervlaktechemie en Katalyse -Karakterisatie en Applicatie Team (COK-KAT)*

KU Leuven, Faculty of Bioscience engineering, Department of Microbial and Molecular Systems (M2S)

#### General expertise of the research group

The research team has a strong focus on porous materials, catalysis and adsorption. The emphasis is on three major themes related to grand societal challenges: water, energy and human health. Energy research is concentrated on renewable fuels (solar hydrogen and ammonia), and hydrogen, CO<sub>2</sub> and green methane storage in clathrate hydrates. Molecular aspects of water upon confinement in nanopores relevant to electrolytic processes and molecular storage are investigated.

#### Specific hydrogen- related expertise & research topics

- Storage of hydrogen, methane and carbon dioxide in clathrate hydrates
- Green ammonia production and cracking, circular nitrogen economy

#### Available equipment/tools:

- Workstation for advanced testing of photoelectrochemical cells & components, electrolysis lab-scale units
- Analytical equipment including ion chromatography, mass spectrometry
- Solid state NMR spectroscopy and XRD for characterizing hydrogen storage materials

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- PROCURA (BE – ETF)(KUL/Energyville, Waterstofnet, VUB, ULiège): Power-to-X and carbon capture & utilization roadmap for Belgium
- HyPERFarm (EU – H2020)(KUL, Aarhus, Fraunhofer): Hydrogen and photovoltaic electrification on farm
- ARCLATH II (FL – Moonshot cSBO): hydrogen storage in artificial clathrates
- WATUSO (EU – ERC AdG): nanoconfined water: a tunable solvent system



Figure 2: H<sub>2</sub>/CH<sub>4</sub> storage in clathrate hydrates

### Main relevant publications

- Beckwée, E.J. et al. (2024). Structure I methane hydrate confined in C8-grafted SBA-15: A highly efficient storage system enabling ultrafast methane loading and unloading. *Applied Energy*, doi: 10.1016/j.apenergy.2023.122120
- Beckwée, E.J. et al. (2023). Enabling hydrate-based methane storage under mild operating conditions by periodic mesoporous organosilica nanotubes. *Heliyon*, doi: 10.1016/j.heliyon.2023.e17662
- Thijs, B. et al. (2022). Demonstration of a three compartment solar electrolyser with gas phase cathode producing formic acid from CO<sub>2</sub> and water using Earth abundant metals. *Frontiers in Chemical Engineering*, doi: 10.3389/fceng.2022.1028811
- Thijs, B. et al. (2022). Matching emerging formic acid synthesis processes with application requirements. *Green Chemistry*, 24(6), pp. 2287–2295.
- Gupta, A. et al. (2021). *Hydrogen Clathrates: Next Generation Hydrogen Storage Materials*. Elsevier B.V., pp. 69–107
- Thijs et al. (2021). Selective electrochemical reduction of CO<sub>2</sub> to formic acid in a gas phase reactor with by-product recirculation. *Sustainable Energy Fuels*, doi: 10.1039/d1se00218j
- Hollevoet et al. (2020). Energy-Efficient Ammonia Production from Air and Water Using Electrocatalysts with Limited Faradaic Efficiency. *ACS Energy Letters*, 5(4), 1124–1127.
- Rongé et al. (2019). Bifunctional earth-abundant phosphate/phosphide catalysts prepared via atomic layer deposition for electrocatalytic water splitting. *Nanoscale Advances*, 1(10), 4166–4172.

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- Professor Christine Kirschhock ([christine.kirschhock@kuleuven.be](mailto:christine.kirschhock@kuleuven.be))





### Spin-offs

- **Solhyd** ([www.Solhyd.eu](http://www.Solhyd.eu)) : «Solar hydrogen for everyone everywhere »
- Contact: Jan Rongé ([jan.ronge@solhyd.eu](mailto:jan.ronge@solhyd.eu))



### Foundation

**Solhydair Foundation:** Solhydair Foundation's disinterested aim is to increase the positive societal impact of technologies, particularly in the areas of energy supply, water supply, and health. It will manage impact licensed technologies for the purpose of clean cooking and cooling with hydrogen, but also the production, filtration and sustainable management of water, having the main goal of improving the physical well-being of humans.



## Department of Electrical Engineering/ Electrical Energy Applications Ghent

### KU Leuven, Faculty of Engineering

The research group carries out applied research related to electrical energy. This comprises: Power electronic applications, storage of electricity, integration of PV, protection of distribution grids under the impact of power electronics and electrical bikes.

#### Specific hydrogen- related expertise & research topics

- Practical evaluation as hydrogen as a storage for electrical distribution grids

#### Available equipment/tools:

- Power analysers (Yokogawa)
- Power-Quality meters (Fluke)
- Test bench for electrical bikes
- Programmable multi-phase AC current and voltage source (Omicron)
- Programmable DC source and load

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- H<sub>2</sub> for all, TETRA

#### Contact persons:

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Tel. +32 9 267 2703

## Departments of Mechanical Engineering & Materials Engineering – LMSD & CMG

### KU Leuven, Faculties of Engineering Science & Engineering Technology

#### General expertise of the research group

- experimental identification of material characteristics of fibre-reinforced composites
- development of numerical modelling strategies for material properties in a multi-scale context, including micro-, meso- and macro-scale
- development of experimental methodologies for the identification and objective quantification of uncertainty and variability in material properties
- development of modelling strategies for manufacturing and processing methods of fibre-reinforced composites
- numerical modelling strategies for structural components at the micro- and macro-scale, both for metals and fibre-reinforced composites
- development of generic numerical formalisms and methodologies for the propagation of uncertainty and variability in structural components
- methodologies for the identification and objective quantification of uncertainty and variability in material properties
- comprehensive methodologies for the propagation of uncertainty and variability in built-up structures, covering processes, materials and structures

#### Specific hydrogen- related expertise & research topics

Application of generic experimental and simulation procedures to characterize pressure vessels, with a focus on reliability:

- filament wound pressure vessels based on axisymmetric geometry, including cylindrical components and dome-like end caps: from micro- to macro-scale [1-8 above]
- $\mu$ CT-scanning procedures and image analysis for the geometrical identification of material structure at the micro-scale (voids and porosities)
- high-pressure vessels ( $10^2$ - $10^3$  bar of differential pressure) for applications in storage of hydrogen in gaseous state
- low-pressure vessels (10-1-100 bar of differential pressure) for applications in storage of hydrogen in liquid state, development of efficient design procedures for thin-walled geometries (cylindrical, spherical, toroidal, conical primitives) with membrane stress only and high volumetric efficiency
- topology design and thermo-mechanical analysis of multi-lobe liquid hydrogen fuel storage tanks for application in reusable launchers and blended-wing aircraft
- topology design and thermo-mechanical analysis of storage tanks for transport of hydrogen as cargo payload in aircraft

Participation in FL/B/EU funded projects with H<sub>2</sub> related research:

- SIM ICON project OptiVaS HBC.2019.0070 Optimized pressure vessels through composite Variability Simulation; start 01 Aug 2020 – extended till 31 Jul 2024, coordinator: Toyota Motor Europe; partners: Siemens Industry Software, Plastic Omnium, KU Leuven
- Horizon EU, call CleanH2-2023, ECOHYDRO, Economic manufacturing process of recyclable composite materials for durable hydrogen storage; start 2024 – end 2028, coordinator Institut Mines Telecom, FR; 15 partners from 7 EU countries, including Airbus and Electra Commercial Vehicles Ltd UK
- SIM SBO project RELFICOM HBC.2017.0321 Reliability of fibre-reinforced composites: materials design & variability; start 01 Jan 2018 – completion 31 Dec 2021, coordinator: KU Leuven ; partners: Toyota Motor Europe, Siemens Industry Software, Plastic Omnium
- FWO doctoral grant strategic basic research, 1SG1523N, Conformable Pressurized Tanks for Hydrogen Storage and Transportation; start 01 Nov 2022 – scheduled till 31 Oct 2026
- VLAIO Baekeland doctoral grant, HBC.2022.0713 Study of the residual stresses in a thermoplastic filament winding process for high-pressure H<sub>2</sub>-storage vessels; 2023-2027, in cooperation with Covess

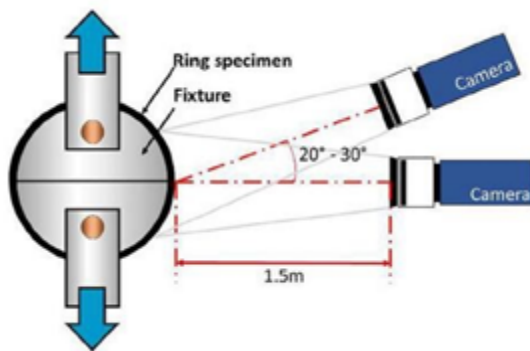


Figure 4: Split-disk test

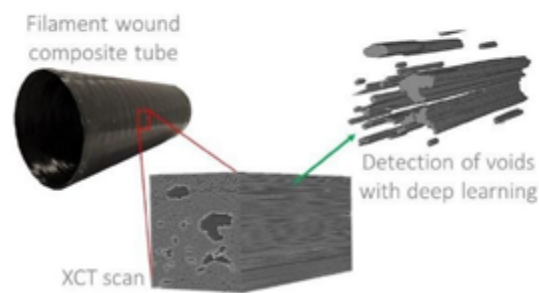


Figure 3: Void characterization in a composite pressure vessel wall via micro-CT

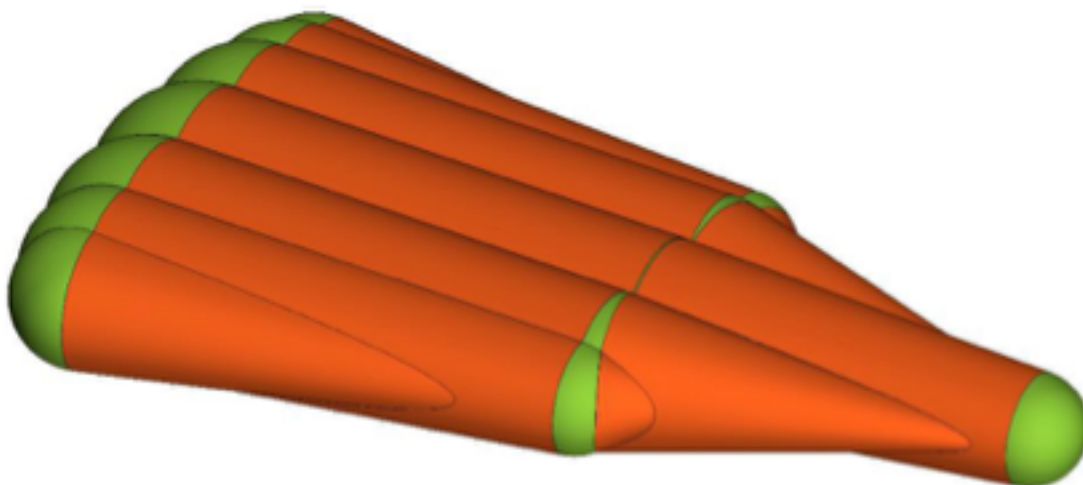


Figure 5: Multi-cell tank topology for maximum volumetric efficiency

#### Available equipment/tools:

- composite processing equipment (hot press, autoclave, RTM, infusion)
- drum winder and filament winding machines
- mechanical testing of composites, including split-ring test setup
- damage monitoring tools for mechanical testing (digital image correlation , acoustic emission), C-scan
- SEM and optical microscopy
- $\mu$ CT-scanning equipment (XCT Core Facilities) and image analysis tools
- DIC equipment and image analysis software
- VoxTex model generation for fibre reinforced composites
- generic finite element analysis software

#### International collaborations:

- Toyota Motor Europe (BE)
- Mines ParisTech (FR)
- Mines Douai (FR)
- European Space Agency (ESA)
- Hyviate (DE)

#### Main relevant publications

- Straumit, I., S. V. Lomov and M. Wevers (2015). "Quantification of the internal structure and automatic generation of voxel models of textile composites from X-ray computed tomography data." *Composites Part A* 69: 150-158. doi:10.1016/j.compositesa.2014.11.016.
- Upadhyay, S., A. G. Smith, D. Vandepitte, S. V. Lomov, Y. Swolfs and M. Mehdikhani (2022). Analysis of voids in filament wound composites using a machine-learning-based segmentation tool. 20th European Conference on Composite Materials (ECCM-20): paper 61918.
- Zhao, Y., P. Druzhinin, J. Ivens, D. Vandepitte and S. V. Lomov (2021). "Split-disk test with 3D digital image correlation strain measurement for filament wound composites." *Composite Structures* 263: 113686. <https://doi.org/10.1016/j.compstruct.2021.113686>.
- Zhao, Y., D. Vandepitte and S. V. Lomov (2021). "The effect of delamination on ring specimen failure in the split-disk test with cohesive zone modelling – Comments on the paper: Zhao Y, Druzhinin P, Ivens J, Vandepitte D, Lomov SV. Split-disk test with 3D Digital Image Correlation strain measurement for filament wound composites, *Composite Structures*, 2021, 263:113686 (doi 10.1016/j.compstruct.2021.113686)." *Composite Structures* 277: 114517. <https://doi.org/10.1016/j.compstruct.2021.114617>.
- Niguse Asfew, K., Ivens, J., Moens, D., (2022). "Temperature dependence of thermophysical properties of carbon/polyamide410 composite". *Functional Composite Materials*, 3, Art.No. 8. doi: 10.1186/s42252-022-00036-6 Open Access
- Ypsilantis, K.I., Faes, M., Ivens, J., Lagaros, N., Moens, D. (2022). "An approach for the concurrent homogenization-based microstructure type and topology optimization problem". *Computers & Structures*, 272, Art.No. 106859. doi: 10.1016/j.compstruc.2022.106859
- Malfroy, J., Van Bavel, B., Steelant, J., Vandepitte, D. (2023), "Thin-walled tapered conformable pressurized tanks: Concept and principles", submitted to *Thin-Walled Structures*
- Malfroy, J. (2022) Design and optimization of a tapered multi-bubble tank for hypersonic aircraft, master's thesis dissertation (supervisors D. Vandepitte and J. Steelant)

Contact persons:

- Mechanical engineering Department, LMSD section
  - Dirk Vandepitte
  - David Moens
  - Johan Steelant
  - Bert Pluymers
- Materials Engineering Department, Composite Materials Group
  - Yentl Swolfs
  - Jan Ivens
  - Mahoor Mehdikhani
  - Stepan Lomov
  - Frederik Desplentere

### 3.1.3. Sirris

## Additive Manufacturing

### Sirris, Advanced Manufacturing

#### General expertise of the research group

- Validation of metallic and polymer material for Additive manufacturing in order to use additive manufacturing for increasing the exchange surfaces (specific surface)
- Proof of concepts realisation to test the cells using the potential of AM for iterations

#### Specific hydrogen- related expertise & research topics

- Dense and porous parts in pure copper (produce by EBM)
- Porous material by using design (lattice) and process setting of L-PBF-LB. (SLM)
- Process validation of porous graded Materials by L-PBF-LB (SLS) process
- Conductive track printing on 3D shapes (3D printing + AJP)

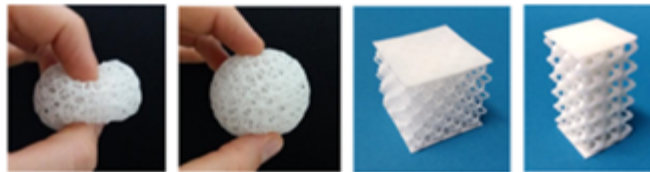
#### Available equipment/tools:

- AM metallic materials validation: 2 PBF-LB (SLM) /1 (PBF-EB) (EBM)/1 DED (cladding)
- AM polymer material validation: 1 MJT/3 VAT PP for loaded material/2 L-PBF-LB (SLS)/2 DLP 3 MEX (FDM) covering a wide range of temperatures/ an extrusion head mounted on a Cobot
- AM Feedstock material characterization: Powder lab/ thermal analysis chain adapted to the field of AM
- AM Part quality: Internal stress (DRX) and deformation (Atos 5 Scanner)/mechanical testing

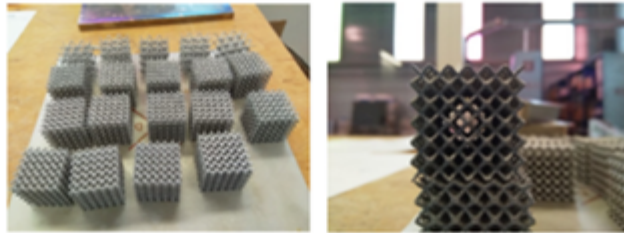
#### International collaborations:

- Focus = Belgium as Belgian technology centre

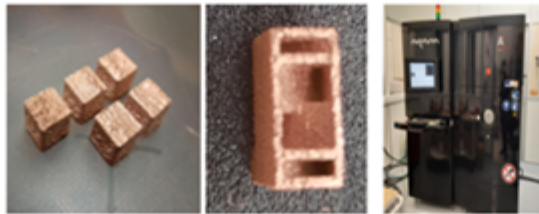
### Manufacturing of dense and porous Materials



*Exemples de structures lattices en polyuréthane thermoplastique (TPU).*



### Pure Copper for Electrical application



### Printed Electronics



### Main relevant publications

- Magnien J, Cosemans P, Nutal N, Kairet T. Current surface issues in additive manufacturing. Plasma Process Polym. 2020;17:e1900154
- YADAV, Pinku, RIGO, Olivier, ARVIEU, Corinne, et al. In situ monitoring systems of the SLM process: On the need to develop machine learning models for data processing. Crystals, 2020, vol. 10, no 6, p. 524
- Pauline Delroisse, Matthieu Marteleur, Olivier Rigo, Catherine Doneux, Gregory Pyka, Martine Wevers, Pascal J. Jacques, Aude Simar: "Comparison of the impact resistance of honeycombs and LBM lattice structures" - Workshop on additive manufacturing for space application- ESTEC Noordwijk, Netherlands, 2014.
- Denis Vandormael, Olivier Rigo, Laurent Seronveaux: "Direct deposition of surface acoustic wave by aerosol jet printing technique" - Smart system Integration - VDE verlag publishing, Berlin, 2012

### Contact persons:

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## Precision Manufacturing

### Sirris, Advanced Manufacturing

#### General expertise of the research group

Sirris Precision Manufacturing is one of the oldest groups of Sirris and is dedicated towards research and services in the field of advanced manufacturing technologies, and in particular, subtractive manufacturing technologies (e.g. milling, turning, laser ablation) and this in combination with advanced Industry 4.0 practices such as adaptive, data driven machining processes and sensor based manufacturing systems.

#### Specific hydrogen- related expertise & research topics

- Ultrashort pulsed laser texturing which can potentially:
  - Increase specific surface area of Hydrogen Fuel Cell electrodes (up to 1500-fold) and hence increase efficiency.
  - Activate or de-activate parts of the electrode for gas evolving reactions (OER).
  - Produce defects close to the surface to increase wettability and enhance the removal of gas bubbles from the electrodes.
  - Create high emissivity (>0,99) and absorption (>99%) surfaces
- Ultrashort pulsed laser machining which can:
  - Cut and structure thin electrode materials in fast and efficient way.
  - Engineer coating and selectively remove very thin (200-300 nm) noble metal layers without damage to substrate.

#### Available equipment/tools:

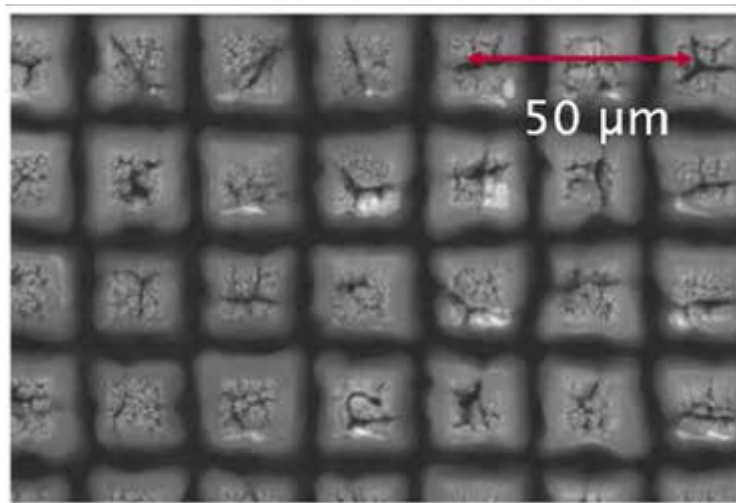
- LASEA LS5-1 Femtosecond laser texturing machine
- Keyence vk-x1100 confocal microscope
- COMSOL Thermal modelling & simulation software
- IR Camera & Vacuum tank
- Photo spectrometer

#### International collaborations:

- Sirris Circular Economy, Coatings and renewable materials (T-ICE)
- Sirris Onshore and Offshore Wind Energy Industry (T-OWI)

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

Currently none, but active in ESA GSTP programs to create functional surfaces for space applications and more specifically ultra black surfaces. Recent work by Karsten Lange (Univ. Hannover, Electrode Structuring by Ultrashort Pulsed Lasers: a new tool for the Hydrogen Economy, PhD Thesis, 2019) showed that the same structures are greatly beneficial for Hydrogen applications. This could be potentially a on ground spin-off of space technology developed by Sirris for ESA/Belspo.



*Figure 6: Multiscale structure in Nickel with enormously increase specific surface area, developed for space applications (ESA) but interesting for Hydrogen applications as well.*

#### Main relevant publications

- Ultrafast Laser Selective Phase Removal for surface modification of nanocomposite materials, J. Han, O. Malek, J. Vleugels, A. Braem, S. Castagne, Optics Express 29 (16), 24834-24845.
- Ultrashort pulsed laser ablation of zirconia-alumina composites for implant applications, J Han, O Malek, J Vleugels, A Braem, S Castagne, Journal of Materials Processing Technology 299, 117335.
- De Tijd "Belgische Onderzoekers lopen mee naar zwaarste zwart" (17/06/2021)

#### Contact persons:

- Olivier Malek, Senior Engineer, [olivier.malek@sirris.be](mailto:olivier.malek@sirris.be)
- Peter ten Haaf, Program Manager, [peter.tenhaaf@sirris.be](mailto:peter.tenhaaf@sirris.be)

## Product Development Hub

### Sirris, Composites

#### General expertise of the research group

Product development in Light, Smart and Micro domains.

The Hub combines the expertise of 6 labs (Conception Lab / Fabrication Lab / Micro Lab / Plastics Lab / Hybrids Lab & Smart Lab) to support the companies in the development of innovative products

#### Specific hydrogen- related expertise & research topics

- Simulation of the structural behaviour of high-pressure composite vessels
- Definition of optimization of the boss and the laminate structure
- Material characterization from specimens produced out of the right process technology

#### Available equipment/tools:

- Simulations through WoundSim/Abaqus chain and Samcef
- Material characterization via universal tensile machine

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

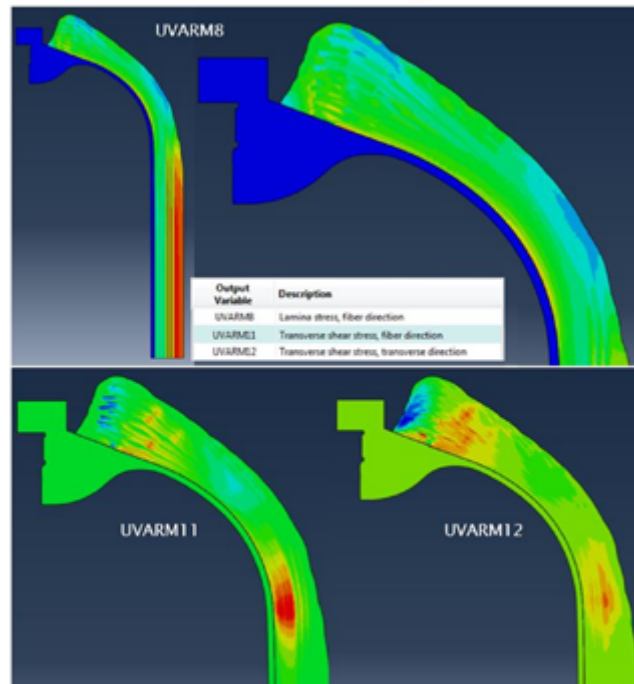
- H2020 THOR
  - Partnership: FAURECIA, CETIM & CETIM Grand Est, Air Liquide, RIA, CNRS, NTNU, Sirris
  - The THOR project aims to develop a cost-effective high-pressure “type 4” thermoplastic composite hydrogen storage vessel for transportation applications.
  - <https://thor-fch2.eu/>

#### International collaborations:

Only through the EY Project THOR described in the next frame



### Simulation results of an axisymmetric model



#### Main relevant publications

- Only internal reporting within project THOR

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+32498919331

### 3.1.4. UAntwerpen

## *Department of Bioscience Engineering: Sustainable Energy, Air and Water Technology Group (DuEL) / Blue App: ElectrifyHy*

### University of Antwerp, Faculty of Science

#### General expertise of the research group

The Sustainable Energy, Air and Water Technology Group (DuEL) focuses on several research areas of societal relevance: (1) Hydrogen technology, (2) purification technologies for various side and waste streams, (3) solar energy utilisation, and (4) microbial cleantech. Concerning hydrogen, DuEL focusses on (i) the production of H<sub>2</sub> from abundant sources (e.g. seawater) or waste streams using light and sustainably produced electricity as primary energy inputs, (ii) design of innovative photo-electrolysers, (iii) characterisation of H<sub>2</sub> carriers (thermal and chemical stability, kinetics, catalyst design), (iv) design of chemical reactors for the storage and release of H<sub>2</sub> to and from liquid and solid carriers, following process intensification. The latter two topics are developed in close connection to Blue App (at ElectrifyHy), whose scope includes the design, simulation (including CFD code development for multiphase turbulent reacting flows), prototyping, experimental characterization and scale-up of intensified reactors. The team can count on a lot of experience in fluidization, various reactors (from 3 to 10 cm ID), including a pre-pilot electrothermal fluidized bed reactors available for testing and validation. At the Blue App building, world class laboratories are available, including a 3-story high pilot hall.

#### Specific hydrogen- related expertise & research topics

- Gas phase analysis of H<sub>2</sub> release reactions.
- Evaluation of innovative H<sub>2</sub> production pathways (e.g. seawater splitting, H<sub>2</sub> recovery from aqueous and gaseous waste streams).
- Solar-responsive catalysts for direct photo(electro)chemical hydrogen evolution.
- Development of innovative photo-electrolyzers, focused on membraneless designs
- Process simulations and CFD-assisted reactor design and optimization simulations
- Design of electrically assisted chemical carriers (e.g., ammonia) cracking reactors
- Design of dehydrogenation units for liquid organic hydrogen carriers (LOHC)
- Test rig for LOHC (up to 250 lpm)
- Design of dense Pd-Ag supported membranes for H<sub>2</sub> removal from reactors
- Pre-pilot electrothermal fluidized bed designed for the pyrolysis of methane into H<sub>2</sub>
- Design, simulation, and experimental validation of e-reactors
- Coke-resistant catalysts for biogas (CH<sub>4</sub> and CO<sub>2</sub>) to syngas applications



### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- ‘CAMELEON’: Electrified catalytic non-oxidative methane coupling for separated hydrogen and ethylene production (2024-2028). VLAIO Moonshot cSBO project (2017-2024). Collaboration with LCT (UGent), and STEN (Ugent)
- Cracking of green ammonia to hydrogen using innovative catalyst and adsorbent assisted plasma technology (HYPACT) (2022-2025). FOD Economie. Federal Government of Belgium. Collaboration with COK-KAT (KULeuven), and PLASMANT (UAntwerp).
- Electrical Cracking of Ammonia for Hydrogen Production (AMELEC) (2024-2025). UAntwerp’s industrial valorization funds (IOF SBO) Research Grant. Supported by the Port of Antwerp-Bruges.
- “Design of innovative reactors for the release of hydrogen from chemical carriers such as liquid organic hydrogen carriers” (2023-2024). UAntwerp’s industrial valorization funds (IOF SBO) Research Grant. Supported by the Port of Antwerp-Bruges.
- ‘Arclath’ 1 and 2 projects on the storage of hydrogen in hydrate clathrates. VLAIO Moonshot cSBO projects (2017-2024). Collaboration with COK-KAT (KULeuven), Comoc (Ugent), Center for Molecular Modelling (Ugent), STEPChem (VUB), and LADCA (UAntwerp)
- “Design of innovative reactors for the release of hydrogen from chemical carriers such as liquid organic hydrogen carriers” (2023-2024). UAntwerp’s industrial valorization funds (IOF SBO) Research Grant. Supported by the Port of Antwerp-Bruges.
- “Electrified chemical reactor for fast release of hydrogen (H<sub>2</sub>) from liquid organic hydrogen carriers (LOHCs) for generator set (genset). H<sub>2</sub> genset testing on a ship (Port of Future)” (2019-2020). UAntwerp’s industrial valorization funds (IOF SBO) Research Grant. Supported by the Port of Antwerp-Bruges.
- BOF DOCPRO4 PhD Fellowship, “CFD-Assisted Design of an Innovative Multiphase Chemical Reactor for Hydrogen Release.”
- “Photoelectrochemical abatement of methane waste with simultaneous energy recovery”. FWO PhD Fellowship
- “Solar hydrogen production from seawater using stabilized plasmonic photocatalysts”. FWO PhD Fellowship
- “In-line quantization of the hydrogen gas yield from photoelectrochemical treatment of volatile organic compounds”. FWO Research Grant
- “Membraneless photo-electrolyzer for solar hydrogen production” (2023-2026) FWO Postdoctoral Fellowship
- (Photo)electrolyzer for pure hydrogen gas production in flow. (2022-2024) UAntwerp industrial valorization fund (IOF) Create Proof of Concept Grant.
- “A 1kW membraneless electrolyzer demonstrator for pure green hydrogen gas production in flow.” (2023-2025) UAntwerp industrial valorization fund (IOF) Develop Proof of Concept Grant.

### Available equipment/tools:

- 10 cm ID electrothermal fluidized bed coupled to an online RGA GC
- Up to 250 lpm LOHC test rig
- Various inductively- and resistively heated reactors fully instrumented
- Various inductively- and resistively heated fluidized bed reactors (up to 100 bar), fully instrumented, including highly sensitive pressure transducers for indirect reactor diagnostic
- Various Sieverts (volumetric) apparatus for the characterization of adsorbents, using highly sensitive pressure transducers, coupled to -50-200 °C cryostats



- Simulated moving bed (SMB) with inductively heated thermal swing section for adsorption processes
- Quadrupole mass spectrometer for transient gas analysis
- Refinery gas GC analyser for steady state gas analysis
- Particle image velocimetry system (LED and laser) for non-intrusive fluid flow characterization
- GC with pulsed-discharge detector for low level H<sub>2</sub> measurements
- Fully automatized gas testing setup
- Potentiostat
- Stereolithographic 3D printer for in-house reactor printing

#### International collaborations:

- Hydrogenious LOHC Technologies, Germany.
- Various spin-offs in the direct air capture, energy generation and CCS sector.

#### Main relevant publications

- Challenges in the use of hydrogen for maritime applications (2021). L Van Hoecke, L Laffineur, R Campe, P Perreault, et al. *Energy & Environmental Science* 14 (2), 815-843
- Combined Methane Pyrolysis and Solid Carbon Gasification for Electrified CO<sub>2</sub>-Free Hydrogen and Syngas Production (2023). P Perreault, CR Boruntea, et al. *Energies* 16 (21), 7316
- Intensified swirling reactor for the dehydrogenation of LOHC (2023). L Van Hoecke, NB Kummamuru, et al. *International Journal of Hydrogen Energy*
- Critical challenges towards the commercial rollouts of a LOHC-based H<sub>2</sub> economy (2023). P Perreault, L Van Hoecke, et al. *Current Opinion in Green and Sustainable Chemistry*, 100836
- Hydrogen clathrates: Next generation hydrogen storage materials (2021). A Gupta, GV Baron, P Perreault, et al. *Energy Storage Materials* 41, 69-107
- Harvesting Hydrogen Gas from Air Pollutants with an Unbiased Gas Phase Photoelectrochemical cell (2017). S.W. Verbruggen, M. Van Hal, T. Bosserez, J. Rongé, B. Hauchecorne, J.A. Martens, S. Lenaerts. *ChemSusChem* 10, 1413-1418
- Tapping Hydrogen Fuel from the Ocean: a Review on Photocatalytic, Photoelectrochemical and Electrolytic Splitting of Seawater (2021). F. Dingenen, S.W. Verbruggen. *Renewable and Sustainable Energy Reviews* 142, 110866

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- Prof. Dr. P. Perreault, [patrice.perreault@uantwerpen.be](mailto:patrice.perreault@uantwerpen.be) (ElectryfHy)  
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## Department of Applied Electrochemistry and Catalysis (ELCAT)

### University of Antwerp, Faculty of Applied Engineering

#### General expertise of the research group

The core research activities within ELCAT are related to the development of state-of-the-art electrochemical reactors and its components, with a view towards large-scale industrial development in the field of industrial electrification, in a green and sustainable way to ultimately replace the traditional chemical processes. The scope there is to improve controllability, flexibility and energy efficiency of the reactions through electrocatalyst and reactor design. This research can thus be subdivided in three main topics, which are interrelated: (i) electrocatalysis, (ii) electrosynthesis and (iii) electrochemical reactor engineering. From those research topics, two major aspects of the identity as a group clearly come to the surface: (1) industrial application and (2) sustainable chemistry.

#### Specific hydrogen- related expertise & research topics

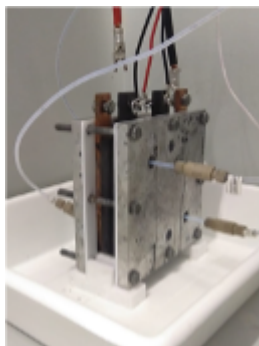
- (Photo-)electrochemical production of hydrogen with a focus on component and reactor development, in-house developed flow-electrolyzers (alkaline and proton-exchange)
- Hydrogen evolution going from catalyst development through GDE preparation and reactor development, with a focus on novel 3D electrodes to improve reactor hydrodynamics (e.g. bubble release, mass transfer, etc.)
- Strategic collaborations already ongoing in the field of alkaline and PEM electrolysis with industry including Agfa and Engie.
- Electrochemical production of formic acid and other CO<sub>2</sub>-derived chemicals as potential hydrogen carriers, utilizing renewable energy

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- VLAIO O&O with Agfa
  - Topic: ELECZIR: Enhancing Electrolyzer and Zirfon separators for alkaline electrolysis
  - Funding source: VLAIO
  - Main partner: Agfa
- FWO-WEAVE proposal
  - Topic: Understanding the role of dopants as a key step towards efficient oxygen evolution catalysts
  - Funding source: FWO-WEAVE
  - Main partners: National Institute of Chemistry, Slovenia
- FWO- PhD Fellowship strategic basic research
  - Topic: Optimisation of Bubble Removal in Alkaline Water Electrolysers at Industrial Current Densities
  - Funding source: FWO
  - Main partners: /



- Threading-CO<sub>2</sub>
  - Topic: Develop CO<sub>2</sub> to CO electrolyzers at pilot and demonstration scale.
  - Funding source: Horizon Europe
  - Main partners: Fairbrics, Deutsche institute fur textile- und faserforschung denkendorf, etc.
- SYN-CAT
  - Develop electrocatalysts and photo-electrocatalytic reactor for the conversion of CO<sub>2</sub> to methanol.
  - Funding: VLAIO-MOT
  - Main partners: UHasselt, Imec, UGent, VUB
- CLUE
  - Topic: Develop electrocatalytic reactor for the conversion of CO<sub>2</sub> into ethylene at larger scale and directly from flue gases.
  - Funding source VLAIO-MOT
  - Main partners: KU Leuven, VITO



*Patented zero-gap reactor*  
*2A/cm<sup>2</sup> current density*  
*T range: 25 – 100°C*  
*P range: up to 2 bar*  
*Targeted voltage: < 2.5 V*

#### Available equipment/tools:

- A wide range of electrosynthesis set-ups going from batch cells to flow-cells in combination with advanced potentiostats, including boosters required for achieving higher currents.
- Electrocatalyst synthesis equipment for wet chemical and electrodeposited catalyst manufacturing: atmosphere-controlled oven, elevated temperature and cryogenic synthesis cells, spray coating, rotavap, hydrostatic pressure vessels, TGA, etc.
- All analytical equipment, including (in-line) GC, HPLC, ICP-MS, DEMS, UV-VIS, etc. to determine the reaction performance and product outcome.
- Necessary pumps and sensors (e.g. pressure, flow, pH) to monitor all operating conditions.
- Explosion-safe oven to allow operation at elevated temperatures.
- Additionally, ELCAT possesses the required equipment to develop optimized electrolyzers at different scales (from 1 cm<sup>2</sup> to 200 cm<sup>2</sup>). It can count on its own MP 45, ISEL milling machine, high-end 3D metal and polymer printers, an accurate 3D laser micromachining setup, a sputter coater and in the future also an automated spray coater.

### International collaborations:

ELCAT is part of the Center of Excellence on Catalysis at UAntwerp. Additionally, T. Breugelmans is part of the group of experts determining the course of the Capture pipeline with respect to CO<sub>2</sub> conversion.

On an international level, ELCAT has close collaborations with ElectroCat in Slovenia, ICMM-CSIC in Spain, Forschungszentrum Jülich in Germany, TU Delft and TNO in the Netherlands, Fritz Haber Institute in Germany, National Laboratories, etc.

### Main relevant publications

- Geboes B., Mintsouli I., Wouters B., Georgieva J., Kakaroglou A., Sotiropoulos S., Valova E., Armyanov S., Hubin A., Breugelmans T., Applied Catalysis B: Environmental, 2014, 150-151, 249.
- Sanchez Gutierrez O., Birdja Y., Bulut M., Vaes J., Breugelmans T., Pant D., Current Opinion in Green and Sustainable Chemistry, 2019, 16, 47-56.
- Daems N., Choukroun D., Merino P., Rettenmaier C., Pacquets L., Bergmann A., Santoro G., Vazquez L., Martinez L. Roldan Cuenya B., Martin Gago J.A., Breugelmans T., ACS Applied Materials & Interfaces, 2022, 14, 2691.
- D. Choukroun, N. Daems, T. Kenis, T. Van Everbroeck, J. Hereijgers, T. Altantzis, S. Bals, P. Cool, T. Breugelmans, The Journal of Physical Chemistry C, 2020, 124, 1369.
- De Mot B., Hereijgers J., Duarte M., Breugelmans T., Chemical Engineering Journal, 2020, 378, 122224-122232.
- De Mot B., Ramdin M., Hereijgers J., Vlugt T., Breugelmans T., ChemElectroChem, 2020, 7, 3839.
- Duarte M., De Mot B., Hereijgers J., Breugelmans T., ChemElectroChem, 2019, 6, 5596.
- Van Daele K., De Mot B., Pupo M., Daems N., Deepak P., Kortlever R., Breugelmans T., ACS Energy Letters, 2021, 6, 4317

### Contact persons:

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- Nick Daems, technological manager ([nick.daems@uantwerpen.be](mailto:nick.daems@uantwerpen.be))
- Kevin Van Daele, H<sub>2</sub> research manager ([kevin.vandaele@uantwerpen.be](mailto:kevin.vandaele@uantwerpen.be))

## Department of Chemistry/ LADCA

### University of Antwerp, Faculty of Science

#### General expertise of the research group

The Laboratory of Adsorption and Catalysis (LADCA) is a pioneer in the synthesis and applications of porous materials and metal-oxides in the field of adsorption and catalysis. The research activities in the laboratory of Adsorption and Catalysis are focussed on: - The development of new micro- and mesoporous inorganic materials; - Optimization of synthesis pathways for inorganic materials with a controlled porosity and surface properties; - Catalytic activation of porous materials; - Optimization of porous materials for efficient gas- and liquid separations; - Characterization of porous materials; -Catalytic applications (redox – and photocatalysis)

#### Specific hydrogen- related expertise & research topics

- Design of heterogeneous catalysts for in-situ hydrogen production for sustainable reduction reactions in water (BOF-GOA project in collaboration with the Organic Chemistry group (prof. B. Maes).
- Development of porous materials with tuned properties as matrix for hydrogen clathrate formation (Vlaio Moonshot project on Artificial clathrates for safe storage, transport and delivery of hydrogen (ARCLATH))
- Photocatalytic and photo-electrocatalytic reduction of CO<sub>2</sub> with hydrogen into added value chemicals (Vlaio Moonshot D2M and Vlaio Moonshot SYN-CAT projects)

#### Available equipment/tools:

- Micro-Raman, in-situ Raman
- FT-IR, in-situ FT-IR
- UV-VIS
- TGA/DTG, TGA-MS
- N<sub>2</sub>-sorption, chemisorption
- TOC
- TPR, TPO
- Photocatalytic set-ups and lamps
- Reactors (photocatalytic, plasma and automotive)
- GC detection

#### International collaborations:

- UNIPD, Padova, Italy
- NCSR Athens, Greece
- National Institute of Chemistry, Ljubljana, Slovenia
- University of Alicante, Alicante, Spain
- Technical University Gheorghe Asachi, Iasi, Romania
- ENMIX (European Nanoporous Materials Institute of Excellence aisbl)
- DZA (Dutch zeolite association)



### Main relevant publications

- Suligoj A., Arcon I., Mazaj M., Drazic G., Arcon D., Cool P., Stangar U.L., Tusar N.N., Surface modified titanium dioxide using transition metals: nickels as winning transition metal for solar light photocatalysis, *J. Mat. Chem. A*, 6 (21), 9882-9892, 2018
- Xin Q., Papavasiliou A., Boukos N., Glisenti A., Li JPH, Yang Y., Philippopoulos C.J., Poulakis E., Katsaros F.K., Meynen V., Cool P., Preparation of CuO/SBA-15 catalyst by the modified ammonia driven deposition precipitation method with a high thermal stability and an efficient automotive CO and hydrocarbons conversion, *Applied Catalysis B- Environmental*, 223, 103-115, 2018
- N. Blommaerts, N. Hoeven, D. Arenas Esteban, R. Campos, M. Mertens, R. Borah, A. Glisenti, K. De Wael, S. Bals, S. Lenaerts, S.W. Verbruggen, P. Cool, Tuning the turnover frequency and selectivity of photocatalytic CO<sub>2</sub> reduction to CO and methane using platinum and palladium nanoparticles on Ti-Beta zeolites, *Chemical Engineering Journal* 410, 128234, 2021
- R.-G Ciocarlan, N. Hoeven, E. Irtem, V. Van Acker, M. Mertens, E.M. Seftel, T. Breugelmans, P. Cool, Ferrite@TiO<sub>2</sub>-nanocomposites as Z-scheme photocatalysts for CO<sub>2</sub> conversion: Insight into the correlation of the Co-Zn metal composition and the catalytic activity, *Journal of CO<sub>2</sub> Utilization*, 36, 177-186, 2020
- Y. Uytendhouwen, V. Meynen, P. Cool, A. Bogaerts, The potential use of core-shell structured spheres in a packed-bed DBD plasma reactor for CO<sub>2</sub> conversion, *Catalysts*, 10, 5, 2020, DOI: 10.3390/catal10050530
- A. Gupta, G. V. Baron, P. Perreault, S. Lenaerts, R.-G. Ciocarlan, P. Cool, P. G.M. Milea, S. Rogge, V. Van Speybroeck, G. Watson, P. Van Der Voort, M. Houllberghs, E. Breynaert, J. Martens, J. F.M. Denayer, Hydrogen clathrates: next generation hydrogen storage materials, *Energy Storage Materials* 41, 69-107, 2021.
- N. B. Kumamuru, G. Watson, R.-G. Ciocarlan, S.W. Verbruggen, P. Cool, P. Van Der Voort, P. Perreault, Accelerated methane storage in clathrate hydrates using mesoporous (Organo-) silica materials, *Fuel* 354, 129403, 2023.
- E.J. Beckwée, M. Houllberghs, R-G Ciocarlan, C.V. Chandran, S. Radhakrishnan, L. Hanssens, P. Cool, J. Martens, E. Breynaert, G.V. Baron, J.F.M. Denayer, Structure I methane hydrate confined in C8-grafted SBA-15: A highly efficient storage system enabling ultrafast methane loading and unloading, *Applied Energy* 353, 122120, 2024.

### Contact persons:

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## Research Group PLASMANT (Plasma Lab for Applications in Sustainability & Medicine – ANTwerp)

### University of Antwerp, Faculty of Science

#### General expertise of the research group

Plasma research by means of computer modelling and experiments, for two main applications, i.e.:

- Green chemistry, including CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub> conversion into value-added chemicals and fuels, or into fertilizers, but also NH<sub>3</sub> cracking for green H<sub>2</sub> production
- Plasma medicine, focusing mainly on cancer treatment, but also virus inactivation

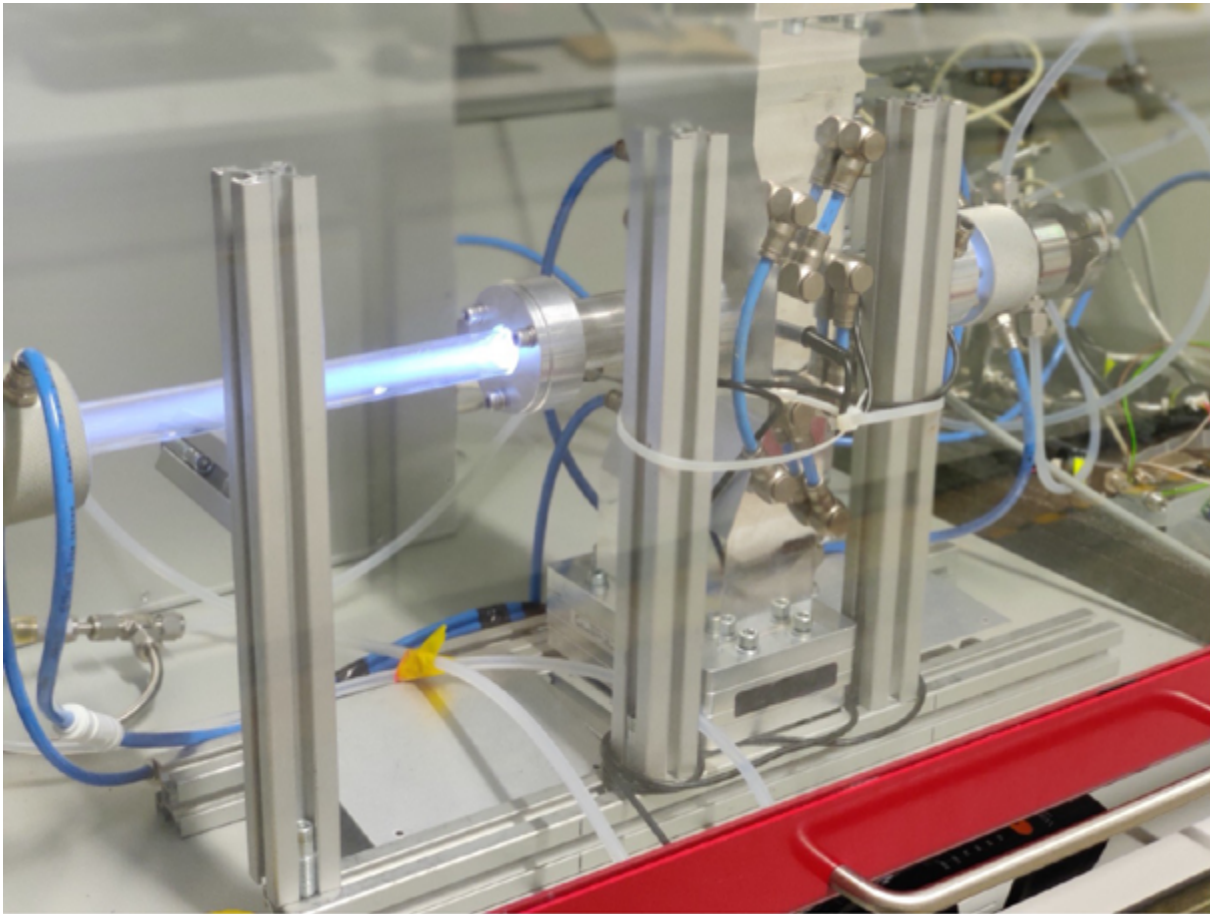
The aim is to obtain better insights in the underlying mechanisms, in order to improve the applications. Indeed, plasma technology is very promising for green chemistry, as energy-efficient alternative to the existing classical conversion methods, because the splitting of inert molecules (such as CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>) is initiated by energetic electrons present in the plasma.

#### Specific hydrogen- related expertise & research topics

- Plasma-based CH<sub>4</sub> conversion into H<sub>2</sub> (and value-added carbon) and into higher hydrocarbons (e.g., ethylene, acetylene) and oxygenates
- Plasma-based dry reforming of methane, including plasma catalysis, for the production of syngas and other value-added chemicals and fuels
- Plasma-based H<sub>2</sub> synthesis from other hydrocarbons (e.g., methanol, ethanol, and even plastic waste pyrolysis products), as well as from NH<sub>3</sub>
- We perform research for all these applications, by a combination of plasma chemistry and plasma reactor modelling, and experiments.

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- HyPACT: Cracking of green ammonia to hydrogen using innovative catalyst and adsorbent assisted plasma technology, ETF project, with Waterstofnet, KULeuven (J. Martens), and UAntwerpen (P. Perreault).
- OPTANIC: Energy-efficient plasma conversion of greenhouse gases to methanol, the fuel of the future, BlueApp POC project, with our spinoff Optanic.
- PLASynth2: Plasma-based green hydrogen synthesis from hydrocarbons, FWO-FNRS Excellence of Science project, with UGent (N. De Geyter, R. Morent), UMONS (R. Snyders) and ULB (F. Reniers).
- P2O: Power to olefins: Electrified steam cracking and plasma booster, Catalisti-Moonshot SBO project, with UGent (K. Van Geem, G. Stefanidis, R. Morent) and VKI.
- SCOPE: Surface-CONfined fast-modulated Plasma for process and Energy intensification in small molecules conversion, ERC Synergy Grant, with Univ. Messina (G. Centi), Warwick Univ. (E. Rebrov) and Univ. Adelaide (V. Hessel).
- Plasma-catalytic hydrogenation of CO<sub>2</sub> to CH<sub>3</sub>OH: Study of the underlying mechanisms by integrated microkinetic modelling of plasma chemistry and surface reactions, FWO mandate.



#### Available equipment/tools:

- Various (gliding) arc plasma reactors, atmospheric pressure glow discharges, microwave plasmas and dielectric barrier discharge plasmas,
- Analysis equipment (GC, MS, non-dispersive IR/UR, optical sensors) for gas conversion.
- Various types of models: quasi-1D chemical reaction kinetics models, 2D/3D fluid dynamics simulations, Monte Carlo, particle-in-cell Monte Carlo, hybrid models, molecular dynamics, density functional theory simulations.

#### International collaborations:

- ERC Synergy Grant “SCOPE”, together with G. Centi, V. Hessel and E. Rebrov: See website ERC Synergy SCOPE
- DIFFER (Dutch Institute for Fundamental Energy Research)
- Eindhoven University of Technology
- Maastricht University
- University of Liverpool
- University of Messina
- University of Warwick
- University of Adelaide
- University of Manchester
- University of Notre Dame
- Dalian University of Technology
- CSIRO-Australia;...



### Main relevant publications

- Plasma technology – a novel solution for CO<sub>2</sub> conversion ? R. Snoeckx and A. Bogaerts, Chem. Soc. Rev. **46**, 5805-5863 (2017). Selected for the cover of the journal (IF 40.182).
- Plasma technology: An emerging technology for energy storage. A. Bogaerts and E. Neyts, ACS Energy Lett. **3**, 1013-1027 (2018). Invited feature article, and selected to be featured in ACS Editors' Choice + Free Open Access (IF 16.331)
- Plasma-based CH<sub>4</sub> conversion into higher hydrocarbons and H<sub>2</sub>: Modelling to reveal the reaction mechanisms of different plasma sources. S. Heijkers, M. Aghaei, A. Bogaerts, J. Phys. Chem. C, **124**, 7016-7030 (2020). Featured in "ACS Editors' Choice", and given open access due to its potential for broad public interest.
- Plasma-catalytic ammonia reforming of methane over Cu-based catalysts for the production of HCN and H<sub>2</sub> at reduced temperature. Y. Yi, X. Wang, A. Jafarzadeh, L. Wang, P. Liu, B. He, J. Yan, R. Zhang, H. Zhang, X. Liu, H. Guo, E.C. Neyts and A. Bogaerts, ACS Catal., **11**, 1765-1773 (2021).
- Plasma-catalytic ammonia decomposition using a packed-bed dielectric barrier discharge reactor. J. A. Andersen, J. M. Christensen, M. Østberg, A. Bogaerts and A. D. Jensen, Int. J. Hydrog. Energy, **47**, 32081-32091 (2022).
- Methane coupling in nanosecond pulsed plasmas: correlation between temperature and pressure and effects on product selectivity. E. Morais, E. Delikonstantis, M. Scapinello, G. Smith, G. D. Stefanidis and A. Bogaerts, Chem. Eng. J. **462**, 142227 (2023). (15 pages)
- Modelling the dynamics of hydrogen synthesis from methane in nanosecond-pulsed plasmas. E. Morais and A. Bogaerts, Plasma Process. Polymers, 2300149 (2023). (10 pages)
- NH<sub>3</sub> decomposition for H<sub>2</sub> production by thermal and plasma catalysis using bimetallic catalysts. S. Meng, S. Li, S. Sun, A Bogaerts, Y. Liu and Y. Yi, Chem. Eng. Sci, 283, 119449 (2024).

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Annemie Bogaerts, spokesperson ([annemie.bogaerts@uantwerpen.be](mailto:annemie.bogaerts@uantwerpen.be))

### 3.1.5. UGent

## Research group COCOON

### Ghent University, Faculty of Sciences

#### General expertise of the research group:

The research group COCOON is part of the Department of Solid State Sciences and is led by Christophe Detavernier and Jolien Dendooven. Our research is directed at developing and understanding thin film materials within a context of applications relevant to society. We develop thin films and nanomaterials and systematically study their properties governed by their composition, structure, and surface and interface nature. We are particularly interested in (1) physical phenomena that occur at surfaces and interfaces during thin film growth or electrochemical energy conversion reactions, (2) solid state reactions that occur at the nanoscale, and (3) ion transport in solid state nanoscale systems. Understanding these fundamental aspects provides the necessary foundation for optimizing deposition processes and developing materials with an improved functionality for the targeted applications. Important research topics include:

- Atomic layer deposition for ultrathin coatings, surface engineering and conformal coating of nanostructured materials.
- In-situ characterization of thin films during deposition/annealing treatments.
- Combinatorial thin film research for fast screening of composition-dependent properties of binary, ternary or even quaternary mixtures.

#### Specific hydrogen- related expertise & research topics:

The COCOON group has a strong track record in investigating thin film materials for applications in microelectronics and battery technology. Since several years, the group is expanding its expertise in thin film technology to applications in electrocatalysis:

- Atomic layer deposition (ALD) of electrocatalysts for hydrogen and oxygen evolution reactions: metal nanoparticles, oxides, phosphates and sulphides with controllable composition and dimensions.
- ALD for tailoring electrochemical interfaces, e.g. passivation layers for photoelectrodes, stabilizing layers to prevent metal nanoparticle catalyst degradation, thin films of mixed ionic electronic conductors.
- Combinatorial magnetron sputtering of alloy thin film libraries for catalyst composition screening.

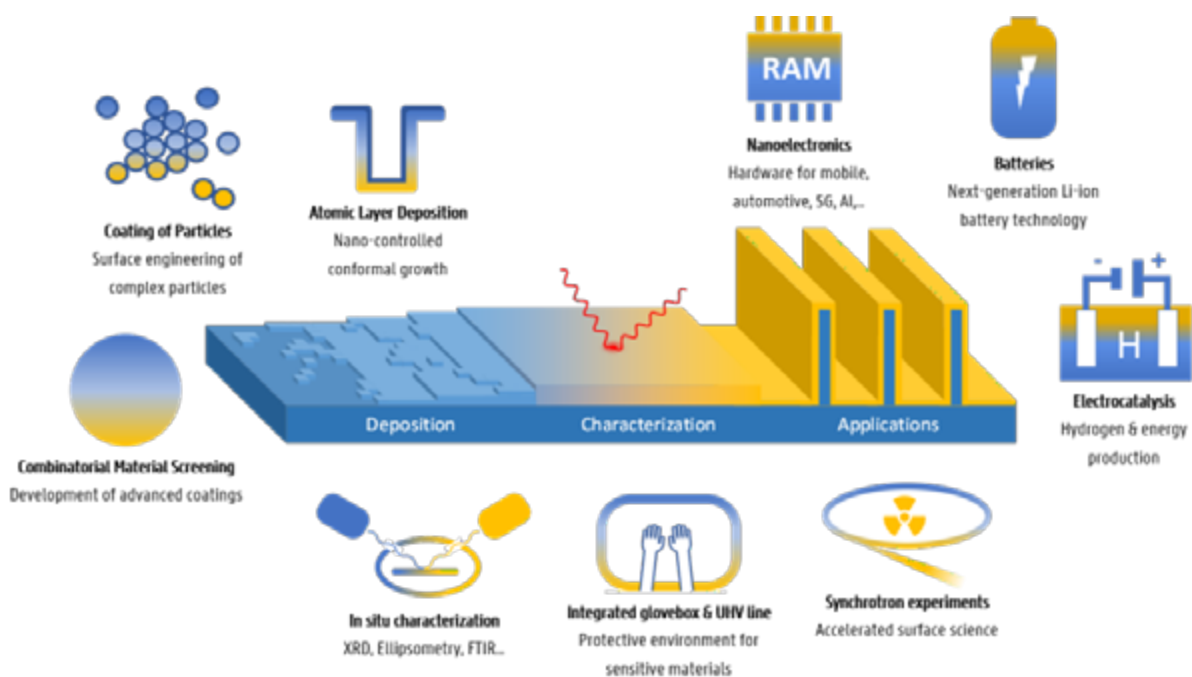


### Available equipment/tools:

- Thermal and plasma-enhanced ALD systems with several integrated in-situ characterization techniques to monitor surface reactions and film deposition during ALD processes.
- Dedicated setups for the sputter deposition of combinatorial thin film libraries. Wafers can be coated with a film that has a uniform thickness and a linear gradient in composition, resulting in a "printed" compositional library of binary, ternary or even quaternary mixtures. In this way, one can easily investigate the properties of >100 different compositions in parallel.
- Several home-built systems for in situ XRD during annealing under controlled ambient (oxidizing, inert, reducing) offering opportunities to efficiently study the evolution of phase, grain size and phenomena such as crystallization and phase transformations during annealing.
- An integrated glovebox infrastructure for thin film deposition onto air-sensitive materials, and for surface and electrochemical characterization, all without exposure to air. All gloveboxes are Ar-filled. Several commercial and home-built potentiostat/galvanostat devices are available.
- UHV cluster tool consisting of an ALD tool, a scanning probe microscope, an instrument for XPS and a vacuum transfer line, which allows for transferring samples between glovebox, deposition and analytical chambers without air exposure.

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- H<sub>2</sub>-MHytic (SBO, Blauwe Cluster, VITO, imec, UGent): H<sub>2</sub> by membrane integrated high surface area nanomesh technology
- SYN-CAT (SBO, VLAIO-MOT, UA, UHasselt, Imec, UGent, VUB): Synergetic design of catalytic materials for integrated photo- and electrochemical CO<sub>2</sub> conversion processes
- TEMPEL (SBO, VLAIO-MOT, VITO, imec, UGent, KULeuven, UA): Temperature assisted water electrolysis
- ALTERPEM (SBO, VLAIO-MOT, KUL, imec, UGent): Alternative for PEM technology with non-fluorinated, integrated membranes and PGM-free nanoarchitecture





### Main relevant publications:

- Mathew, F.; Van den Hoek, J.; Poonkottil, N.; Zhao, B.; Rampelberg, G.; Choukroun, D.; Hereijgers, J.; Hens, Z.; Poelman, D.; Breugelmans, T.; Detavernier, C.; Dendooven, J. Crystalline Tin Disulfide by Low-Temperature Plasma-Enhanced Atomic Layer Deposition as an Electrode Material for Li-Ion Batteries and CO<sub>2</sub> Electroreduction, *ACS Applied Energy Materials* 6 (24), 12526-12538 (2023).
- Henderick, L.; Dhara, A.; Werbrouck, A.; Dendooven, J.; Detavernier, C. Atomic layer deposition of metal phosphates, *Applied Physics Reviews* 9, 011310 (2022).
- Trompoukis, C.; Feng, J.-Y.; Bosserez, T.; Rongé, J.; Dendooven, J.; Detavernier, C.; Baets, R.; Martens, J. A. ALD Pt nanoparticles and thin-film coatings enhancing the stability and performance of silicon photocathodes for solar water splitting, *Sustainable Energy Fuels* 5, 3115-3123 (2021).
- Rongé, J.; Dobbelaere, T.; Henderick, L.; Minjauw, M. M.; Sree, S. P.; Dendooven, J.; Martens, J. A.; Detavernier, C. Bifunctional earth-abundant phosphate/phosphide catalysts prepared via atomic layer deposition for electrocatalytic water splitting, *Nanoscale Advances* 1, 4166 - 4172 (2019).
- Dendooven, J.; Ramachandran, R. K.; Solano, E.; Kurttepli, M.; Geerts, L.; Heremans, G.; Minjauw, M. M.; Dobbelaere, T.; Devloo-Casier, K.; Martens, J. A.; Vantomme, A.; Bals, S.; Portale, G.; Coati, A.; Detavernier, C. Independent tuning of size and coverage of supported Pt nanoparticles using atomic layer deposition, *Nature Communications* 8, 1074 (2017).
- Mattelaer, F.; Bosserez, T.; Rongé, J.; Martens, J. A.; Dendooven, J.; Detavernier, C. Manganese oxide films with controlled oxidation state for water splitting devices through a combination of atomic layer deposition and post-deposition annealing, *RSC Advances* 6, 98337-98343 (2016).
- Rongé, J.; Deng, D.; Sree, S. P.; Bosserez, T.; Verbruggen, S. W.; Singh, N. K.; Dendooven, J.; Roeffaers, M. B. J.; Taulelle, F.; De Volder, M.; Detavernier, C.; Martens, J. A., Air-based photoelectrochemical cell capturing water molecules from ambient air for hydrogen production, *RSC Advances* 4 (55), 29286-29290 (2014).

### International collaborations:

- COCOON coordinates the HYCOAT network ([www.hycoat.eu](http://www.hycoat.eu)) with international partners at Aalto University, CIC nanoGUNE, Ruhr-Universität Bochum, TNO, Tyndall National Institute, University of Helsinki & University of Oslo.

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- Prof. Dr. Jolien Dendooven ([Jolien.Dendooven@UGent.be](mailto:Jolien.Dendooven@UGent.be))
- <https://www.ugent.be/we/solidstatesciences/cocoon/en>

## Laboratory for Chemical Technology

### Ghent University, Faculty of Engineering and Architecture

#### General expertise of the research group:

The Laboratory for Chemical Technology (LCT) integrates chemical science and engineering in its research on catalysis, polymerization, kinetics, reactor design and process design. LCT is part of the Department of Materials, Textiles and Chemical Engineering within the Faculty of Engineering and Architecture at Ghent University in Belgium and member of the Centre for Sustainable Chemistry (CSC) of Ghent University. LCT aims at research excellence and bottom-up innovation in the framework of technological, industrial, and societal challenges.

#### Specific hydrogen- related expertise & research topics:

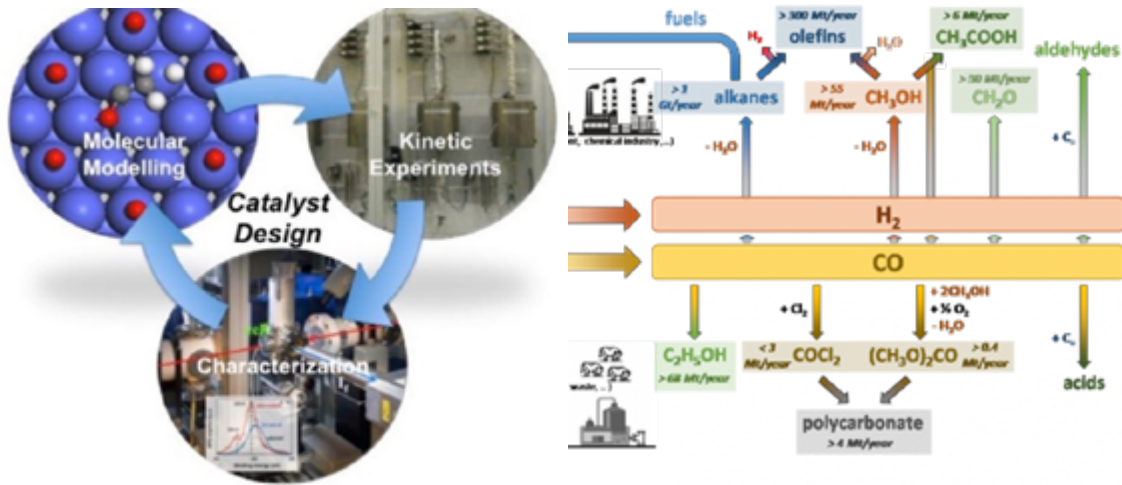
- Production of e-fuels
- Economics of e-fuels
- Chemical looping
- Catalytic processes

#### Available equipment/tools:

- Lab scale reactors for investigating thermal, catalytic, chemical looping and adsorptive reaction processes
- Chemical looping pilot plant with a production capacity in the order of kg/day
- Catalyst synthesis
- Materials characterization (redox/acid-base properties, porosity, ...)
- Software for:
  - Mechanistic investigations
  - Fluid Dynamics calculations
  - Process design
  - (micro)kinetic modelling

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- MuSE (Energy Transition Fund, 2022-2025, 1 PhD)
- CATCO<sub>2</sub>RE (SBO, 2018-2021, 3 PhD)
- CO<sub>2</sub>PERATE (cSBO, 2018-2022, 1 PhD)
- C<sub>2</sub>O (MOT3 sSBO, 2021-2022, 2 PhD)
- Be-HyStore (Energy Transition Fund, 2023-2026, 1 PhD)
- See website: [research.ugent.be](https://research.ugent.be)



#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- V. Singh, L. C. Buelens, H. Poelman, M. Saeys, G. B. Marin, V. V. Galvita, Intensifying blue hydrogen production by in situ CO<sub>2</sub> utilisation, *Journal of CO<sub>2</sub> Utilization*, 2022, 61, 102014.
- De Vrieze J, Urbina Blanco CA, Thybaut J, Saeys M. Autocatalytic role of molecular hydrogen in copper-catalyzed transfer hydrogenation of ketones. *ACS CATALYSIS*. 2019;9(9):8073–82.
- Van Geem K, Galvita V, Marin G. Making chemicals with electricity. *SCIENCE*. American Association for the Advancement of Science (AAAS); 2019. p. 734–5.

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## Dept. Electromechanical, Systems and Metal Engineering – EELAB & Lemcko

Ghent University, Faculty of Engineering and Architecture

General expertise of the research group:

- Low frequency electromagnetic fields and magnetic materials
- Power Systems
- Power Electronics
- Drive systems and control for electrical machines
- Energy and cluster management

Specific hydrogen- related expertise & research topics:

- Electrolyser electrical grid integration aspects, flexibility
- power-to-X
- power generation grid support (X-to-power)

Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- BEST (Energy Transition Fund, PhD with UCLouvain)
- InduFlexControl (Catalisti cSBO)
- CO2PERATE (Catalisti SBO)
- GREENPORTS (Flux50 ICON)
- See website: [research.ugent.be](http://research.ugent.be)



#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- Dadkhah A, Bozalakov D, De Kooning J, Vandevelde L. On the optimal planning of a hydrogen refuelling station participating in the electricity and balancing markets. INTERNATIONAL JOURNAL OF HYDROGEN ENERGY. 2021;46(2):1488–500.
- Ebneali Samani A, D'Amicis A, De Kooning J, Bozalakov D, Silva P, Vandevelde L. Grid balancing with a large-scale electrolyser providing primary reserve. IET RENEWABLE POWER GENERATION. 2020;14(16):3070–8.
- Baetens J, De Kooning J, Van Eetvelde G, Vandevelde L. A two-stage stochastic optimisation methodology for the operation of a chlor-alkali electrolyser under variable DAM and FCR market prices. ENERGIES. 2020;13(21).

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## Industrial Catalysis and Adsorption Technology (INCAT)

Ghent University, Faculty of Engineering and Architecture

General expertise of the research group:

The Industrial Catalysis and Adsorption Technology research group (INCAT) focuses mainly on the development of catalysts and adsorbents with a strong focus on renewable resources and environmental management. This involves the catalytic conversion of biomass-derived streams, their upgrading and separation into useful chemicals, with a strong application-oriented goal. This goal is pursued by the many running research projects in collaboration with consortium and industrial partners, including smaller and middle-sized companies in the broader chemical industry.

- Heterogeneous catalysis
- Membrane technologies
- Separation technologies
- Separation and membrane technologies not elsewhere classified
- (Waste)water treatment processes

Specific hydrogen- related expertise & research topics:

- catalyzed sodium borohydride hydrolysis (NaBH<sub>4</sub> as storage for hydrogen)

Available equipment/tools:

- reactors
- catalyst synthesis
- characterization
- See: <https://incat.ugent.be/infrastructure.html>

International collaborations:

- H<sub>2</sub>Fuel: [www.H<sub>2</sub>-fuel.nl](http://www.H2-fuel.nl)
- bilateral projects with H<sub>2</sub>CiF, H<sub>2</sub>Fuel
- See website: [research.ugent.be](http://research.ugent.be)





#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- B. Van Vaerenbergh, J. Lauwaert, P. Vermeir, J. Thybaut, and J. De Clercq, "Towards high-performance heterogeneous palladium nanoparticle catalysts for sustainable liquid-phase reactions," REACTION CHEMISTRY & ENGINEERING, vol. 5, no. 9, pp. 1556–1618, 2020.

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## *Mechanics of Materials and Structures (MMS)*

Ghent University, Faculty of Engineering and Architecture

### General expertise of the research group:

The research group Mechanics of Materials and Structures (MMS) is part of the Department of Materials, Textiles and Chemical Engineering (MaTCh). This group has more than 40 years of experience in the design, simulation, testing and inspection of fiber-reinforced composites. In the last decade, also expertise in additive manufactured materials has been developed.

The group has a long-term tradition in numerical simulation and design of composites, in static, impact, fatigue and creep loading conditions. A wide range of experimental test facilities is available for mechanical characterization of materials, and also for Non-destructive Testing (NDT) of materials and components.

### Specific hydrogen- related expertise & research topics:

The research group has expertise on :

- simulation and design of filament wound composite pressure vessels for hydrogen storage. Investigated topics relate to the vessel design, the effect of fatigue damage during filling/depleting cycles, the instability of the liner (buckling, cracking), the interaction with the metallic inserts, etc.
- analytical theories for stress calculation of filament wound composite hydrogen tanks and pipes, to improve on the currently used netting theory for tank design.
- Non-destructive Testing (NDT) techniques are developed for inspection of these thick-walled composites. Ultrasound, thermography and shearography techniques are investigated to detect manufacturing defects or in-service damage in the tank, and locate and size the defects. Acoustic Emission is explored for Structural Health Monitoring of hydrogen tanks in service.
- micro-mechanical tests to characterize the fibre/matrix interface in composites. Those tests could also be used for ageing tests in the presence of hydrogen
- design and simulation of fuel cell stacks in terms of stiffness, strength and durability (impact/crash, bolting/gaskets)
- topology optimization codes for material choice in thermo-mechanical loading scenarios
- simulation of performance and damage development in flexible transport pipes (typically for offshore applications)

#### Available equipment/tools:

- wide range of lab equipment for static/dynamic/fatigue testing of composite materials and components
- variety of Non-destructive Testing (NDT) techniques for inspection of parts and components
- Finite Element software for mechanical design and simulation (relevant for hydrogen storage tanks, fuel cell engineering, flexible pipelines)
- in-house Topology Optimization codes for multi-material design in thermo-mechanical loading conditions
- micro-mechanical testing facilities for ageing of fibre/matrix interfaces

#### Main relevant publications:

- <https://research.ugent.be/web/person/wim-van-paepegem-0/publications/en>

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B-9052 Gent

## Center for Molecular Modelling

Ghent University, Faculty of Engineering and Architecture/Sciences

### General expertise of the research group:

The Center for Molecular Modelling focuses on frontier research in six major areas - chemical kinetics in nanoporous materials, computational material research on the nanoscale, spectroscopy, many-particle physics, model development & bio- and organic chemistry. Our multidisciplinary research team is currently composed of about 40 researchers from the Faculties of Sciences (WE05) and Engineering and Architecture (EA17, EA08) of Ghent University.

### Specific hydrogen- related expertise & research topics:

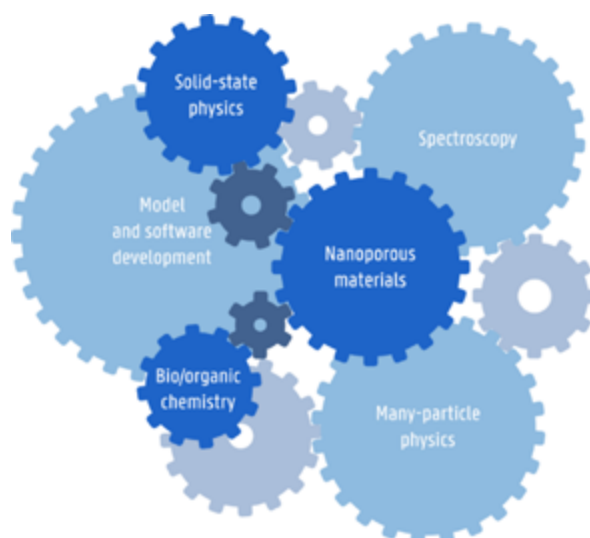
- Design of Materials for H<sub>2</sub> storage and conversion of chemicals

### Available equipment/tools:

- Expertise in a very broad range of molecular modelling engines (Gaussian, ADF, MOLPRO, CHARMM, CPMD, CP2K, Orca, VASP,...)
- Developer of own software codes available via <https://molmod.ugent.be/software>, Member of the developer teams of large-scale software engines such as LAMMPS, CP2K,...
- Largest user of HPC infrastructure at the Flemish level and pilot user in newly installed HPC clusters

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- See website: [research.ugent.be](http://research.ugent.be)



#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- Vandeputte A, Sabbe M, Reyniers M-F, Van Speybroeck V, Waroquier M, Marin G. Theoretical study of the thermodynamics and kinetics of hydrogen abstractions from hydrocarbons. JOURNAL OF PHYSICAL CHEMISTRY A. AMER CHEMICAL SOC; 2007;111(46):11771–86.
- Martínez-Espín JS, De Wispelaere K, Janssens TVW, Svelle S, Lillerud KP, Beato P, et al. Hydrogen transfer versus methylation : on the genesis of aromatics formation in the Methanol-To-Hydrocarbons reaction over H-ZSM-5. ACS CATALYSIS. 2017;7(9):5773–80.
- Van Houteghem M, Verstraelen T, Ghysels A, Vanduyfhuys L, Waroquier M, Van Speybroeck V. Analysis of the basis set superposition error in molecular dynamics of hydrogen-bonded liquids : application to methanol. JOURNAL OF CHEMICAL PHYSICS. 2012;137(10).

#### Contact persons:

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T +32 496 63 16 01
- Prof. Veronique Van Speybroeck ([Veronique.VanSpeybroeck@ugent.be](mailto:Veronique.VanSpeybroeck@ugent.be))  
Tech Lane Ghent Science Park Campus A  
Technologiepark 46  
9052 Zwijnaarde  
Belgium

## Center for Ordered Materials, Organometallics & Catalysis

### Ghent University, Faculty of Science

#### General expertise of the research group:

The synthesis of new porous materials and their application in heterogeneous catalysis, adsorption and biomedical systems.

The Center for Ordered Materials, Organometallics and Catalysis (COMOC) is internationally very renowned for the development of novel porous materials, as adsorbents, heterogeneous catalysts, photocatalysts, electrodes for photocatalysis, electrodes for electrocatalysis, materials for sensing and luminescence.

The group typically consists of 1 director (Prof. Pascal Van Der Voort), 5 postdocs, 10-15 PhD students, 5-10 undergraduates and visiting PhD students (interns). They are fully equipped for the characterization and testing of the materials.

#### Specific hydrogen- related expertise & research topics:

- Development and synthesis of novel crystalline highly porous materials
- Development and synthesis of highly porous crystalline polymers
- Storage/Separation of gases in highly porous media (MOFs, COFs)
- Hydrogenation reactions
- Photocatalytic total water splitting
- Z-scheme tandem cells for photocatalysis (heterojunctions)
- Electrocatalysis
- Development of COF

#### Available equipment/tools:

- GC, HPLC, state of the art sorption equipment (high pressure, low pressure, chemisorption, TPD, TPR, TPD), CHNS elemental analysis, FTIR, FT-Raman, dispersive Raman, UV-VIS, electrocatalytic setups, photocatalytic setups, powder XRD, single crystal XRD, ...

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- See website: [research.ugent.be](http://research.ugent.be)
- Group website: [www.ugent.comoc.be](http://www.ugent.comoc.be)
- Twitter: @COMOC\_research
- COMOC is active in the Flanders Moonshot Projects on Hydrogen Generation and Hydrogen Storage (MOT-4) with one running project and one project currently being reviewed.

### International collaborations:

COMOC collaborates with the leading international groups on porous materials, heterogeneous catalysis, photo- and electrocatalysis, including prof. Markus Antonietti (MPI-Potsdam), prof. Bettina Lotz (MPI-Stuttgart), prof. Christian Serre (Versailles), prof. Arne Thomas (TU Berlin), prof. Mietek Jaroniec (Kent State Univ, USA), and many others.



### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- Group website: [www.comoc.ugent.be](http://www.comoc.ugent.be)
- RESEARCH-ID: <http://www.researcherid.com/rid/D-3800-2012>
- ORCID: <http://orcid.org/0000-0002-1248-479X>
- GOOGLE SCHOLAR: <https://scholar.google.be/citations?user=DdI5E8QAAAAJ&hl=en>
- PUBLONS: <https://publons.com/researcher/1309466/pascal-van-der-voort/>

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- COMOC group  
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Krijgslaan 281 - building S3 (Campus Sterre) 9000 Gent  
Tel: +32-9-2644442

## Particle and Interfacial Technology Group (PaInT)

### Ghent University, Faculty of Bioscience Engineering

#### General expertise of the research group:

The Particle and Interfacial Technology Group (PaInT) is a research group within the Faculty of Bioscience Engineering at Ghent University, which focuses on separation processes for physical-chemical water treatment. The name PaInT stems from the fact that the research is focus on interfacial phenomena and selective separations. The key know-how of the group lies in:

- Industrial water treatment (high-quality applications, cooling & ultrapure water)
- Membrane-based processes (focus on transport phenomena), including reverse and forward osmosis, nano/micro/ultra-filtration, membrane distillation, and electrolysis/electrodialysis.
- Increasing selectivity and fouling resistance of interfaces.
- Resource recovery

#### Specific hydrogen- related expertise & research topics:

- Physical and chemical water treatment for ultrapure water for H<sub>2</sub> production in electrolysis
- Decentralised & alternative energy-powered desalination for ultrapure water
- Link between thermolysis of organic matter, formation of organics acids and H<sub>2</sub>-assisted corrosion phenomena in steam-water cycles (in collaboration with Prof. Kim Verbeken)

#### Available equipment/tools:

- lab- & pilot-scale (ultrapure) water treatment technology
- Mobile IMPROVED pilot-plant infrastructure for on-site water treatment, coupled with process (e.g., steam boiler) simulation and online corrosion measurements
- Lab-scale stacks for conventional electrodialysis and bipolar membrane and mono-selective membrane applications, including automated potentiostats.
- Lab-scale stacks for electrolysis applications
- Medium and large-size Pilot scale units for electrodialysis applications

#### International collaborations:

- Large academic network throughout Europe, United States, Australia & South-East Africa
- Numerous industrial research collaborations with large multinationals (DOW, Yara, Sabic, DSM, Kurita,...)

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- AquaSPICE (H2020; started 12/2020)
- Improved (Interreg; finished 2020)
- RUSTICA (H2020; started 1/2021)
- BIOSTABLE (SBO; started 10/2020)
- REvived (H2020, finished 2021)
- Condensate Polishing (ISPT, started 2019)
- Numerous local grants
- See website: [research.ugent.be](https://research.ugent.be)



Figure 7: Electrodialysis reversal (EDR) pilot plant, capacity: 1.75 m<sup>3</sup>/d product water.

#### Main relevant publications:

- See website: [biblio.ugent.be](https://biblio.ugent.be)

#### Contact persons:

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- Prof. Arne Verliefde ([Arne.Verliefde@ugent.be](mailto:Arne.Verliefde@ugent.be))
- Dr. Leo Gutierrez ([Leonardo.GutierrezGarces@ugent.be](mailto:Leonardo.GutierrezGarces@ugent.be))  
Department of Green Chemistry and Technology Particle and Interfacial Technology group (PalnT)  
Coupure Links 653  
B-9000 Ghent Belgium



## Pore-scale Processes in Geo-materials (PProGRess)

### Ghent University, Faculty of Sciences

#### General expertise of the research group:

The research group PProGRess is part of Ghent University's department of Geology and Center for X-ray tomography (UGCT). PProGRess studies the various physical and chemical processes that occur inside porous rocks and sediments. The group specializes in non-destructive 3D and 4D imaging of pore structures and processes in them, from the nano- to macro-scale; mainly using X-ray micro-computed tomography.

#### Specific hydrogen- related expertise & research topics:

- Storage of hydrogen and CO<sub>2</sub> in subsurface rock formations (the latter in the context of Carbon Capture and Storage, e.g. for blue hydrogen). Microscopic (pore-scale) studies of:
  - Multiphase flow in porous rocks (gas and brine natively present)
  - Salt precipitation in porous rocks due brine evaporation in hydrogen/CO<sub>2</sub>
  - Rock alteration processes due to hydrogen-mineral or CO<sub>2</sub>-mineral interactions
  - Relation between geo-mechanics and fluid transport in the subsurface
- Imaging of fluid menisci in porous materials (e.g. hydrogen-water in fuel cells)

#### Available equipment/tools:

- Micro-computed tomography: time-resolved and high-resolution 3D imaging of the internal structure of a sample
- X-ray transparent fluid flow cells (up to 120 bars/100°C)
- High-pressure high-precision piston pumps

#### International collaborations:

On pore-scale fluid transport and interactions in rocks: Université de Pau et Pays de l'Adour (UPPA), Universiteit Hasselt, Heriot-Watt University, TU Eindhoven, Imperial College London, Shell.

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- FWO junior research project: "Energy storage in the geological subsurface: impact of salt precipitation in porous media". Collaboration with H. Derluyn (CNRS/UPPA)
- FWO research project: "VisioFlow: Advanced macro-model generation based on micro-scale visualization experiments of two-phase flow through porous sedimentary rocks". Collaboration with S. Pop (UHasselt)
- H2020 INFRAIA-grant EXCITE: "Electron and X-ray microscopy Community for structural and chemical Imaging Techniques for Earth materials"

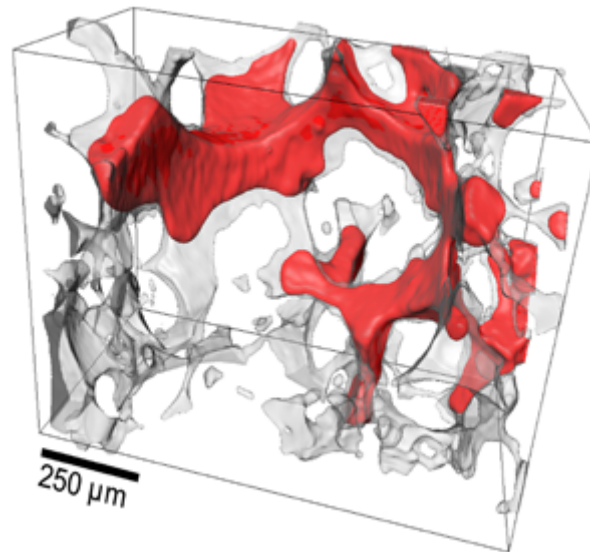


Figure 8: High-resolution 3D image of fluid menisci in the pores of a rock sample, made by X-ray imaging.

#### Main relevant publications:

- Withers, P. J., Bouman, C., Carmignato, S., Cnudde, V., Grimaldi, D., Hagen, C. K., ... Stock, S. R. (2021). X-ray computed tomography. NATURE REVIEWS METHODS PRIMERS, 1(1).
- Mascini A, Cnudde V, Bultreys T. Event-based contact angle measurements inside porous media using time-resolved micro-computed tomography. JOURNAL OF COLLOID AND INTERFACE SCIENCE. 2020;572:354–63.
- Bultreys T, Lin Q, Gao Y, Raeini AQ, AlRatrouf A, Bijeljic B, et al. Validation of model predictions of pore-scale fluid distributions during two-phase flow. PHYSICAL REVIEW E. 2018;97(5).
- Bultreys T, De Boever W, Cnudde V. Imaging and image-based fluid transport modelling at the pore scale in geological materials : a practical introduction to the current state-of-the-art. EARTH-SCIENCE REVIEWS. 2016;155:93–128.
- Bultreys T, Boone M, Boone M, De Schryver T, Masschaele B, Van Hoorebeke L, Cnudde, V. Fast laboratory-based micro-computed tomography for pore-scale research : illustrative experiments and perspectives on the future. ADVANCES IN WATER RESOURCES. 2016;95:341–51.

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### 3.1.6. UHasselt

## *Institute for Materials Research (IMO-IMOMEc) / Materials for Energy Applications*

Hasselt University, Faculty of Engineering Technology & Imec Associated Laboratory

#### General expertise of the research group

Our research team focuses on developing chalcogenide and new materials for Photovoltaic (PV) and PV-integrated solar fuel devices. Additionally, Photoelectrochemical and photocatalytic pathways are being explored as a testbed to study fundamental interactions at semiconductor electrolyte interface. Our research team consists of around 16 members including 5 senior researchers, 8 PhD students and various thesis/internship students with strong expertise in materials development, advanced optoelectronic characterization and catalyst engineering.

#### Specific hydrogen- related expertise & research topics

- Development of high-efficiency PV tandem devices which can be integrated to water electrolytic cells for PV-EC applications.
- Engineering various chalcogenide and emerging promising materials as photo absorbers and cocatalysts for photoelectrochemical water splitting.
- Development of photoelectrochemical (PEC) and photocatalytic (PC) cells for direct solar to hydrogen generation.
- Designing flow cells and electrode materials for efficient and low-overpotential electrocatalytic hydrogen generation systems.
- Advanced opto-electrical, structural, and configuration characterization of potential materials and devices applicable to PV and photo-electrochemical studies.

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research

- Development of high-efficiency tandem PV, e.g. for PV-EC
  - PERCISTAND (<https://cordis.europa.eu/project/id/850937>) Development of all thin-film perovskite on cis tandem photovoltaics
  - LASERGRAPH (<https://www.era-learn.eu/network-information/networks/fetflag-02-2018/flag-era-joint-transnational-call-jtc-2019/in-situ-laser-fabrication-of-graphene-electrodesand-interlayers-for-next-generation-cigs-perovskite-solar-cells>) In-situ laser fabrication of graphene electrodes and interlayers for next generation CIGS/ Perovskite solar cells
  - LAFLEX2T (<https://projecten.topsectorenergie.nl/projecten/flexible-large-area-2tmonolithic-tandem-psc-cigs-33526>) Flexible Large area 2T monolithic Tandem PSC-CIGS
  - ARLEA (<https://www.uhasselt.be/nl/projecten/detail/23616-project-r-13035>) Advanced Recombination Junction Layer Engineering and Application for Scalable and Stable Monolithic Perovskite Tandem Solar Cells with Two Different Bottom Cells. (Si-CIGS)
  - SITA (<https://www.sitasolarcells.eu/imec>) Stable Inorganic TAndem solar cell with superior device efficiency and increased durability
- Development of chalcopyrite materials for photo-electrochemical applications
  - SYNCAT (<https://moonshotflanders.be/mot3-syn-cat/>) Synergetic design of catalytic

- materials for integrated photo-and electrochemical CO<sub>2</sub> conversion
- T-REX (<https://www.uhasselt.be/en/projects/detail/21780-project-r-12321>) Conversion of CO<sub>2</sub> into renewable materials via electrified routes
- Procura Belgium (<https://procurabelgium.be/en>) Power to X, carbon capture & utilization roadmap for Belgium
- CHALCON (<https://cordis.europa.eu/project/id/101067667>) Chalcogenide-Silicon tandem PEC for CO<sub>2</sub> reduction
- Development of kesterite materials for photo-electrochemical applications
  - KESPER (<https://www.uhasselt.be/en/projects/detail/24269-project-r-13406>) Kesterite-based Photoelectrodes for Water and Nitrogen Reduction
  - Hydrogen Booster, EMR Interreg project (<https://www.emrh2booster.eu/>) Energy transition towards the development of carbon-free energy solutions by SMEs.



#### Available equipment/tools

- Physical vapor deposition tool including large scale (35 x 35 cm<sup>2</sup>) deposition
- Tabletop Tescan SEM equipped with EDX for elemental analysis
- Electrical D.C. Hall measurement Setup
- Steady state and transient Photoluminescence spectrometer
- X-ray diffractometer (XRD)
- LCR electronics for capacitance measurements (temperature and illumination dependent)
- Secondary Ion Mass Spectrometer (SIMS)
- State-of-the-art facility for hybrid PV cells development under controlled environment
- Solar simulators
- Electrochemical workstation for photoelectrochemical PV-electrolyzer testing

#### International collaborations

- International Iberian Nanotechnology Laboratory, Portugal
- Technical University of Denmark
- University of California, Berkeley
- University of New South Wales, Australia
- Nanyang Technological University Singapore, Singapore
- Foundation for Research and Technology Hellas, Greece
- Karlstad University, Sweden

### Main relevant publications

- Santos, D., Shukla, S., Vermang, B., (2023) Prospects of copper–bismuth chalcogenide absorbers for photovoltaics and photoelectrocatalysis, *J. Mater Chem A*, 11, 22087–22104. <https://doi.org/10.1039/D3TA03564F>.
- Scaffidi, R., Birant, G., Brammertz, G., de Wild, J., Flandre, D., Vermang, B. (2023) Ge-alloyed kesterite thin-film solar cells: previous investigations and current status – a comprehensive review. *J. Mater. Chem. A*, 11, 13174–13194. <https://doi.org/10.1039/D3TA01218B>.
- Silvano, J., Hamtaei, S., Verding, P., Vermang, B., Deferme, W., (2023) Investigating the Fabrication of Perovskite Solar Cells by Ultrasonic Spray Coating: A Design of Experiments Approach. *ACS Appl. Energy Mater.*, 6, 14, 7363–7376. <https://doi.org/10.1021/acsaem.3c00491>.
- Joos, B., Elen, K., Ham, J., Meulendijks, N., Buskens, P., Paulus, A., Wouters, K., Manca, J., D'Haen, J., Shukla, S., Vermang, B., Van Bael, M., Hardy, A. (2023) Facile Aqueous Solution-Gel Route toward Thin Film CuBi<sub>2</sub>O<sub>4</sub> Photocathodes for Solar Hydrogen Production. *Adv. Sustainable Syst.* 7, 8, 2300083. <https://doi.org/10.1002/adsu.202300083>
- de Wild, J., Scaffidi, R., Brammertz, G., Birant, G. and Vermang, B.,(2023) Dielectric Front Passivation for Cu(In,Ga)Se<sub>2</sub> Solar Cells: Status and Prospect. *Adv. Energy Sustainability Res.* 2200132. <https://doi.org/10.1002/aesr.202200132>
- Ramesh, S., Tuomiranta, A., Hajjiah, A., M. Meuris, B. Vermang, J. Poortmans. (2022) Physics-based electrical modelling of CIGS thin-film photovoltaic modules for system-level energy yield simulations. *npj Flex Electron* 6, 87. <https://doi.org/10.1038/s41528-022-00220-5>
- Birant, G., de Wild, J., Meuris, M., Poortmans, J. and Vermang, B. (2022) “To Spin or Not to Spin?” — Is Spin-Coating the Ideal Technique for Pre-Deposition of Sodium Fluoride for CIGS Rear Surface Passivated Ultrathin Solar Cells?. *Phys. Status Solidi A*, 219: 2100830. <https://doi.org/10.1002/pssa.202100830>
- Ratz, T., Nguyen, N. D., Brammertz, G., Vermang, B., Jean-Yves Raty, J.-Y., (2022) Relevance of Ge incorporation to control the physical behaviour of point defects in kesterite, *J. Mater. Chem. A*, 10, 4355–4365. <https://doi.org/10.1039/d1ta09620f>

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## *Institute for Materials Research (IMO-IMOMEc)/Design and synthesis of inorganic nanomaterials (DESINe)*

Hasselt University, Faculty of Science

### General expertise of the research group

The DESINe group specializes in environmentally friendly methods for synthesizing nanostructured inorganic materials for sustainable energy applications. Recent efforts target oxide, metal, polyanionic, and sulfide-based materials for energy storage in batteries, including lithium-ion, sodium-ion, and lithium-sulfur batteries. The applications extend to thermochromic coating windows, photo/electrocatalytic CO<sub>2</sub> reduction, and hydrogen production, contributing to enhanced energy efficiency and diverse power supply applications.

### Specific hydrogen-related expertise & research topics:

- Regarding H<sub>2</sub> generation, the DESINe group is currently focusing on materials for:
  - Photocatalytic hydrogen generation: stabilizing ZnOAl as a photocatalyst, understanding the interplay between synthesis, formation of defects, and catalytic function
  - Photoelectrochemical hydrogen generation: design and synthesis of thin films and powder-based materials with catalytic activity in the photoelectrochemical water splitting
  - (PEM) electrolysis: design and synthesis of catalysts for hydrogen and oxygen evolution reactions in PEM electrolysis cells
- DESINe's research activities in this scope concentrate on:
  - The design and synthesis of light harvesting and electrocatalytic materials with optimal composition and morphology.
  - Establishing innovative synthesis methods while assessing atom and energy efficiency, enabling precise control over material properties such as light absorption, crystal phase, size, morphology, porosity, and surface characteristics.
  - Analysing structure-morphology-function relationships comprehensively using spectroscopic and microscopic tools
  - Assessing the fundamental functional properties of materials, both as solar absorbers and electrocatalysts in standalone components.

### Participating in FL/B/EU funded projects with H<sub>2</sub>-related research:

- Green Hydrogen Lab: Relance Vlaamse Veerkracht project
- Grand challenges BOF project UHasselt, Clean H<sub>2</sub>, partnering Dirk Vanderzande, An Hardy, Koen Vandewal, Momo Safari, and Robert Malina of UHasselt.
- Bilateral BOF PhD scholarship UHasselt – UNamur on photocatalytic water splitting with AZO, partners: M.K. Van Bael, An Hardy, and Peter Adriaensens (UHasselt), Carmela Aprile and Luca Fusaro (UNamur). Also, in collaboration with Sammy Verbruggen, Pegie Cool and Silvia Lenaerts at UAntwerp.
- BE-HYFE: BE-HyFE – Belgian Hydrogen Fundamental Expertise; ETF project
- T-REX: On the transition to more Renewable Energy in power-to-X applications: ETF project
- SYN-CAT: Synergetic design of catalytic materials for integrated photo- and electrochemical CO<sub>2</sub> conversion processes; Funding: VLAIO-MOT

- LUMEN: Zonlicht als brandstof voor duurzame chemische processen; Interreg VI-NI project
- SPOTLIGHT: SPOTLIGHT solar fuels: a disruptive photonic technology to create carbon neutral fuels: Horizon 2020 project

#### Available equipment/tools:

- State-of-the-art chemical synthesis and analytical laboratories (commissioned in 2020) including Nanolabs up to risk level 3 (high risk)
- Solution synthesis equipment (solvothermal reactors with sampling possibilities, Schlenk lines, etc)
- Spraydryer for particle production
- High-temperature furnaces and RTP
- High-speed centrifuge (max. 20 000g)
- Coating equipment (tape-casting, Spin-coater, dip-coater and spray-coater)
- Gloveboxes (N<sub>2</sub> and Ar)
- Potentiostats and (photo-)electrochemical cells
- Custom built setup for evaluating the light-assisted catalytic reactions, equipped with a Xe-arc light source and MicroGC Gas chromatography
- N<sub>2</sub> sorption – BET
- XRD
- SEM and TEM
- FTIR and Raman, UV-Vis spectroscopy
- Mass spectrometry

#### International collaborations:

- Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (TNO) Eindhoven, The Netherlands dr. Pascal Buskens
- Korea Advanced Institute of Science & Technology (KAIST) Daejeon, South-Korea Prof. dr. Byungha Shin

#### Main relevant publications

- Facile Aqueous Solution-Gel Route toward Thin Film CuBi<sub>2</sub>O<sub>4</sub> Photocathodes for Solar Hydrogen Production; Bjorn Joos, Ken Elen, Jonathan van den Ham, Nicole Meulendijks, Pascal Buskens, Andreas Paulus, Koen Wouters, Jean Manca, Jan D'Haen, Sudhanshu Shukla, Bart Vermang, Marlies Van Bael, An Hardy; *Advanced Sustainable Systems*, 2300083
- Photocatalytic Performance of Undoped and Al-Doped ZnO Nanoparticles in the Degradation of Rhodamine B under UV-Visible Light: The Role of Defects and Morphology; Alessandra Piras, Chiara Olla, Gunter Reekmans, An-Sofie Kelchtermans, Dries De Sloovere, Ken Elen, Carlo Maria Carbonaro, Luca Fusaro, Peter Adriaensens, An Hardy, Carmela Aprile, Marlies K Van Bael; *International Journal of Molecular Sciences* 23 (24), 15459
- Sunlight-Powered Reverse Water Gas Shift Reaction Catalysed by Plasmonic Au/TiO<sub>2</sub> Nanocatalysts: Effects of Au Particle Size on the Activity and Selectivity; Jordi Volders, Ken Elen, Arno Raes, Rajeshreddy Ninakanti, An-Sofie Kelchtermans, Francesc Sastre, An Hardy, Pegie Cool, Sammy W Verbruggen, Pascal Buskens, Marlies K Van Bael; *Nanomaterials* 12 (23), 4153
- Comparing the Performance of Supported Ru Nanocatalysts Prepared by Chemical Reduction of RuCl<sub>3</sub> and Thermal Decomposition of Ru<sub>3</sub>(CO)<sub>12</sub> in the Sunlight-Powered Sabatier Reaction; Daria Burova, Jelle Rohlf, Francesc Sastre, Pau Martinez Molina, Nicole Meulendijks, Marcel A Verheijen, An-Sofie Kelchtermans, Ken Elen, An Hardy, Marlies K Van Bael, Pascal Buskens; *Catalysts* 12 (3), 284



- Precursor Design Strategies for the Low-Temperature Synthesis of Functional Oxides: It's All in the Chemistry; W Marchal, D De Sloovere, M Daenen, MK Van Bael, A Hardy; Chemistry–A European Journal 26 (42), 9070-9083
- Remarkable lowering in the synthesis temperature of LiMn<sub>2</sub>O<sub>4</sub> via citrate solution-gel synthesis facilitated by ethanol, Maino, G; Carleer, R.; Marchal, W.; Bonneux, G.; Hardy, A.; Van Bael, M.K. Dalton Transactions, 2017 46 (43) 14934-14946
- Ultrasonic spray deposition of metal oxide films on high aspect ratio microstructures for 3D all-solidstate Li-ion batteries ; E. Jonathan van den Ham, Sven Gielis, Marlies Van Bael, An Hardy; ACS Energy Letters, 2016 1, p.1184-1188
- Factors influencing the conductivity of aqueous sol(ution)-gel processed Al-doped ZnO films; H. Damm, P. Adriaensens, C. De Dobbelaere, B. Capon, K. Elen, J. Drijkoningen, B. Conings, J. Manca, J. D'Haen, C. Detavernier, P.C.M.M. Magusin, J. Hadermann, A. Hardy, M.K. Van Bael , Chemistry of Materials 26(20) (2014) 5839-5851

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- Marlies K. Van Bael <https://www.uhasselt.be/fiche?email=marlies.vanbael>  
 Email: [marlies.vanbael@uhasselt.be](mailto:marlies.vanbael@uhasselt.be)



## Institute for Materials Research (IMO-IMOMECC)/Group of Electrochemical Engineering

Hasselt University, Faculty of Engineering Technology & Electrochemical Engineering

### General expertise of the research group

- Electrochemical engineering
  - Porous electrode design & characterization
  - Kinetics & charge transport
  - Electrochemical characterization
  - Mathematical modelling
  - Aging and post-mortem analysis

### Specific hydrogen- related expertise & research topics

- PEM water electrolyzer
  - MEA preparation and optimization
  - Polarization and aging tests
  - Electrochemical characterization and physics-based modelling

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- CleanH2 (BOF)

### Available equipment/tools:

- MEA preparation: Mixing, Coating, hot press
- Mercury porosimeter
- 500W PEM water electrolyzer automatic test station
- Electrochemical characterization: Potentio- and Galvano-static + EIS

### Main relevant publications

- 'A techno-economic evaluation of solar-powered green hydrogen production for sustainable energy consumption in Belgium', N Srettiwat, M Safari, H Olcay, R Malina, *International Journal of Hydrogen Energy* (2023) 48 (100), 39731-39746
- 'Bridging the microstructural evolutions from slurry to porous electrode of a lithium-ion battery', H Hamed, Z Alamooti, A Agrawal, J D'Haen, A Hardy, M Safari, *Energy Chemistry* (2023) 84, 329-334.
- 'Non-Uniform Distribution of Current in Plane of Large-Area Lithium Electrodes', S Yari, MK Van Bael, A Hardy, M Safari, *Batteries & Supercaps* (2022) 5 (10), e202200217.

### Contact persons:

- Prof. Momo Safari ([momo.safari@uhasselt.be](mailto:momo.safari@uhasselt.be))
- Dr. Lieve De Doncker ([lieve.dedoncker@uhasselt](mailto:lieve.dedoncker@uhasselt))

# *Institute for Materials Research (IMO-IMOMEc) / Hybrid Halide Perovskites for Energy Applications (HyMaD)*

Hasselt University, Faculty of Science, Imec Associated Laboratory

## General expertise of the research group

The research institute Imo-Imomec at UHasselt is a joint initiative of imec and UHasselt with a joint expertise. About half of our research activity is related to thin film photovoltaic, including CIGS, organic, inorganic, hybrid perovskites PV. The expertise of our 3 divisions (Chemistry, Physics and Engineering Technology) is brought together and use towards fundamental research, applied research and device engineering of (semi-)conductor materials. It covers synthesis, structural characterization, material processing and device physics. The institute has developed many original contributions to the chemistry and physics of conjugated small molecules and polymers including development of novel synthesis routes and has built up an internationally recognized strong reputation in the domain. Since 2016, the synthesis activities include ammonium functionalized chromophores for integration in 2D layered Hybrid Organic Inorganic Perovskites (HOIP) (Dirk VANDERZANDE (UHasselt), Laurence LUTSEN (Imec-imomec)).

## Specific hydrogen- related expertise & research topics

- Development of high-efficiency and stable hybrid perovskite (3D and 2D layered) and organic semiconductor molecules for application in PEC and PV+EC.
- Structural characterization
- Thin film morphology

## Available equipment/tools

- Fully equipped organic and hybrid materials synthesise and spectroscopic characterisations including Schlenk lines to work under inert conditions.
- Liquid NMR
- Solid state NMR to evaluate both amorphous and crystalline phases and molecular miscibility of blends at the nm scale.
- State-of-the-art glovebox systems to produce perovskite materials under inert conditions.
- Solvent purification system connected to the glovebox
- MALDI-TOF
- Vacuum sublimation system for small organic molecules
- FTIR, Raman, UV-Vis spectroscopy
- SEM and TEM
- Etc

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research

- CLEANH2, Fundamental Research in Solar-driven Hydrogen Generation using Earth-abundant Catalysts and Durable Hybrid Perovskites as Light Absorbers. Funding agency: BOF project. UHasselt research groups, 5 principal Investigators. 2021-2025.
- PROCEED, Hybrid Perovskites as Material Platform for Conversion, Emission and Detection of Light. Funding agency: FWO, SBO project. UHasselt, UGent, KULeuven, UAntwerpen and IMEC as the coordinator of the project. 2020-2024
- FWO senior research project. A fundamental study of energy and charge transfer processes in low dimensional organic-inorganic hybrid perovskites. Funding agency: FWO. PI: Dirk Vanderzande. FWO 019-16
- FWO PhD fellowship Martijn Mertens. 2D perovskite-induced self-organization of conjugated chromophores for efficient and stable optoelectronic applications. 01/01/2018-31/12/2021
- FWO PhD fellowship Arthur Maufort. Self-assembly of organic donor-acceptor complexes within a perovskite structure: a fundamental study of the relationship between optoelectronic and structure properties. 01/11/2020-31/10/2024



### International collaborations

- TUDelft, Prof. Dr. Ferdinand Grozema, Time-resolved Microwave Conductivity
- Arizona State University, Prof. Dr. Brent Nannenga, Cryo Electron Microscopy
- CSEM, Dr. Brett Kamino and Dr. Björn Niesen, large area perovskite solar cells
- Solaronix, Dr. David Martineau, large area perovskite solar cells
- University of Toronto, Dr. Amin Morteza Najarian (Sargent group), Electro Optical Modulation
- Rijksuniversiteit Groningen, Prof. Dr. Maria Antonietta Loi, photophysics and solar cells
- Victoria University of Wellington, Dr. Kai Chen, femtosecond luminescence
- TUEindhoven, Prof. Dr. René Janssen, in-situ absorption spectroscopy during spin-coating

### Main relevant publications

- 2D layered perovskite containing functionalised benzothieno-benzothiophene molecules: formation, degradation, optical properties and photoconductivity. Van Gompel, Wouter T. M.; Herckens, Roald; Denis, Paul-Henry; Mertens, Martijn; Gelvez-Rueda, Maria C.; Van Hecke, Kristof; Ruttens, Bart; D'Haen, Jan; Grozema, Ferdinand C.; Lutsen, Laurence; Vanderzande, Dirk. *Journal of Materials Chemistry C: Materials for Optical and Electronic Devices*, 2020, 8(21), 7181-7188.
- Inducing charge separation in solid-state two-dimensional hybrid perovskites through the incorporation of organic charge-transfer complexes. Gelvez-Rueda, Maria C.; Van Gompel, Wouter T. M.; Herckens, Roald; Lutsen, Laurence; Vanderzande, Dirk; Grozema, Ferdinand C. *Journal of Physical Chemistry Letters*, 2020, 11(3), 824-830.
- Lead-Halide Perovskites Meet Donor-Acceptor Charge-Transfer Complexes. Marchal, Nadege; Van Gompel, Wouter; Gelvez-Rueda, Maria C.; Vandewal, Koen; Van Hecke, Kristof; Boyen, Hans-Gerd; Conings, Bert; Herckens, Roald; Maheshwari, Sudeep; Lutsen, Laurence; Quarti, Claudio; Grozema, Ferdinand C.; Vanderzande, Dirk; Beljonne, David. *Chemistry of Materials*, 2019, 31(17), 6880-6888.
- Low-Dimensional Hybrid Perovskites Containing an Organic Cation with an Extended Conjugated System: Tuning the Excitonic Absorption Features. Van Gompel, Wouter T. M.; Herckens, Roald; Van Hecke, Kristof; Ruttens, Bart; D'Haen, Jan; Lutsen, Laurence; Vanderzande, Dirk. *ChemNanoMat*, 2019, 5(3), 323-327.
- Towards 2D layered hybrid perovskites with enhanced functionality: introducing charge-transfer complexes via self-assembly. Van Gompel, Wouter T. M.; Herckens, Roald; Van Hecke, Kristof; Ruttens, Bart; D'Haen, Jan; Lutsen, Laurence; Vanderzande, Dirk. *Chemical Communications*, 2019, 55(17), 2481-2484.
- Layered hybrid organic-inorganic perovskite materials. Lutsen, Laurence; Vanderzande, Dirk. IMEC VZW, Belg.; Universiteit Hasselt. Jan 31, 2019. Patent WO 2019020612A1.
- Multi-layered hybrid perovskites templated with carbazole derivatives: optical properties, enhanced moisture stability and solar cell characteristics. Herckens, Roald; Van Gompel, Wouter T. M.; Song, Wenya; Gelvez-Rueda, Maria C.; Maufort, Arthur; Ruttens, Bart; D'Haen, Jan; Grozema, Ferdinand C.; Aernouts, Tom; Lutsen, Laurence; Vanderzande, Dirk. *Journal of Materials Chemistry A: Materials for Energy and Sustainability*, 2018, 6(45), 22899-22908.
- Degradation of the Formamidinium Cation and the Quantification of the Formamidinium Methylammonium Ratio in Lead Iodide Hybrid Perovskites by Nuclear Magnetic Resonance Spectroscopy. Van Gompel, Wouter T. M.; Herckens, Roald; Reekmans, Gunter; Ruttens, Bart; D'Haen, Jan; Adriaensens, Peter; Lutsen, Laurence; Vanderzande, Dirk. *Journal of Physical Chemistry C*, 2018, 122(8), 4117-4124.

### Contact persons

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Email : [dirk.vanderzande@uhasselt.be](mailto:dirk.vanderzande@uhasselt.be)
- Laurence Lutsen (Imec-Imomec)  
<https://www.uhasselt.be/fiche?email=laurence.lutsen>  
Email: [Laurence.lutsen@uhasselt.be](mailto:Laurence.lutsen@uhasselt.be) / [laurence.lutsen@imec.be](mailto:laurence.lutsen@imec.be)

## Institute for Materials Research (IMO-IMOMECC) / Organic Opto-Electronics Research (OOE)

Hasselt University, Faculty of Sciences, Materials Physics, Imec Associated Laboratory

### General expertise of the research group

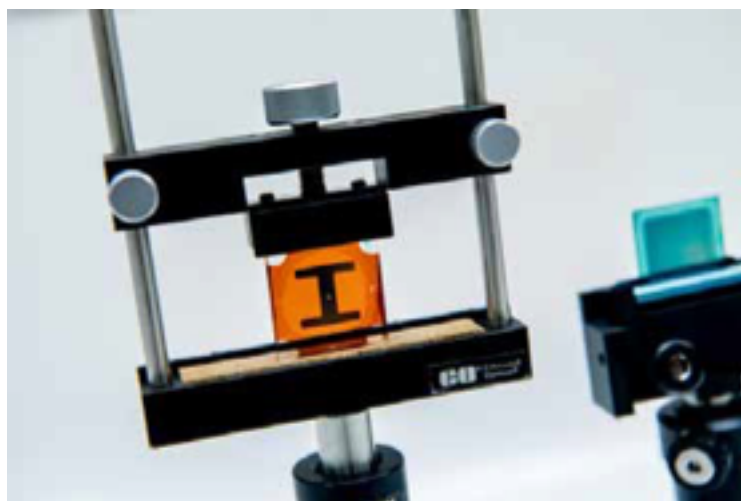
The organic opto-electronics research group has the aim to solve fundamental questions in organic, hybrid and molecular electronics with relevance in opto-electronic devices such as OLEDs, sensors, solar cells and photovoltaic systems. The group is led by Prof. Dr. Ir. Koen Vandewal, who is well known for his seminal work on the characterization and description of charge-transfer states at organic interfaces. The group's expertise lies in the fabrication and characterization of thin film devices based on organic and hybrid perovskite materials, as well as advanced device characterization and device physics.

### Specific hydrogen- related expertise & research topics

- Integration of organic and perovskite PV-elements with electrochemical cells.
- Engineering of photovoltaic interfaces.

### Available equipment/tools

- Glovebox with spincoater and thermal evaporator for sample and device preparation
- AM1.5g solar simulator
- Steady-state spectroscopy: UV/Vis/NIR transmission/reflection/absorption and photocurrent spectroscopy (350 nm – 2500 nm), emission (photoluminescence/electroluminescence/thermal) spectroscopy (350 nm – 20 μm)
- Photothermal deflection and photoluminescence excitation spectroscopy with wavelength tuneable laser excitation (450 – 650 nm & 900 – 1300 nm)
- Time gated iCCD for time resolved spectroscopy (400 – 800 nm). 2 ns minimum gating time



### International collaborations

- TU Dresden (device physics and engineering)
- Stanford University (Synchrotron x-ray analysis)

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research

- CLEANH2 – Fundamental Research in Solar-driven Hydrogen Generation using Earth-abundant Catalysts and Durable Hybrid Perovskites as Light Absorbers, BOF.
- ConTROL – Charge-transfer states for high performance organic electronics, ERC Consolidator Grant
- Joint FWO project with HyMAT - Self-assembly of organic donor-acceptor complexes within the confinement of a perovskite lattice: a fundamental study of the relation between structure and opto-electronic properties. (R-11232)

### Main relevant publications

- Emissive and charge-generating donor–acceptor interfaces for organic optoelectronics with low voltage losses. S. Ullbrich, J. Benduhn, X. Jia, V. C. Nikolis, K. Tvingstedt, F. Piersimoni, S. Roland, Y. Liu, J. Wu, A. Fischer, D. Neher, S. Reineke, D. Spoltore, K. Vandewal. *Nature materials*, 2019, 18.5: 459-464.
- Lead-Halide Perovskites Meet Donor–Acceptor Charge-Transfer Complexes. N. Marchal, W. Van Gompel, M. C. Gélvez-Rueda, K. Vandewal, K. Van Hecke, H-G. Boyen, B. Conings, R. Herckens, S. Maheshwari, L. Lutsen, C. Quarti, F. C. Grozema, D. Vanderzande, D. Beljonne. *Chemistry of Materials*, 2019, 31(17), 6880-6888.
- High voltage vacuum-deposited CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>–CH<sub>3</sub>NH<sub>3</sub> PbI<sub>3</sub> tandem solar cells. J. Ávila, C. Momblona, P. Boix, M. Sessolo, M. Anaya, G. Lozano, K. Vandewal, H. Míguez, H. J. Bolink. *Energy & Environmental Science*, 2018, 11(11), 3292-3297.
- Intrinsic non-radiative voltage losses in fullerene-based organic solar cells. J. Benduhn, K. Tvingstedt, F. Piersimoni, S. Ullbrich, Y. Fan, M. Tropicano, K. A. McGarry, O. Zeika, M. K Riede, C. J. Douglas, S. Barlow, S. R. Marder, D. Neher, D. Spoltore, K. Vandewal. *Nature Energy*, 2017, 2(6), 17053.
- Reducing voltage losses in cascade organic solar cells while maintaining high external quantum efficiencies. V. C. Nikolis, J. Benduhn, F. Holzmueller, F. Piersimoni, M. Lau, O. Zeika, D. Neher, C. Koerner, D. Spoltore, K. Vandewal. *Advanced Energy Materials*, 2017, 7(21), 1700855.

### Contact persons

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### 3.1.7. VITO

## *Sustainable chemistry*

### VITO – Separation and Conversion Technology (SCT)

#### General expertise of the research group

VITO is a leading European independent research/consultancy centre in the areas of cleantech and sustainable development, elaborating solutions for the grand societal challenges of tomorrow: climate change, food security, a sustainable energy supply, the ageing population and scarcity of resources. The business unit of Separation and Conversion Technology is composed of >100 researchers, managers, support staff and students and has organized its strategic research program around the theme ‘Sustainable Chemistry’ with special focus on (1) process intensification through the integration of separation processes with chemical, microbial, enzymatic or bio-electrochemical conversion processes, and (2) the use of alternative feedstocks, such as CO<sub>2</sub>.

#### Specific hydrogen- related expertise & research topics

- Integration of reaction technology (bio, electrochemical) and separation technologies
- Expertise in alkaline and PEM fuel cell development and testing
- Development of low cost and efficient electrodes and membranes
- The gas diffusion electrodes to be used as air cathodes in MFCs are considered as the state-of-the-art and are currently being optimized for CO<sub>2</sub> conversion processes
- Activities in the electrosynthesis field with projects on conversion of CO<sub>2</sub> to ethanol, methanol, formic acid and conversion of acids to alcohols and production of ionic liquids.
- Techno-economic and life cycle assessment of the hydrogen value chain.
- Energy system modelling, long-term system scenario modelling (2030-2050)

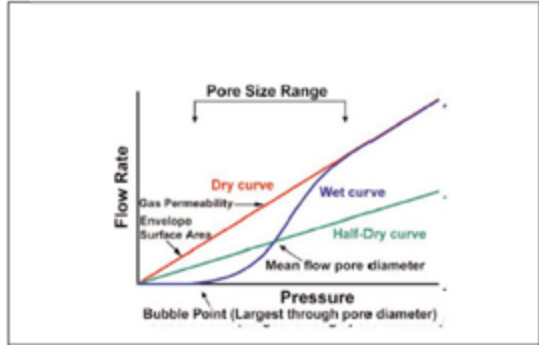
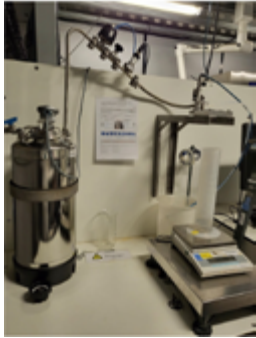
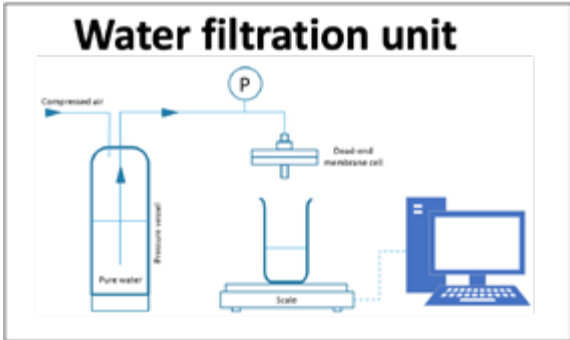
#### Available equipment/tools:

- 3 laboratory test stands
  - Single cell/small stack
  - Operational ranges
    - 15 bar, 90°C
    - 35 bar, 90°C
    - 15 bar, 70°C
  - Labview
  - Sensing Pressure,Temp,Q\_flows
  - Gas quality (HTO, Gas Chromatography...)
  - Electrochemical characterization (I-V,EIS)
- Demo setup
  - Up to 3 kW
  - Design range: 50 bar, 90°C
  - PLC based
  - Sensing P,T,Q,HTO...
  - GC/EIS

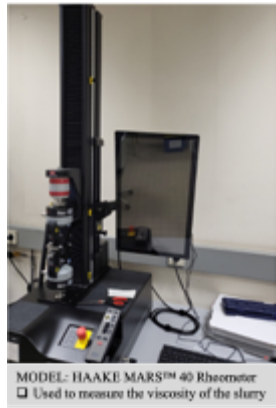
- Durability test benches
  - Parallel 2x2 cm testing of 5 samples
  - 10 bar, 80°C- 120°C



- Ex-situ tools for membrane characterization
  - Water permeability (via Water filtration unit)
  - IEC measurement (via titration)
  - Capillary Flow Porometry (CFP) (via Porolux) to determine:
    - First Bubble Point (FBP), Smallest pore size (SP), Mean Flow Pore diameter (MFP), Gas permeability (GP)
  - Scanning electron microscopy (SEM)
  - Hg porosimetry measurements
  - Thermogravimetric analysis
  - Tensile strength measurements

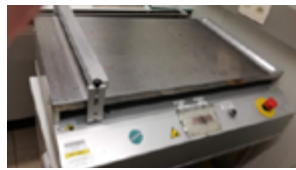






**ELCOMETER 4340 Automatic Film Applicator**

- dimensions: 20/30cm
- Heated coating bed



**BRAVE 4340 SP Automatic Film Applicator**

- dimensions: 50/60cm



**Roll-to-Roll Film Applicator**

- dimensions: 15cm width
- speed: 1 to 800 cm/min



**Pressurized polymer  
solution delivery system**



**MIXERS / DISOLVERS**  
0.1 -> 8 kg



**20-ton hydraulic press**

Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- Bac-To-Fuel, Bacterial conversion of CO<sub>2</sub> and renewable H<sub>2</sub> into biofuels, H2020 Project ID: 825999
- BIORECO2VER, Biological routes for CO<sub>2</sub> conversion into chemical building blocks, H2020 Project ID: 760431
- LOTER.CO2M, CRM-free low temperature electrochemical reduction of CO<sub>2</sub> to methanol, H2020 Project ID 761093-2
- PERFORM, PowerPlatform: Establishment of platform infrastructure for highly selective electrochemical conversions, H2020 Project ID : 820723
- CATCO2RE, Conversion of solar energy and CO<sub>2</sub> to chemicals and fuels, FWO, VITO/UGent/KUL/VUB
- CO2PERATE, The catalytic conversion of CO<sub>2</sub> to formic acid, Cluster SBO, VITO/UGent/KUL/UA/BEP
- PROCURA, Power to X and carbon capture and utilization roadmap for Belgium, ETF, VITO/IMEC/Waterstofnet/KUL/VUB/University of Liège
- BREGILAB, Investigation of the practical realisation of further expansion of renewable electricity sources in Belgium, ETF, VITO/KUL/UHasselt/IMEC/KMI
- E2C Interreg Project: Electrons to high value Chemical products
- ELYINTEGRATION Horizon 2020 project “Grid integrated multi megawatt high pressure alkaline electrolyzers for energy applications”, FCH Initiative.
- REselyser FP7 Project “Hydrogen from RES: pressurised alkaline electrolyser with high efficiency”, FCH Initiative
- H<sub>2</sub>-MHytic – VLAIO SBO: H<sub>2</sub> BY MEMBRANE INTEGRATED HIGH SURFACE AREA NANOMESH TECHNOLOGY (VITO, Imec and Ghent University)



### Main relevant publications

- Sánchez, O.G.\* , Birdja, Y.Y.\* , Bulut, M., Vaes, J., Breugelmans, T. and Pant, D, Recent advances in industrial CO<sub>2</sub> electroreduction. *Current Opinion in Green and Sustainable Chemistry*. 2019, 16, 47-56.
- König, M., Vaes, J., Klemm, E. and Pant, D., Solvents and Supporting Electrolytes in the Electrocatalytic Reduction of CO<sub>2</sub>. *iScience*, 2019, 19, p.135.
- Doyen, W., Alvarez Gallego, Y., Stoops, L., Molenbergh, B., Reissner, R., Schiller, G., Guelzow, E., Vaes, J. and Bowen, J.R., 2014. The e-bypass separator: the solution to the inherent problem of alkaline water electrolysis under challenging working conditions. 2014 Membrane Symposium, 08. Sept. 2014, Aachen, Deutschland.
- König, M, Bulut, M., Vaes, J., Klemm, E., Pant, D. 2019. Electrochemical CO<sub>2</sub> conversion. EU patent EP19213008.
- Prato, R.A., Van Vught, V., Eggermont, S., Pozo, G., Marin, P., Fransaer, J. and Dominguez-Benetton, X., 2019. Gas Diffusion Electrodes on the Electrosynthesis of Controllable Iron Oxide Nanoparticles. *Scientific reports*, 9(1), pp.1-11.
- Van Dael, M., Kreps, S., Virag, A., Kessels, K., Remans K., Thomas, D., and De Wilde, F., 2018, Techno-economic assessment of a microbial power-to-gas plant – case study in Belgium, *Applied Energy*, 2015, pp.416-425

### Contact persons:

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- Jan Vaes – [jan.vaes@vito.be](mailto:jan.vaes@vito.be)

### 3.1.8. VIVES Hogeschool

## *Climate & Energy – research group hydrogen (Production)*

### VIVES University of Applied Sciences

#### General expertise of the research group

The research group hydrogen can rely on a fully equipped laboratory of the hydrogen energy chain. From production, up to the use of hydrogen in different applications. The group has gained expertise in practical use and implementation of various aspects, including green hydrogen production, hydrogen storage, regulatory aspects and safety considerations related to hydrogen, utilization of hydrogen as a fuel for internal combustion engines, hydrogen fuel cell systems, fuel cell vehicles, and the production and utilization of green methanol.

#### Specific hydrogen- related expertise & research topics

- Expertise in production of green hydrogen with solar and wind energy and PEM electrolyser (10 kW)
- Control management and data acquisition and visualisation of a PEM electrolyzer
- System modelling and optimization
- Training and education

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- Project: H<sub>2</sub> ElektrolyzE – topic: PEM electrolyser demonstrator for production of green hydrogen – funding source: VLAIO PWO (projectmatig wetenschappelijk onderzoek) – industrial partners: Cinergy, AA Technics, e-BO enterprises, Bekaert, Van Marcke Technics
- Project: Hyde, sustainable and “green” energy applications for military use – topic: modelling and building of a demonstrator – funding source: BELSPO DEFRA – project partners: KU Leuven, Solenco and Royal Military Academy





#### Available equipment/tools:

- Solar panels
- PEM electrolyser 10 kW with water treatment
- Compressor 300 bar
- Hydrogen storage
- Hydrogen supply infrastructure

#### International collaborations:

- TU Delft
- Solent University Southampton
- UPHF – Université Polytechnique Hauts-de-France
- NICE – Noordelijk Innovatielab Circulaire Economie
- BDI – Bretagne Développement Innovation

#### Main relevant publications

- J. Mus et al., "Design and Characterisation of an Alkaline Electrolyser," 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), 2022, pp. 253-259, doi: 10.1109/ICRERA55966.2022.9922902.
- De Wilde, B., Schotte, S. (contr.) (2022). Hogeschool VIVES opent nieuw waterstofcentrum VRT NWS.
- Mus, J., Mylle, S., Schotte, S., Fevery, S., Latré, S., Buyschaert, F. (2022). CFD Modelling and Simulation of PEMFCs in STAR-CCM+. In: 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), (260-267). Presented at the International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey,

#### Contact persons:

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- Steven De Tollenaere: [steven.detollenaere@vives.be](mailto:steven.detollenaere@vives.be)

### 3.1.9. VKI

## *VKI: Research Expertise Group on Liquid & Solid Propulsion*

### von Karman Institute for Fluid Dynamics / Aerospace Department

#### General expertise of the research group

##### DENSIFIED CRYOGENIC STORAGE

Experimental testing and numerical simulation of the fluid dynamic behaviour for 2-phase flows and multiphase flows, with application for liquid hydrogen and other cryogenic (e-)fuels. Extensive expertise is available from research on the propellant management system for space launchers. This expertise which has been developed for space applications, is now being transferred to terrestrial applications, both for terrestrial mobility (in ships, aircraft, heavy duty trucks...) and for energy applications (long term H<sub>2</sub> storage and long distance H<sub>2</sub> transport).

#### Specific hydrogen- related expertise & research topics

- In general: numerical simulations of liquid hydrogen behaviour and performing experimental tests to validate the modelling
- Densified Cryogenic eFuels ("Slush"): hydrogen, methane, LNG (also applicable to CO<sub>2</sub>)

#### Available equipment/tools:

- Numerical simulation platforms for CFD (Computational Fluid Dynamics), e.g. EcosimPro, OpenFOAM®
- Experimental test facilities:
  - PREDICT and BECASSINE Facility: for testing for densified cryogenic (e-)fuels.
  - Particle Image Velocimetry

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- [SPACE] PREDICT DREAMS is the continuation of PREDICT (experimental characterization of a slurry flow or densified cryogenic flow in hydraulic similitude with future cryogenic propellant at the triple point) in the framework of a PhD thesis. In this activity, both numerical simulation and experimental investigations are carried out. A CFD solver based on a Euler-Euler approach coupled with the Granular Kinetic Energy theory is in development, satisfactory results were obtained once validated against the PREDICT experimental data. The final ambitious goal targets experiments characterizing a slush flow and possibly evaluate the solver performances. Funding: FRIA/FNRS and ESA – NPI.
- [ENERGY] Be-HyFE (Belgian Hydrogen Fundamental Expertise): this project aims at developing a Belgian PhD network with PhD level research on hydrogen, about many different topics across the hydrogen value chain. The VKI PhD will focus on advanced characterization of thermodynamic properties of densified cryogenic hydrogen (or e-fuels more in general): composition (crystals shape and size), aging dynamics (stratification, melting), rheology and behaviour in pipelines and their components. This densified cryogenic slush is a promising solution to increase the volumetric density for storage and increase the resistance against boil-offs and heat losses during long distance transportation. Funding: Energy Transition Fund, by the Belgian Federal Public Services "Economy".



#### International and industrial collaborations:

- Ariane Group (FR, DE)
- CiRA (UK)
- DLR (DE)
- Numeca (BE)
- Open Engineering (BE)
- Waseda University Tokyo (JPN)



*Figure 9: PREDICT Facility, for experimental characterization of densified cryogenic fuels*

#### Main relevant publications

- Two-Phase Flows Investigations in Liquid Propulsion Systems: “TRL Booster” research at the von Karman Institute, by Jean-Baptiste Gouriet, Cryogenic Heat & Mass Transfer symposium, TU Twente (Enschede), november 2019

#### Contact persons:

- Jean-Baptiste Gouriet – Research Manager
- Peter Simkens – Business Development Manager

### 3.1.10. VUB

## Department of Chemical Engineering

### Vrije Universiteit Brussel, Faculty of Engineering Sciences

#### General expertise of the research group

The Department of Chemical Engineering at VUB has extended expertise in separation processes, in particular separation and purification of gas and liquid mixtures by adsorption and chromatography. Advanced experimental techniques (lab on a chip, high- throughput experimentation, ...) are combined with state-of-the-art computer modelling methods, including molecular modelling and computational fluid dynamics, to obtain insight in the fundamental adsorption, diffusion and mass and heat transfer effects. The department has 3 core research topics: adsorptive separation processes, HPLC technology and analysis and microfluidics and microreactors

#### Specific hydrogen- related expertise & research topics

- Adsorption, gas separation, purification and storage
- Hydrogen storage in porous solids
- Hydrogen clathrate formation
- Study of kinetics, uptake and thermodynamics of hydrogen storage
- Experimental assessment and modelling of storage
- CFD modelling for flow field design of electrolyzers and fuel cells
- Know-how on gas sampling, in-line/ on-line / off-line gas analysis

#### Available equipment/tools:

- Ultra-precise (in-house built) gravimetric experimental setup to study H<sub>2</sub>-storage in porous solids: kinetics of storage, uptake capacity, thermodynamics in a broad range of conditions (77K, -30 to 70°C, up to 15 MPa, density measurement, many types of gases)
- Volumetric setup to study gas storage in porous solids
- Breakthrough setup to study purification of hydrogen streams (removal of trace impurities)
- Gas analysis equipment (GC, GC-MS, MS)
- Software tools to simulate H<sub>2</sub>-storage processes

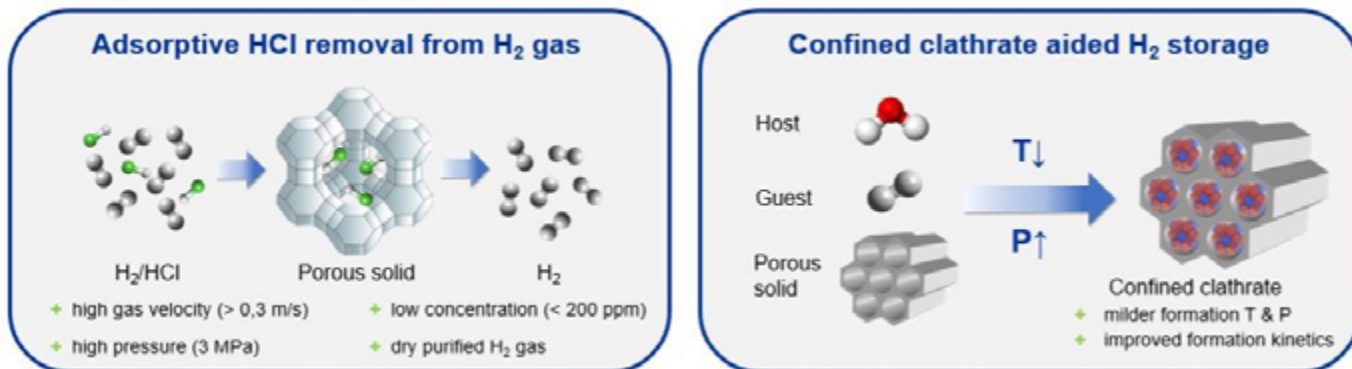
#### International collaborations:

- ITQ Valencia (Prof. F. Rey): micro- and mesoporous solids
- Université de Montpellier (Prof. G. Maurin): molecular modelling of adsorption



Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- ARCLATH, H<sub>2</sub> storage in artificial clathrates, VLAIO, Project coordinator: KULeuven, Prof. J. Martens, main partners: KULeuven, UGent, UAntwerpen, VUB.



Main relevant publications

- Gupta, A., Baron, G. V., Perreault, P., Lenaerts, S., Ciocarlan, R.-G., Cool, P., ... ,Denayer, J. F. M. (2021). Hydrogen Clathrates: Next Generation Hydrogen Storage Materials. *Energy Storage Materials*, 41, 69–107. <https://doi.org/10.1016/j.ensm.2021.05.044>.
- Sharma, R., Cousin-saint-remi, J., Tiriana, S., Delplancke, M., Pletincx, S., Baert, K., ... Denayer, J. F. M. (2022). Metal-organic framework ZIF-8 for exceptional HCl removal from Hydrogen gas by reaction. *International Journal of Hydrogen Energy*, 47(47), 20556–20560. <https://doi.org/10.1016/j.ijhydene.2022.04.244>
- Sharma, R., Segato, T., Delplancke, M.-P., Terry, H., Baron, G. V., Denayer, J. F. M., & Cousin-Saint-Remi, J. (2020). Hydrogen chloride removal from hydrogen gas by adsorption on hydrated ion-exchanged zeolites. *Chemical Engineering Journal*, 381(August 2019), 122512. <https://doi.org/10.1016/j.cej.2019.122512>.
- De Schepper, P., Danilov, V. A., & Denayer, J. F. M. (2016). Cathode flow field design for nitric oxide/hydrogen fuel cell in cogeneration of hydroxylamine and electricity. *International Journal of Energy Research*, 40(10), 1355–1366. <https://doi.org/10.1002/er.3519>

Contact persons:

- Prof. Joeri Denayer, [joeri.denayer@vub.be](mailto:joeri.denayer@vub.be)
- Business developer dr. ir. Marleen Claeys, [marleen.claeys@vub.be](mailto:marleen.claeys@vub.be)

## Thermo and Fluid Dynamics (FLOW)

### Vrije Universiteit Brussel, Faculty of Engineering

#### General expertise of the research group

At FLOW, we focus on ensuring access to sustainable energy for all, which is one of the sustainable development goals of the United Nations. We tackle this challenging mission through 3 research topics: circular energy, low emissions, and flexible energy systems. We have expertise in thermodynamics, fluid mechanics, combustion, CFD simulations, system modelling and data driven modelling. In the field of Hydrogen, our current focus is on the combustion of hydrogen and related e-fuels for heat and power production and other industrial applications, including safety issues related to hydrogen storage and use.

#### Specific hydrogen- related expertise & research topics

- Combustion of H<sub>2</sub> and H<sub>2</sub>-based carriers
- CFD simulations
- Kinetic mechanisms
- Thermodynamic process modelling and integration
- Power plants
- Flue gas treatment
- Storage
- H<sub>2</sub> leakages

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- BEST: Belgian Energy System. Role of e-fuels in the Belgian energy system, 2020-2024, ETF: Energy Transition Funds. Partners: UCL, ULB, UMONS, UGent.
- BE-HyFE: Belgian Hydrogen Fundamental Expertise, 2021-2025, ETF: Energy Transition Funds. Partners: UGent, UCLouvain, ULB, UAntwerpen, UMONS, KULeuven, ULiège, UHasselt, IMEC, VKI, VITO, WaterstofNet, TWEED.
- H<sub>2</sub>-HeatNet: A planification tool for the integration of hydrogen-based energy systems into urban district heating networks, 2022-2024, Innoviris: Joint R&D project. Partners: ULB, Sibelga.
- H<sub>2</sub>-GridTwin: A digital twin of a hydrogen-to-grid living lab, 2023-2025, ETF: Energy Transition Funds. Partners: ULB, Sibelga.

#### Available equipment/tools:

- Micro-gas turbine Turbec T100 (100 kWe)

### Main relevant publications

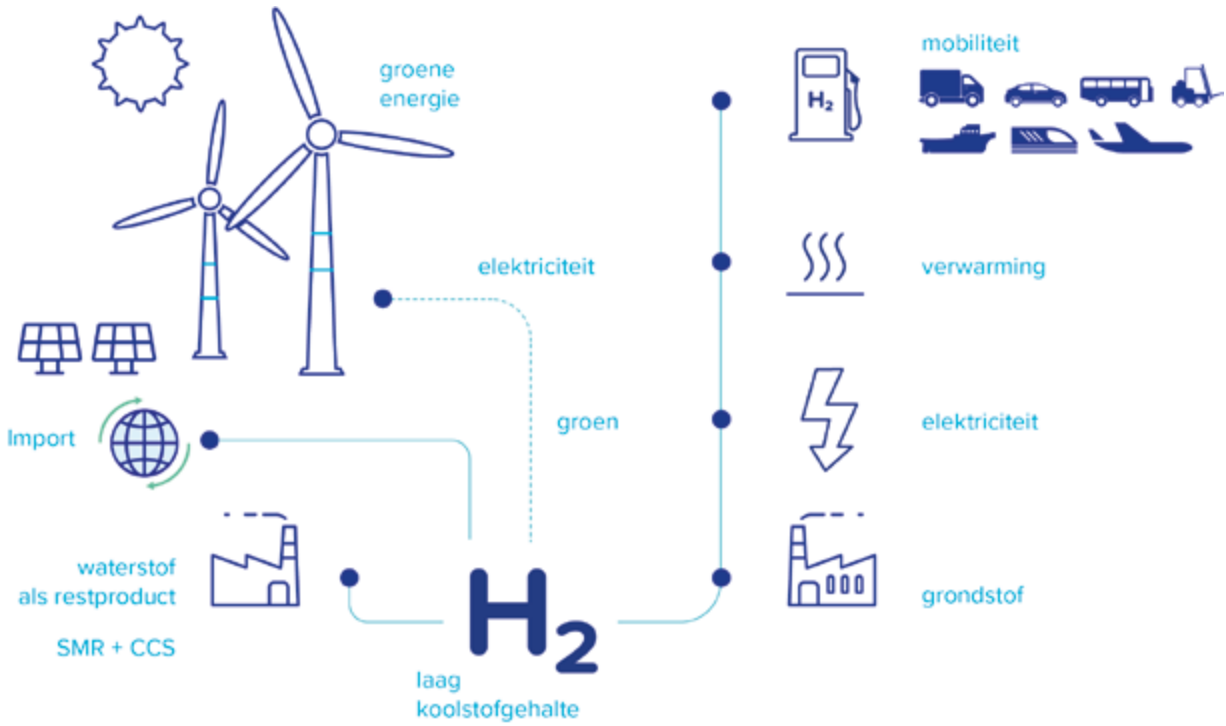
- Is Blue Hydrogen a Better Alternative Than Post-Combustion Carbon Capture for Combined Cycle Gas Turbines? A Thermodynamic Point of View, MJ Mendoza Morales, A Verhaeghe, L Bricteux, J Blondeau, W De Paepe, Turbo Expo: Power for Land, Sea, and Air 86946, V002T03A012, 2023.
- Large Eddy Simulation investigation of pressure and wall heat loss effects on rich ammonia-hydrogen-air combustion in a gas turbine burner. K Bioche, J Blondeau, L Bricteux. International Journal of Hydrogen Energy 47 (85), 36342-36353, 2022.
- Towards Zero-Carbon Emission Cogeneration Through Hydrogen Fueling: Assessment of the Impact of CH<sub>4</sub>/H<sub>2</sub> Blends on the Thermodynamic Performance of a Gas Turbine CHP Unit. MJ Mendoza Morales, J Blondeau, W De Paepe. International Conference on Applied Energy, 2022.
- Large Eddy Simulation of rich ammonia/hydrogen/air combustion in a gas turbine burner, K Bioche, L Bricteux, A Bertolino, A Parente, J Blondeau, International Journal of Hydrogen Energy 46 (79), 39548-39562, 2021.

### Contact persons:

Julien Blondeau, [Julien.blondeau@vub.be](mailto:Julien.blondeau@vub.be)  
0473/695.895.



### 3.2. Use of hydrogen



### 3.2.1. KU Leuven

## *Mechanical Engineering Department/LowCarb Research Group*

### KU Leuven, Faculty of Engineering Technology

#### General expertise of the research group:

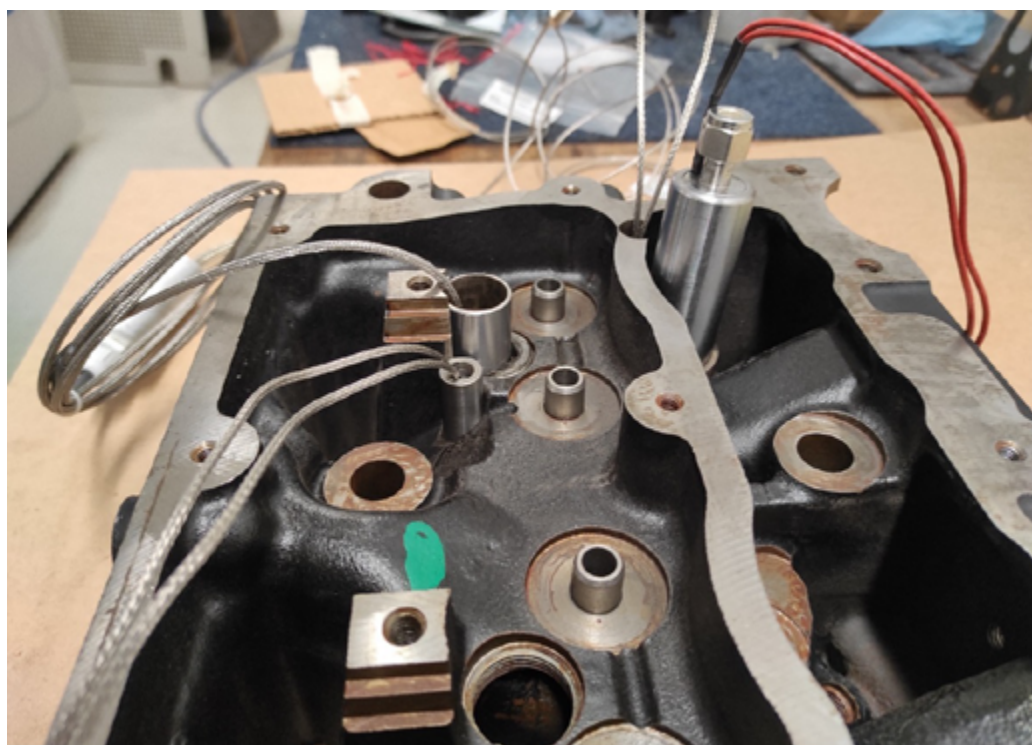
The LowCarb Research Group specializes in the decarbonization of transportation and power generation through the use of electrification and low- and zero-carbon alternative fuels. The group utilizes a variety of experimental and numerical methodologies to characterize the combustion of alternative fuels, and to evaluate the energy efficiency of novel powertrains and propulsion systems. There is significant experience within the group concerning hydrogen engine systems in particular, and more general expertise in the direct injection of gaseous fuels.

#### Specific hydrogen- related expertise & research topics:

- Use of hydrogen for heat and power
- Advanced direct injection strategies for hydrogen in reciprocating engines
- Abnormal combustion limit of hydrogen, hydrogen/natural gas blends
- Flexible oxy-fuel combustors with hydrogen-enrichment
- Combustion of zero carbon fuel blends (ammonia/hydrogen), in-situ cracking of ammonia for hydrogen-enhanced ammonia combustion
- Storage of intermittent, renewable energy using 'green' hydrogen injected into the natural gas network

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- BeHyFE (Belgian Hydrogen Fundamental Expertise) – targeting projects for PhD students involving all aspects of the hydrogen value chain (hydrogen production, storage/logistics and end-use), FOD ETF, knowledge institutions and universities throughout Belgium (12 total partners)
- ICO<sub>2</sub>CH (Integrated CO<sub>2</sub> Capture and Hydrogen Production) – novel reactor producing green hydrogen connected to oxy-fuel reciprocating engine valorising CO<sub>2</sub>/O<sub>2</sub> byproducts, VLAIO Moonshot, VITO/IMEC/VUB/KU Leuven
- Highly efficient and robust zero-carbon emission engines using directly-injected, spark-ignited hydrogen – conducting innovative engine experiments with directly-injected hydrogen, the capability to inject multiple times per cycle and direct measurements of wall heat flux, KU Leuven Internal Funds C3 project, KUL/VIVES Kortrijk/Eneria



Modified engine cylinder head with instrumentation for direct measurement of surface temperature and wall heat flux (small cylinder near the centre of the image) as well as a prototype direct injector for hydrogen (large cylindrical object in the top right of the image)

#### Available equipment/tools:

- 300 kW ABB DC dynamometer
- Engine test bed with suite of instrumentation (i.e. in-cylinder pressure transducers, etc.)
- CO<sub>2</sub> analyser with 0-100% volume range for oxy-fuel combustion testing
- High-speed tomographic particle image velocimetry (PIV) system
- Phase doppler anemometry (PDA) instrument for measurements of velocity and particle size
- Flexible 20 kW burner apparatus (premixed-swirl or diffusion flame modes)
- High-speed image-intensifier, Nikkor UV lens and visualization hardware
- Array of mass flow controllers to mix gases for air/partial oxy-fuel/full oxy-fuel combustion
- Electron impact ionization mass spectrometer for H<sub>2</sub> detection
- In-house LabVIEW-based combustion analysis software and commercial GT-Power software for combustion and powertrain simulation
- Vehicle powertrain and drive cycle simulation software via Argonne National Labs Autonomie

#### International collaborations:

- University of Melbourne Thermodynamics Laboratory
- Engine Combustion Network (ECN)

#### Main relevant publications:

- Joel Mortimer, Farzad Poursadegh, Michael Brear, Stephen Yoannidis, Joshua Lacey, Yi Yang, Extending the knock limits of hydrogen DI ICE using water injection, Fuel, 2022.
- M.R. Yosri, J.Z. Ho, M. Meulemans, M. Talei, R.L. Gordon, M.J. Brear, D. Cosby, J.S. Lacey, Large-eddy simulation of methane direct injection using the full injector geometry, Fuel, Volume 290, 2021.
- Zhewen Lu, Junqiu Jiang, Yi Yang, Joshua Lacey, Michael J. Brear, Hydrogen oxidation near the second explosion limit in a flow reactor, Proceedings of the Combustion Institute, 2020.
- Mortimer, J, Yoannidis, S, Poursadegh, F, Lu, Z, Brear, M, Yang, Y, Etherington, D, Heijkoop, M, & Lacey, J. "An Experimental and Numerical Study of a Hydrogen Fueled, Directly Injected, Heavy Duty Engine at Knock-Limited Conditions." Proceedings of the ASME 2020 Internal Combustion Engine Division Fall Technical Conference. ASME 2020 Internal Combustion Engine Division Fall Technical Conference. Virtual, Online. November 4–6, 2020. V001T01A002. ASME.

#### Contact persons:

Assistant Professor Joshua Lacey, M.S.E., Ph.D.

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Phone: +32 1632 1727

## Dept. Mechanical Engineering/ TME (M-Group)

KU Leuven - Bruges Campus, Faculty of Engineering Technology

### General expertise of the research group

The M-Group research team has a unique composition, including three departments - Mechanical Engineering, Electrical Engineering, and Computer Science. The primary focus of the M-Group is to investigate the reliability and dependability of highly automated interconnected mechatronic systems, where the TME@M-Group has a particular emphasis on unmanned aerial systems and hybrid hydrogen-based propulsion systems. The team consists of experts in various areas, including sensor networks and algorithms (Prof. H. Hallez), software dependability (Prof. J. Boydens), hardware and system safety (Prof. D. Pissoort), Artificial Intelligence and machine learning (Prof. M. Verbeke), H<sub>2</sub> based systems for drone applications (Prof. F. Buysschaert), and dependable lightweight structures for aeronautics (Prof. G. Serhat).

### Specific hydrogen- related expertise & research topics

- Dependable hybrid drone propulsion with fuel cells.

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- HYDE. Hydrogen technology for Defence applications, DEFRA Belspo. Partners: KU Leuven, VIVES Zuid, VIVES Noord, Solenco Power.
- H<sub>2</sub>-4-All. Fuel cell technologies for industry, VLAIO TETRA. Partners: VIVES-Zuid, KU Leuven, VIVES-Noord

### Available equipment/tools:

- Electronic loads
- FRA
- Fuel cells
- Modified Climate chambers, including mechanical stress (tension, pressure and shearing) and UV radiation
- Halt (Highly Accelerated lifetime testing)
- EMC test equipment (via FMEC, M-Group)



### Main relevant publications

- Mus, J., Vanhoutte, B., Schotte, S., Fevery, S., Latré, S., Kleemann, M., Buysschaert, F. (2022). Design and Characterisation of an Alkaline Electrolyser. In: 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), (253-259). Presented at the International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 18 Sep 2022-21 Sep 2022. ISBN: 978-1-6654-7140-4. doi: 10.1109/ICRERA55966.2022.9922902
- Mus, J., Mylle, S., Schotte, S., Fevery, S., Latré, S., Buysschaert, F. (2022). CFD Modelling and Simulation of PEMFCs in STAR-CCM+. In: 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), (260-267). Presented at the International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 18 Sep 2022-21 Oct 2022. ISBN: 978-1-6654-7140-4. doi: 10.1109/ICRERA55966.2022.9922908
- Buysschaert, F., Mus, J. (2022). Waterstof en drones. Presented at the Drone West 22, Ostend, Belgium. (professionally oriented)
- Buysschaert, F., Van Luchem, P. (2022). Hydrogen Tech Day - Workshop: Regulations. Presented at the Hydrogen Tech Day, Kortrijk, Belgium. (professionally oriented)
- Mus, J., Buysschaert, F. (2022). Modelling & Characterization of Electrochemical Energy Systems. Presented at the Chemical Research in Flanders - Chemistry Conference for Young Scientists (CRF-ChemCYS), Blankenberge, Belgium.
- Schotte, S., De Tollenaere, S., Buysschaert, F., Mus, J., Uytterhaegen, B., van luchem, P. (2020). H<sub>2</sub>-4-All presentation Fuel cell system. Presentation H<sub>2</sub>-4-All basics Fuel cells system.
- Buysschaert, F., Mus, J., De Tollenaere, S., Schotte, S., Van Luchem, P. (2021). Webinar: Hoe starten met toepassingen op waterstofgas?

### Contact persons:

- Frank Buysschaert ([frank.buysschaert@kuleuven.be](mailto:frank.buysschaert@kuleuven.be))
- Dries Vanoost ([dries.vanoost@kuleuven.be](mailto:dries.vanoost@kuleuven.be))

### 3.2.2. UGent

## Transport Technology

### Ghent University, Faculty of Engineering and Architecture

#### General expertise of the research group:

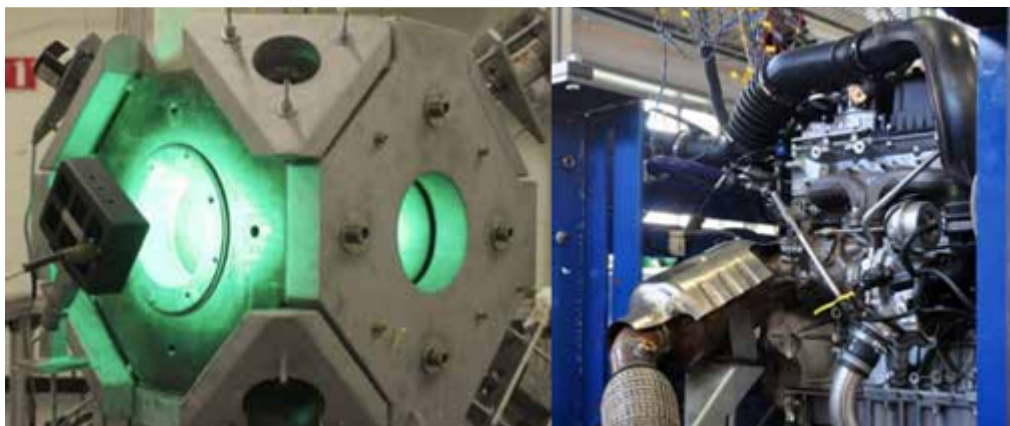
The research group Transport Technology at Ghent University is specialized in internal combustion engines operating on renewable fuels. The group's research is going from the heart of the engine: the in-cylinder processes (spray formation, combustion, heat transfer and emission formation), to the engine as part of a sustainable energy system (power-to-x, vehicle propulsion, ...). The group's vision is to enable the transition to sustainable transportation through finding the best engine and fuel for each application. Its mission is therefore to provide appropriate R&D tools to the research community and industry, training to students and researchers, and guidelines to policy makers.

#### Specific hydrogen- related expertise & research topics:

- Internal combustion engines (ICEs) on e-fuels, with the main expertise being on hydrogen and methanol
- Power, efficiency, emissions
- Simulations of ICE on e-fuels Available equipment/tools:
- 5 engine test benches, with dynamometer capability to 300 kW
- Combustion vessel with high-speed camera
- Gaseous emissions measurement (CO, CO<sub>2</sub>, NO<sub>x</sub>, O<sub>2</sub>)

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- FASTWATER (EU, 2020-2024, 1 PhD)
- BEST (National, 2020-2024, 1 PhD)
- PhD Baekeland (Flemish, 2020-2024, 1 PhD)
- CHyPS (Intercluster cSBO, 2022-2024, 1 PhD)
- MMU (VIL COOCK, 2021-2024, 1 PhD)
- See website: [research.ugent.be](https://research.ugent.be)



#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- Verhelst S., Sierens R., A quasi-dimensional model for the power cycle of a hydrogen fuelled ICE. *International Journal of Hydrogen Energy*, Vol. 32, pp. 3545-3554, October 2007
- Verhelst S., Wallner T., Hydrogen-Fueled Internal Combustion Engines. *Progress in Energy and Combustion Science*, Vol. 35, pp. 490-527, December 2009
- Verhelst S., Wallner T., Eichseder H., Naganuma K., Gerbig F., Boyer B., Tanno S., Electricity Powering Combustion: Hydrogen Engines, *Proceedings of the IEEE* Vol. 100, pp. 427-439, February 2012
- Vancoillie J., Demuynck J., Sileghem L., Van De Ginste M., Verhelst S., Comparison of the renewable transportation fuels, hydrogen and methanol formed from hydrogen, with gasoline - Engine efficiency study, *International Journal of Hydrogen Energy* Vol. 37, pp. 9914-9924
- Verhelst S., Recent progress in the use of hydrogen as a fuel for internal combustion engines, *International Journal of Hydrogen Energy*, invited paper, Vol. 39, pp. 1071-1085, January 2014
- Verhelst S., Demuynck J., Sierens R., Scarcelli R., Matthias N., Wallner T., Hydrogen-fueled internal combustion engines, in 'Renewable Hydrogen Technologies. Production, Purification, Storage, Applications and Safety', Chapter 16, pp381-400, edited by L.M. Gandía, G. Arzamendi, P.M. Diéguez, Elsevier, ISBN 978-0444563521
- Verhelst S., Wallner T., Hydrogen-fueled internal combustion engines, in 'Handbook of Hydrogen Energy', pp. 821-901, edited by S.A. Sherif, Y. Goswami, E. Stefanakos, A. Steinfeld; CRC/Taylor and Francis, ISBN 978-1420054477.

#### Contact persons:

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Hydrogen Platform Manager UGent  
T +32 496 63 16 01
- Prof. Sebastian Verhelst ([Sebastian.Verhelst@ugent.be](mailto:Sebastian.Verhelst@ugent.be))  
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T: +32 9 264 32 88

### 3.2.3. VIVES Hogeschool

## *Climate & Energy – research group hydrogen (Fuel Cell Systems)*

### VIVES University of Applied Sciences

#### General expertise of the research group

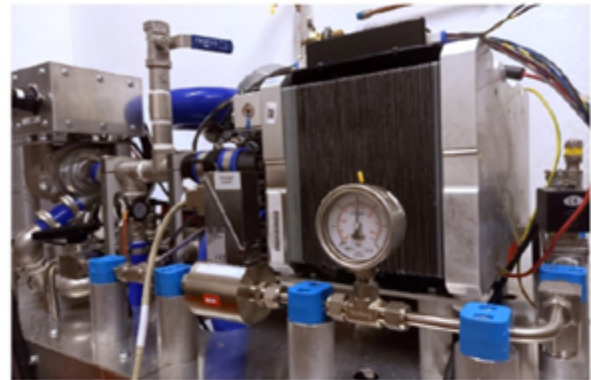
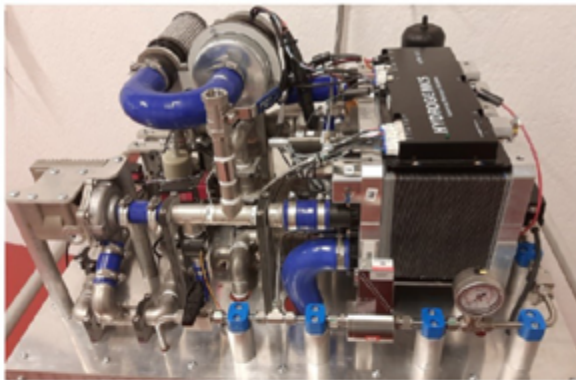
The research group hydrogen can rely on a fully equipped laboratory of the hydrogen energy chain. From production, up to the use of hydrogen in different applications. The group has gained expertise in practical use and implementation of various aspects, including green hydrogen production, hydrogen storage, regulatory aspects and safety considerations related to hydrogen, utilization of hydrogen as a fuel for internal combustion engines, hydrogen fuel cell systems, fuel cell vehicles, and the production and utilization of green methanol.

#### Specific hydrogen- related expertise & research topics

- Expertise in hydrogen PEM Fuel cell systems (small size), system design, control, and data acquisition
- Expertise in fuel cell vehicle technology, reverse engineering, system layout, and working principles
- Fuel cell system modelling, control, and implementation
- Fuel cell system testing

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- Project: H<sub>2</sub>-4-All – topic: H<sub>2</sub>-4-All is developing a testbed for fuel cell systems and consolidating regulations for hydrogen use in businesses.– funding source: Flemisch Tetra-project from VLAIO – project partners: KULeuven, Solenco Power, Agoria, EUKA, Eliet, Eoly, Addax motors, Atlas Copco, WaterstofNet, Bekaert, E-Bo enterprises, Geoxyz, Kaseco, Lieven Deneckere, Mol Cy, Vandaele machinery, Stad Kortrijk, Schneider Electric, Van Marcke, Robuust



#### Available equipment/tools:

- Slow filling station for FCEV
- Fuel cell system 8 kW
- Fuel cell system 6.8 kW
- Toyota Mirai
- 4W vehicle Test bench
- 2W vehicle Test bench
- Engine test bench water brake
- ZERT 002 H<sub>2</sub> KART 12.5 kW FC
- Didactical IX35 FCEV setup



### Main relevant publications

- Conference on Renewable Energy Research and Application (ICRERA), 2022, pp. 253-259, doi: 10.1109/ICRERA55966.2022.9922902.
- Buyschaert, F., Mus, J., De Tollenaere, S., Schotte, S., Van Luchem, P. (contr.) (2021). Webinar: Hoe starten met toepassingen op waterstofgas?
- Mus, J., Mylle, S., Schotte, S., Fevery, S., Latré, S., Buyschaert, F. (2022). CFD Modelling and Simulation of PEMFCs in STAR-CCM+. In: 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), (260-267). Presented at the International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey
- All – energy Australia, Melbourne 25/10/2023 Green hydrogen in Flanders

### Contact persons:

- Sam Schotte: [sam.schotte@vives.be](mailto:sam.schotte@vives.be)
- Steven De Tollenaere: [steven.detollenaere@vives.be](mailto:steven.detollenaere@vives.be)



## Climate & Energy – research group hydrogen (ICE)

### VIVES University of Applied Sciences

#### General expertise of the research group

The research group hydrogen can rely on a fully equipped laboratory of the hydrogen energy chain. From production, up to the use of hydrogen in different applications. The group has gained expertise in practical use and implementation of various aspects, including green hydrogen production, hydrogen storage, regulatory aspects and safety considerations related to hydrogen, utilization of hydrogen as a fuel for internal combustion engines, hydrogen fuel cell systems, fuel cell vehicles, and the production and utilization of green methanol.

#### Specific hydrogen- related expertise & research topics

- Expertise in **H<sub>2</sub>-ICE** technology (hydrogen internal combustion engine)
- In-house proficiency in dual fuel technology, particularly diesel-hydrogen systems, demonstrated with a 250 kVA generator set
- Specialization in converting petrol engines into 100% hydrogen combustion engines
- Specialized knowledge in low-level control management for dual fuel systems
- Proficient in control management, data acquisition, and visualization techniques

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- Project: ISHY (implementation of ship hybridisation) – topic: retrofit of an existing diesel genset 250 kVA to dual fuel mode (hydrogen and pilot diesel) – funding source: Europe Interreg 2 Seas - industrial partners: Port of Ostend, Parkwind, GeoXYZ, TU Delft, Solent University, Hybrid marine
- Project: Direct injection of hydrogen for ICE – topic: building a demonstrator for testing of direct injection of hydrogen and strategies – funding source: Industrial research Fund (IOF) Category 3 (C3) – project partners: In cooperation with KU Leuven





### Available equipment/tools:

- Genset Atlas Copco dual fuel diesel – hydrogen – methanol 250 kVA
- Genset Caterpillar Direct injection 33kVA
- Testbench with single cylinder experimental setup for PFI and DFI
- Resistive load bench 20 kW & 300 kW
- Engine test bench water brake

### International collaborations:

- TU Delft
- Solent University Southampton
- UPHF – Université Polytechnique Hauts-de-France
- NICE – Noordelijk Innovatielab Circulaire Economie
- BDI – Bretagne Développement Innovation

### Main relevant publications

- Conference on Renewable Energy Research and Application (ICRERA), 2022, pp. 253-259, doi: 10.1109/ICRERA55966.2022.9922902.
- De Wilde, B., Schotte, S. (contr.) (2022). Hogeschool VIVES opent nieuw waterstofcentrum VRT NWS.
- Buyschaert, F., Mus, J., De Tollenaere, S., Schotte, S., Van Luchem, P. (contr.) (2021). Webinar: Hoe starten met toepassingen op waterstofgas?
- Mus, J., Mylle, S., Schotte, S., Fevery, S., Latré, S., Buyschaert, F. (2022). CFD Modelling and Simulation of PEMFCs in STAR-CCM+. In: 2022 11th International Conference on Renewable Energy Research and Application (ICRERA), (260-267). Presented at the International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey
- All – Energy Australia, Melbourne 25/10/2023 Green hydrogen in Flanders

### Contact persons:

- Sam Schotte: [sam.schotte@vives.be](mailto:sam.schotte@vives.be)
- Steven De Tollenaere: [steven.detollenaere@vives.be](mailto:steven.detollenaere@vives.be)



# Climate & Energy – research group hydrogen green methanol

## VIVES University of Applied Sciences

### General expertise of the research group

The research group hydrogen can rely on a fully equipped laboratory of the hydrogen energy chain. From production, up to the use of hydrogen in different applications. The group has gained expertise in practical use and implementation of various aspects, including green hydrogen production, hydrogen storage, regulatory aspects and safety considerations related to hydrogen, utilization of hydrogen as a fuel for internal combustion engines, hydrogen fuel cell systems, fuel cell vehicles, and the production and utilization of green methanol.

### Specific hydrogen- related expertise & research topics

- expertise in green methanol production from CO<sub>2</sub> and H<sub>2</sub>
- expertise in green methanol utilization
- methanol combustion systems (dual-fuel, mono-fuel)
- methanol combustion characteristics, performance, etc.

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

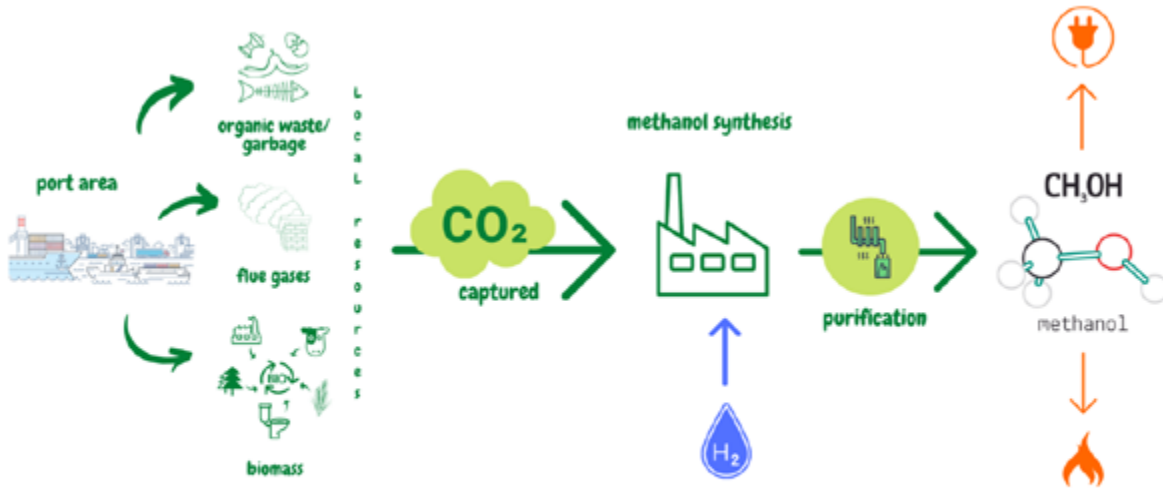
- Project: REDII ports: Renewable energy development an intelligent implementation in PORTS
  - topic: resource study and building of a CCU demonstrator for green methanol production and use in an internal combustion engine
  - funding source: European Interreg north sea region
  - project partners: Port of Skagen, Ports Niedersachsen, Korsør Havn, NICE, BDI, Port of Brest, Port of Brussels

### Available equipment/tools:

- Set-up methanol production from CO<sub>2</sub> and H<sub>2</sub>
- Genset Atlas Copco (250 kVA) on dual fuel technology (diesel – methanol)
- One-cylinder combustion engine on methanol
- Testbench with single cylinder experimental setup for PFI and DFI
- Resistive load bench 20 kW & 300 kW
- Engine test bench water brake

International collaborations:

- Assistant professor Atul Bansode and prof. Urakawa (TuDelft)



Pilot 2.6

REDII Ports

Interreg North Sea



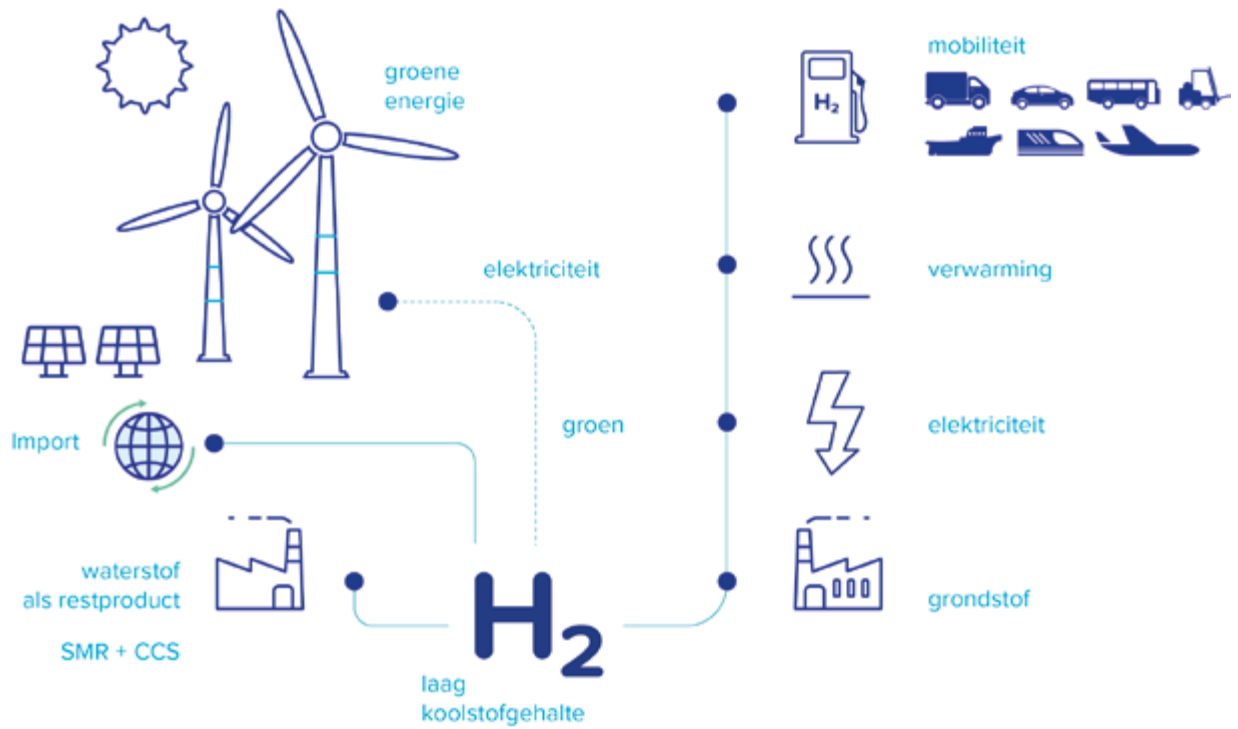
Co-funded by the European Union

Contact persons:

- Sam Schotte: [sam.schotte@vives.be](mailto:sam.schotte@vives.be)
- Steven De Tollenaere: [steven.detollenaere@vives.be](mailto:steven.detollenaere@vives.be)



### 3.3. Hydrogen general topics



### 3.3.1. KU Leuven

## *Department of Mechanical Engineering/ Energy Systems Integration and Modelling (ESIM) Research Group*

### KU Leuven, Faculty of Engineering Science

#### General expertise of the research group

Research focus and expertise is on quantitative tools, supporting an efficient operation of, and transition towards, a low-carbon energy system (mathematical modelling of energy systems). A major strength of the group is its interdisciplinary focus (techno-economic models considering multiple energy vectors, link to energy markets and policies). Modelling focus is on unit commitment models, generation expansion planning models, equilibrium models and agent-based models. Applications relate to flexibility through energy systems integration, market design, renewables support mechanisms and emission trading.

#### Specific hydrogen- related expertise & research topics

- Integrated energy systems modelling
  - Including natural gas networks
  - Long term (seasonal) storage modelling
  - Interactions between electricity and gas sector
- Policy impact assessment
  - Interaction with, e.g., emission trading systems (EU ETS)

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- 2020-2025 PROCURA - Power to X and Carbon Capture & Utilization Roadmap for Belgium – Energy Transition Fund Belgium

#### International collaborations:

- Hydrogen workgroup in EERA Joint Program on Energy Systems Integration

### Main relevant publications

- Mertens, T., Bruninx, K., Duerinck, J., Delarue, E. (2021). Capacity credit of storage in long-term planning models and capacity markets. *Electric Power Systems Research*, 194, Art.No. 107070.
- Belderbos, A., Bruninx, K., Delarue, E., D'haeseleer, W. (2020). Facilitating renewables and power-to-gas via integrated electrical power-gas system scheduling. *Applied Energy*, 275, Art.No. 115082.
- Belderbos, A., D'haeseleer, W. (sup.), Delarue, E. (cosup.) (2019). Storage via Power-to-Gas in Future Energy Systems: The Need for Synthetic Fuel Storage in Systems with High Shares of Intermittent Renewables. PhD Thesis, KU Leuven, Leuven, Belgium.
- Belderbos, A., Delarue, E., Kessels, K., D'haeseleer, W. (2017). Levelized Cost of Storage - Introducing Novel Metrics. *Energy Economics*, 67, pp. 287-299.
- Belderbos, A., Virag, A., D'haeseleer, W., Delarue, E. (2017). Considerations on the need for electricity storage requirements: Power versus energy. *Energy Conversion and Management*, 143, 137-149.
- Vandewalle, J., D'haeseleer, W. (supervisor) (2014). Natural Gas in the Energy Transition - Technical challenges and opportunities of natural gas and its infrastructure as a flexibility-providing resource. PhD Thesis, KU Leuven, Leuven, Belgium.
- Vandewalle, J., Bruninx, K., D'haeseleer, W., 2015. Effects of large-scale power to gas conversion on the power, gas and carbon sectors and their interactions. *Energy Conversion and Management*, vol. 94, pp 28-39.

### Available equipment/tools:

- Optimization models for the operation of energy systems (e.g., using Mixed Integer Linear Programming - MILP).
- Optimization models for energy planning and scenario analyses.
- Equilibrium models describing the interactions of various (market) actors in the liberalized electric power sector (e.g., consumers, generators, system operators).
- Agent-based models to describe the electricity system as a complex adaptive system. This modelling approach captures the complex interactions among the physical infrastructure, the actors' behaviour, and the institutions that govern those behaviours in an energy system.
- All of the above can be combined with various policy instruments.

### Contact persons:

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- Erik Delarue [erik.delarue@kuleuven.be](mailto:erik.delarue@kuleuven.be)
- William D'haeseleer [william.dhaeseleer@kuleuven.be](mailto:william.dhaeseleer@kuleuven.be)

## *Dept. Materials Engineering/ Surface and Interface Engineered Materials (New Materials / iR)*

### KU Leuven – Bruges, Faculty of Materials Engineering

#### General expertise of the research group

The New Materials / iR group at KU Leuven – Brugge concentrates on the experimental development, using chemical synthesis methods and interface modification techniques, and characterization of novel functional (polymer) materials for sustainable solutions in various applications.

#### Specific hydrogen- related expertise & research topics

- Material surface area characterization by gas adsorption techniques
- Underground hydrogen gas storage in rock salt caverns
- Polymer membrane development
- Characterization of degradation of polymer membranes
- Electrochemistry

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- HYDE: Hydrogen technology for Defence applications, DEFRA Belspo. Partners: KU Leuven, VIVES Zuid, VIVES Noord, Solenco Power

#### Available equipment/tools:

- Electrochemical equipment (Metrohm Autolab potentiostat/galvanostat with impedance station and NOVA2 software)
- Electrosynthesis equipment (ElectraSyn)
- Automated film applicator
- Spin coater, dip coater, spray coater
- Fumehoods and chemical synthesis equipment, autoclaves, ovens, centrifuge, etc
- Ultrasonic probe
- Tube furnace
- Ion chromatograph
- Viscometer
- Pull-off adhesion tester



### Main relevant publications

- Madhav, D., Shao, C., Mus, J., Buyschaert, F., Vandeginste, V. (2023). The effect of salty environments on the degradation behaviour and mechanical properties of Nafion membranes. *Energies*, 16(5), Art.No. 2256. doi:10.3390/en16052256
- Vandeginste, V., Ji, Y., Buyschaert, F., Anoyatis, G. (2023). Mineralogy, microstructures and geomechanics of rock salt for underground gas storage. *Deep Underground Science and Engineering*, 2 (2), 129-147. doi.org/10.1002/dug2.12039
- Xie, W., Wang, M., Vandeginste, V., Chen, S., Yu, Z., Wang, J., Wang, H., Gan, H. (2022). Adsorption behavior and mechanism of CO<sub>2</sub> in the Longmaxi shale gas reservoir. *RSC ADVANCES*, 12 (40), 25947-25954.
- Martin-Clave, C., Ougier-Simonin, A., Vandeginste, V. (2021). Impact of second phase content on rock salt rheological behaviour under cyclic mechanical conditions. *Rock Mechanics and Rock Engineering*, 54, 5245-5267.

### Contact persons:

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### 3.3.2. OCAS

## *Metallurgy department*

### OCAS, R&D Centre

#### General expertise of the research group

Applied research and development of materials. Supported by a state-of-the-art lab, OCAS can perform decent metallurgical investigations and testing of materials in different environments with the ability to closely represent the operational circumstances. Solving questions of customers about material compatibility considering degradation, design life and safety aspects. Ranking of candidate materials, material selection and risk mitigation.

#### Specific hydrogen- related expertise & research topics

- Applied R&D on the interaction between hydrogen and materials.
- Thorough knowledge and understanding of the metallurgical phenomena.
- Testing, standard and non-standard test equipment, for determination and understanding of the effect of hydrogen on the material performance under specific conditions and w/o loading: unloaded, static or dynamic loading.
- Determination of the behaviour of a material in an environment with presence of hydrogen at certain operating conditions.
- Modelling of interaction between hydrogen and materials by empirical testing and numerical simulations. Models to optimise production processes, maintenance schedules and prediction of material/component lifetime in a hydrogen environment.
- Failure analysis. During such an analysis, investigation tries to clarify material damage, component failure due to hydrogen-related degradation mechanisms. Expertise on damage triggers such as hydrogen embrittlement and hydrogen induced cracking
- Material compatibility concerns. Advise on material selection, material degradation, corrosion and coating related to hydrogen. This advice may result in a dedicated material program that demonstrates material compatibility with respect to a certain goal. Notified bodies can be involved in such examinations
- Hydrogen testing in sour environment (OCAS dedicated H<sub>2</sub>S lab, NACE testing, qualification)
- National and international exchange on R&D, organisation of a series of international conferences Steelyhydrogen – 5th edition to be defined





#### Available equipment/tools:

All analytical equipment for measuring hydrogen content, in and through materials. OCAS is accredited for a series of analyses and qualified to work with deuterium.

- Equipment for charging: electrolytical or autoclave
- Equipment for H determination (hot and melt extraction)
- Equipment for H diffusion and permeation
- Thermal desorption
- Equipment for Microstructural investigation

#### Mechanical testing:

- Constant load
- Slow and high strain rate testing
- Disc rupture testing
- Fracture mechanics
- Fatigue testing

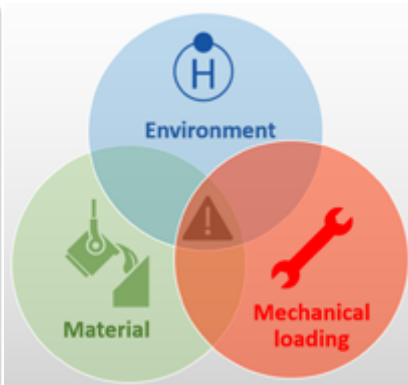
#### Equipment for NACE testing (H<sub>2</sub>S)

#### International collaborations:

OCAS mainly works on a bilateral agreement between national or international customers. Different extends are possible, from a single measurement up to a dedicated research program. OCAS aims to accelerate the R&D at the customer, giving support by sharing competences and specific equipment.

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- Open to collaborate in funded projects
- FORGE - Development of novel coating materials for a sustainable future (Evaluation of hydrogen pick up and hydrogen embrittlement) - H2020-NMBP-ST-IND-2018-2020.
- HYDRO-REAL - Study the sensitivity of ultra-high strength cold rolled steels to hydrogen embrittlement - RFCS-02-2019
- INiTiAl - Advanced implementation of novel corrosion resistant high strength maraging steels with improved process robustness via tuned intermetallic nano-precipitation - RFCS-02-2017
- Charge & Load - Hydrogen embrittlement and delayed fracture of advanced multiphase highstrength steels - RFSR-CT-2006-00025
- HYDRAMICROS - Hydrogen sensitivity of different advanced high strength microstructures – RFSRCT - 2010-00020
- SUPERHIGH - In-use properties of Super High strength steels generated by a range of metallurgical strategies RFCS-PR-12161
- NOHENTRY - Reuse of existing pipeline systems for H<sub>2</sub> transport via surface functionalisations inhibiting Hydrogen entry - ETF 2021
- SAFEH2PIPE - Guidelines for material selection and qualification for safe transportation of H<sub>2</sub>-NG mixtures in EU pipelines - RFCS 2022
- HYWAY - Multiscale Characterisation and Simulation for Hydrogen Embrittlement Assessment: Development of an Open Knowledge Platform to Foster Capability Integration - HORIZON-CL4-2023
- PILGRHYM - Pre-normative research on integrity assessment protocols of gas pipes repurposed to Hydrogen and mitigation guidelines - HORIZON-JTI-CLEANH2-2023
- FEATHER - Steel For nExt generATion H<sub>2</sub> cylindERs - RFCS 2022



### Main relevant publications

- Investigation of hydrogen trapping in retained austenite via deuterium charging at high temperature. L Moli-Sanchez, Z Zermout, L Duprez. Proceedings 3rd International Conference on Metals and Hydrogen, May 2018, Ghent, Belgium
- Hydrogen embrittlement of 4 martensitic steels with strength levels above 1000 MPa. L. Moli-Sanchez, Z. Zermout, L. Duprez, L. Malet. (Proceedings SteelyHydrogen 2014)
- Effect of in-situ hydrogen charging on the mechanical properties of advanced high strength steels. T. Depover, D. Pérez Escobar, E. Wallaert, Z. Zermout. International Journal of Hydrogen Energy. Vol. 39 (2014) pp. 4647–4656
- Hydrogen embrittlement in various steels with strength levels above 1000 MPa. L Duprez, M Arafin, F Van den Abeele, N Bernier. Joint HYDROGENIUS and I2CNER International Workshop on Hydrogen - Materials Interactions 2012 Kyushu University
- Combined thermal desorption spectroscopy, differential scanning calorimetry, scanning electron microscopy and X-ray diffraction study of hydrogen trapping in cold deformed TRIP steel. D. Perez Escobar, T. Depover, L Duprez, K. Verbeken and M. Verhaege. (2012) ACTA MATERIALIA. 60(6-7). p.2593-2605
- Thermal desorption spectroscopy study of the interaction between hydrogen and different microstructural constituents in lab cast Fe-C alloys. D. Pérez Escobar, T. Depover, E. Wallaert, L. Duprez, M. Verhaege, K. Verbeken. Corrosion Science. Vol. 65 (2012) pp. 199-208
- Evaluation of hydrogen trapping in high strength steels by thermal desorption spectroscopy. D. Perez Escobar, K Verbeken, L Duprez, M Verhaege (2012) MATERIALS SCIENCE AND ENGINEERING A-STRUCTURAL MATERIALS PROPERTIES MICROSTRUCTURE AND PROCESSING. 551. p.50-58
- Internal and surface damage of multiphase steels and pure iron after electrochemical hydrogen charging. D Perez Escobar, C Minambres, L Duprez, K Verbeken, M Verhaege (2011) CORROSION SCIENCE. 53(10). p.3166-3176
- Selecting hydrogen embrittlement resistant materials by means of the disc rupture test. Elke Leunis, Lode Duprez. 18th World Hydrogen Energy Conference 2010, Essen / Germany

### Contact persons:

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- [Philippe.thibaux@ocas.technology](mailto:Philippe.thibaux@ocas.technology)



## Department applications and solutions

### OCAS, R&D Centre

#### General expertise of the research group

Applied research and development of materials. Supported by a state-of-the-art lab, OCAS can perform decent metallurgical investigations and testing of materials in different environments with the ability to closely represent the operational circumstances. Solving questions of customers about material compatibility considering degradation, design life and safety aspects. Ranking of candidate materials, material selection and risk mitigation.

#### Specific hydrogen- related expertise & research topics

- Applied R&D on the interaction between hydrogen and materials.
- Thorough knowledge and understanding of the metallurgical phenomena.
- Testing, standard and non-standard test equipment, for determination and understanding of the effect of hydrogen on the material performance under specific conditions and w/o loading: unloaded, static or dynamic loading.
- Determination of the behaviour of a material in an environment with presence of hydrogen at certain operating conditions.
- Modelling of interaction between hydrogen and materials by empirical testing and numerical simulations. Models to optimise production processes, maintenance schedules and prediction of material/component lifetime in a hydrogen environment.
- OCAS differentiates by focussing on large scale testing, test setups that cannot be performed in normal-sized labs, considering real operating conditions and safety aspects of the bigger industrial installations and infrastructure.
- Building of specific test equipment for testing under high pressure (including hydrogen, pure or blend) exposing materials and/or components. This service comprises the design and assembly of tailor-made test rigs for multipurpose i.e. focussing on a specific component of which the fitness-for-purpose of the design is assessed with respect to a certain application, operating conditions and safety aspects.
- Assessment of pass / fail criteria on re-purposing assets such as pipelines and pressure vessels towards using hydrogen as transport or storage medium.
- Acceptance testing on fit for use aspects of seals (threaded metal-to-metal and other) in combination with different mixtures of hydrogen towards transmission, storage and end-use applications (e.g. downhole, pipeline, pressure vessel, gas bottle, connections, ... )

### Available equipment/tools:

All analytical equipment for measuring hydrogen content, in and through materials. OCAS is accredited for a series of analyses and qualified to work with deuterium.

- See equipment as specified in section Metallurgy
- Specialised software and modelling tools
- Upscale fatigue bench for large scale components or structures
- Heavy testing bench with possibilities for external and internal loading (installed in pressure pit)
- New to build, tailor-made test rigs for customer dedicated

### International collaborations:

OCAS mainly works on a bilateral agreement between national or international customers. Different extends are possible, from a single measurement up to a dedicated research program. OCAS aims to accelerate the R&D at the customer, giving support by sharing competences and specific equipment.

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- Open to collaborate in funded projects
- HYWAY - Multiscale Characterisation and Simulation for Hydrogen Embrittlement Assessment: Development of an Open Knowledge Platform to Foster Capability Integration - HORIZON-CL4-2023



### Main relevant publications

See an excerpt of OCAS publications in section Metallurgy

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## Department of surface engineering

### OCAS, R&D Centre

#### General expertise of the research group

At the department of surface engineering, OCAS focusses on applied research and development concerning surface preparation, coating processes, morphologies, and other surface aspects such as corrosion. Supported by a state-of-the-art lab, OCAS can perform a full characterisation of surfaces besides several tools for testing surface properties and performing surface exposure and accelerated degradation tests. On the semi-industrial plating line (electrodeposition), OCAS can make samples for customers and assist in projects looking to, e.g.: alternative electrolytes, optimisation of process parameters or improvement of coating morphology including all related analyses thereof.

#### Specific hydrogen- related expertise & research topics

- Applied R&D on the interaction between hydrogen and materials.
- Thorough knowledge and understanding of the metallurgical phenomena.
- Modelling of interaction at the interface of hydrogen and substrate material: diffusion, adsorption kinetics, saturation.
- Numerical simulations for prediction of lifetime in a hydrogen environment.
- Coatings for H-barriers
- Corrosion testing in hydrogen related circumstances
- Hydrogen ingress during electrochemical coating processes (Process simulations on electroplating pilot line: <https://vimeo.com/458463355>)
- Hydrogen effusion from substrate materials during degassing
- Enamelling and hydrogen-related issues (fish scale)

#### Available equipment/tools:

All analytical equipment for measuring hydrogen content, in and through materials. OCAS is accredited for this analysis and qualified to work with deuterium.

- See equipment as specified in section Metallurgy
- State of the art lab for surface characterisation
- Techniques for appearance, roughness, hardness, 2D/3D-topography, ...

#### International collaborations:

OCAS mainly works on a bilateral agreement between national or international customers. Different extends are possible, from a single measurement up to a dedicated research program. OCAS aims to accelerate the R&D at the customer, giving support by sharing competences and specific equipment.



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development

General

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#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- Open to collaborate in funded projects
- **FORGE** - Development of novel coating materials for a sustainable future (Evaluation of hydrogen pick up and hydrogen embrittlement) - H2020-NMBP-ST-IND-2018-2020.
- **NOHENTRY** - Reuse of existing pipeline systems for H<sub>2</sub> transport via surface functionalisations inhibiting Hydrogen entry - ETF 2021

#### Main relevant publications

See an excerpt of OCAS publications in section Metallurgy

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### 3.3.3. UGent

## *Center for Microbial Ecology and Technology*

### Ghent University, Faculty of Biosciences Engineering

#### General expertise of the research group:

The Center for Microbial Ecology and Technology (CMET) is a part of the Faculty of Bioscience Engineering at Ghent University. CMET is specialized in the study and application of mixed microbial cultures or communities and the development of technology in a context of wastewater treatment, bioproduction and others. CMET researchers focus on the one hand on the optimal management of microbial resources, on the other hand (supporting) technologies such as (bio)electrochemical systems and monitoring systems are under development.

#### Specific hydrogen- related expertise & research topics:

- Applied Microbial Ecology
- Microbial Monitoring
- Microbial CO<sub>2</sub> conversions
- H<sub>2</sub> upgrading
- Hydrogen driven microbiological processes: Exploring possibilities of the microbial hydrogen metabolism to produce microbial protein (feed and food for the future), to bioremediate pollutants in (waste)water, to remove nutrients for the enhancement of drinking water biostability, ...

#### Available equipment/tools:

- (Online) microbial analysis, based on single cell and molecular principles
- Bacterial isolation, cultivation, characterisation and ecosystem assembly
- (Bio)Reactor systems
- Pilot scale systems
- Biomass synthesis
- Standard chemical analysis (GC, IC, HPLC, ...)

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- CO2Perate
- Baekelandt project
- FWO-SB and HEC scholarship on high-rate hydrogen-driven bioprocess for CO<sub>2</sub> bioconversions
- H2020 project Electra
- FWO-SB & SBO project Biostable on drinking water stability
- SBO project MicroDetox on micropollutant removal
- See website: [research.ugent.be](http://research.ugent.be)

### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- De Vrieze J, Verbeeck K, Pikaar I, Boere J, Van Wijk A, Rabaey K, et al. The hydrogen gas bio-based economy and the production of renewable building block chemicals, food and energy. *NEW BIOTECHNOLOGY*. 2020;55:12–8.
- Barbosa RG, van Veelen HPJ, Pinheiro V, Sleutels T, Verstraete W, Boon N. 2021. Enrichment of Hydrogen-Oxidizing Bacteria from High-Temperature and High-Salinity Environments. *Applied and Environmental Microbiology* 87.(Impact factor: 4,016; Quantile: Q1)
- PrévotEAU A, Carvajal-Arroyo J, Ganigué R, Rabaey K (2020) Microbial electrosynthesis from CO<sub>2</sub>: forever a promise? *CURRENT OPINION IN BIOTECHNOLOGY*, 62, 48-57. IF 2019: 8.288;
- Hu XN, Kerckhof FM, Ghesquiere J, Bernaerts K, Boeckx P, Clauwaert P, Boon N. 2020. Microbial Protein out of Thin Air: Fixation of Nitrogen Gas by an Autotrophic Hydrogen-Oxidizing Bacterial Enrichment. *Environmental Science & Technology* 54:3609-3617.(Impact factor: 7,149; Quantile: Q1)
- Barbosa RG, Sleutels T, Verstraete W, Boon N. 2020. Hydrogen oxidizing bacteria are capable of removing orthophosphate to ultra-low concentrations in a fed batch reactor configuration. *Bioresource Technology* 311.(Impact factor: 6,669; Quantile: Q1)
- Ehsani E, Dumolin C, Arends JBA, Kerckhof FM, Hu XN, Vandamme P, Boon N. 2019. Enriched hydrogen-oxidizing microbiomes show a high diversity of co-existing hydrogen-oxidizing bacteria. *Applied Microbiology and Biotechnology* 103:8241-8253.(Impact factor: 3,67; Quantile: Q2)
- Ramio-Pujol S, Ganigué R, Baneras LI, Colprim J (2018) Effect of ethanol and butanol on autotrophic growth of model homoacetogens. *FEMS MICROBIOLOGY LETTERS*, 365 (10), fny084. IF 2017: 1.735;
- Puig S, Ganigué R, Batlle-Vilanova P, Balaguer MD, Bañeras LI, Colprim J (2017) Tracking biohydrogen-mediated production of commodity chemicals from carbon dioxide and renewable electricity. *BIORESOURTE TECHNOLOGY*. 228, 201 - 209. IF 2017 : 5.807;
- Matassa S, Verstraete W, Pikaar I, Boon N. 2016. Autotrophic nitrogen assimilation and carbon capture for microbial protein production by a novel enrichment of hydrogen-oxidizing bacteria. *Water Research* 101:137-146.(Impact factor: 5,528; Quantile: Q1)
- Matassa S, Boon N, Verstraete W. 2015. Resource recovery from used water: The manufacturing abilities of hydrogen-oxidizing bacteria. *Water Research* 68:467-478.(Impact factor: 5,323; Quantile: Q1)
- Hosseinkhani B, Hennebel T, Van Nevel S, Verschuere S, Yakimov MM, Cappello S, Blaghen M, Boon N. 2014. Biogenic Nanopalladium Based Remediation of Chlorinated Hydrocarbons in Marine Environments. *Environmental Science & Technology* 48:550-557.(Impact factor: 5,481; Quantile: Q1)

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- Prof. Ramon Ganigué ([Ramon.Ganigue@ugent.be](mailto:Ramon.Ganigue@ugent.be))  
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## Centre of environmental & energy law

### Ghent University, Faculty of Law Criminology

#### General expertise of the research group:

Energy Law is the part of the law that regulates the human acting dealing with production/exploitation, transports an use of energy. The contemporary Energy Law is very recent. Especially the European liberalisation and Climate change have led to a juridification of the traditional technical approach of “the energy business” and to an appearance of Energy law.

Energy Law is extremely technical and complex, fast evolving Law Branch.

The Centre for Environmental and Energy Law has built a specific expert’s centre regarding Energy Law. This unit works within Ghent University together to bound research, valorization and cooperation with other research groups of Energy Law.

#### Specific hydrogen- related expertise & research topics:

- The division of competence in the field of hydrogen and green molecules;
- Certification of hydrogen and green molecules

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- See website: [research.ugent.be](http://research.ugent.be)

#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- Vandendriessche F, Claeys P. “Target setting” in het Europese energie- en klimaatbeleid : het “Clean Energy Package.” TIJDSCHRIFT VOOR MILIEURECHT. 2019;(3):262–83.
- Maes T, Van Eetvelde G, De Ras E, Block C, Pisman A, Verhofstede B, et al. Energy management on industrial parks in Flanders. RENEWABLE & SUSTAINABLE ENERGY REVIEWS. 2011;15(4):1988–2005.

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# Ghent Institute for International Studies / Centre for Sustainable Development

## Ghent University, Faculty of Political & Social Sciences

### General expertise of the research group:

GIIS is conducting research into six distinctive research areas in two overarching domains: security & foreign policy, and the development of the multilateral system.

At CDO, scientific researchers from different disciplines (political scientists, economists, educational scientists, (bio)engineers, sociologists, environmentalists, physicists, urban planners, etc.) work together to conduct research on sustainable development. Taking sustainable development in its multiple dimensions (economic, social, physical-ecological, institutional and ethical) as a guiding – though not determining – perspective, interdisciplinarity and transdisciplinarity are key aspects of research conducted at CDO.

### Specific hydrogen- related expertise & research topics:

- Geopolitics and international governance of H<sub>2</sub>
- political analysis, socio-technical system innovation, governance of transitions such as the transition of the energy-intensive industry

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- See website: [research.ugent.be](http://research.ugent.be)

### International collaborations:

- International Renewable Energy Agency (IRENA) – geopolitics of the hydrogen economy

The politics of the circular economy



Sustainable Cities



Science, Technology and Politics



Indicators, Assessments and Monitoring



Sustainability Education



Transitions and Future Studies



#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- Van de Graaf, T., Overland, I., Scholten, D., & Westphal, K. (2020). The new oil? The geopolitics and international governance of hydrogen. *Energy Research & Social Science*, 70, 101667.
- Van de Graaf, T. (2021). The Next Prize: Geopolitical Stakes in the Clean Hydrogen Race. In *Oxford Energy Forum* (No. 126, pp. 30-34).

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## Mechanical Construction - Soete Laboratory

### Ghent University, Faculty of Engineering and Architecture

#### General expertise of the research group:

At Soete Laboratory, we are pushing the boundaries in fracture mechanics and tribology. As researchers we are active in both experimental and numerical research on fatigue, fracture, friction, wear, reliability and durability of machine parts and mechanical constructions.

Within Soete Laboratory, the fatigue & fracture mechanics research group is headed by Prof. Wim De Waele and Prof. Stijn Hertelé. The activities of the group can be divided into three topics: Fatigue lifetime analysis, joining and additive manufacturing (Prof. De Waele) and quasi-static fracture and damage mechanics (Prof. Hertelé).

#### Specific hydrogen- related expertise & research topics:

- Effects of hydrogen on mechanical properties of steel (embrittlement), mostly in a transport/storage context (pipelines)
- Effect of hydrogen on accelerated rolling contact fatigue failure of roller bearings

#### Available equipment/tools:

- Universal test rigs for small- and large-scale mechanical testing (up to 8 MN)
- In-house test procedures for advanced mechanical testing (e.g. low-constraint fracture toughness testing)
- Development of material models involving hydrogen diffusion, hydrogen assisted degradation and resulting material damage

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- FWO research project on hydrogen embrittlement
- SIM SBO MaSiWEC
- See website: [research.ugent.be](http://research.ugent.be)



#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- Depover T, Hertelé S, Verbeken K. The effect of hydrostatic stress on the hydrogen induced mechanical degradation of dual phase steel : a combined experimental and numerical approach. ENGINEERING FRACTURE MECHANICS. 2019;221.

#### Contact persons:

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## Sustainable Materials Science

### Ghent University, Faculty of Engineering and Architecture

#### General expertise of the research group:

The research group Sustainable Materials Science is part of the Department of Materials, Textiles and Chemical Engineering (MaTCh) and has a large amount of experimental and characterization facilities at its disposal. Experimental work is complemented with simulations and modelling efforts. Main research expertise is the study of the interaction of metallic materials with hydrogen and how hydrogen impacts the performance of these metals. Apart the work on hydrogen induced degradation, the groups also study the degradation of metals resulting from interaction with their environment (corrosion processes) and high-temperature metallurgical processes (pyrometallurgy)

#### Specific hydrogen- related expertise & research topics:

The research group has internationally recognized expertise in generating high impact research based on developing experimental methodologies related to hydrogen embrittlement which are going beyond the state-of-the-art. The strategy is to design innovative experimental set-ups e.g. by combining different sets of equipment, while keeping in mind the very specific nature of hydrogen/microstructure interaction such as the low hydrogen solubility and high hydrogen diffusivity in BCC-steel, whereas hydrogen has a high solubility and low diffusivity in FCC-alloys. For the moment 10 PhD students and two postdocs are working on hydrogen related research topics.

Specific research topics are focusing on the interaction of hydrogen with amongst others wire steels, pipeline steels, bearings, additive manufactured alloys, titanium, tungsten, duplex stainless steels, austenitic stainless steel, automotive steel grades (first, second and third generation advanced high strength steels). Both fundamental and application-oriented aspects are highlighted.

The group has a vast amount of knowledge on high-end material characterization techniques, alloy development and offers an in-depth understanding and expertise on all metallurgical phenomena.

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

For the moment, 10 PhD students and 2 postdocs are working on hydrogen related research. Topics include the interaction of hydrogen with amongst others pipeline steels, bearing steels, additive manufactured alloys, titanium, wire steels, duplex stainless steels, austenitic stainless steel, automotive steel grades (first, second and third generation advanced high strength steels). This work is funded by a wide variety of funding schemes including FWO, SIM, UGent, Vlaio and EU funding

See also website: [research.ugent.be](http://research.ugent.be)

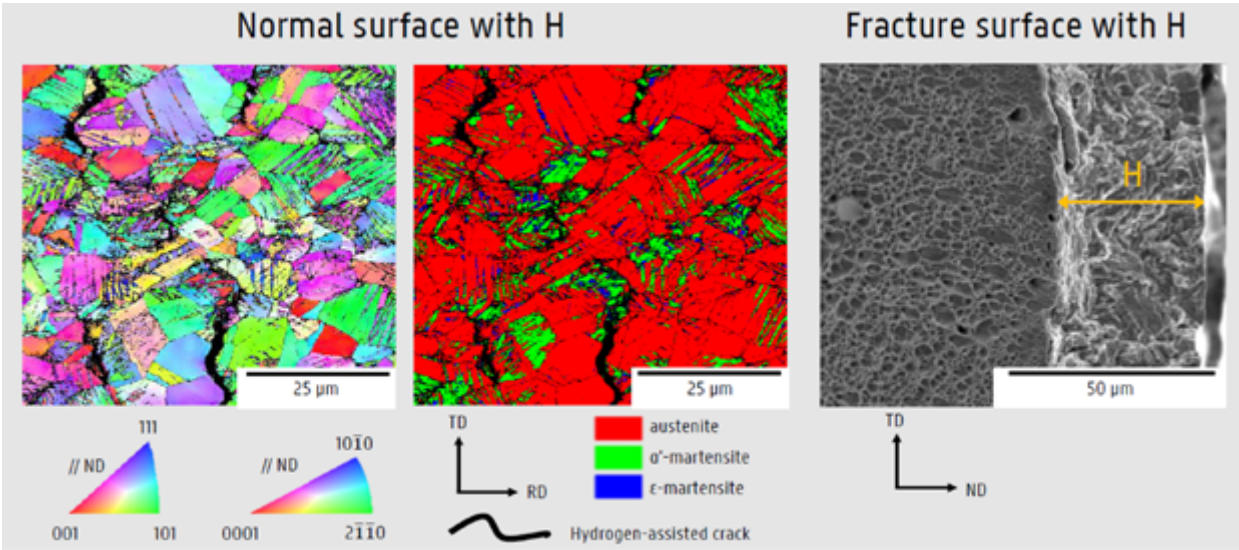
Available equipment/tools:

- thermal desorption spectroscopy
- various equipment and set-ups for electrochemical hydrogen charging and gaseous hydrogen charging via autoclaves
- electrochemical hydrogen permeation, incl. applying mechanical load during permeation test demonstrating effect of mechanical load on hydrogen diffusion coefficient
- diffusion based models
- hot and melt extraction to determine hydrogen content of metal
- various set-ups for in-situ mechanical tests (performing mechanical test while material remains in contact with hydrogen environment). Tests include slow strain rate tensile tests, constant load tests, bending tests, single edge notch tensile tests
- advanced microstructural characterization tools (e.g. for crack initiation and propagation, phase transformation, role of hydrogen on deformation mechanism, identification of hydrides) such as scanning electron microscopy, transmission electron microscopy, electron backscatter diffraction,
- micro-tensile device inside scanning electron microscopy

International collaborations:

The group is involved in multiple international collaborations with academic partners and research institutes. Demonstrated examples are found in joint work with among others colleagues from NTNU (Norway), MCL Leoben (Austria), TU Graz (Austria), University of Queensland (Australia), Ecole des Mines Saint-Etienne (France), Paristech (France), TUEindhoven (The Netherlands), RWTH Aachen (Germany), Max-Planck Institute fur Eisenforschung (Germany). Curtin University (Australia), Kyushu University (Japan),...

Multiple collaborations are ongoing with international industrial partners. Due to NDA's, names can however not be revealed.



### Main relevant publications:

- Via the following links for more info as the research group as over 100 relevant papers
  - <https://research.ugent.be/web/person/kim-verbeken-1/publications?1>
  - <https://www.ugent.be/ea/match/sms/en>
- The potential of the internal friction technique to evaluate the role of vacancies and dislocations in the hydrogen embrittlement of steels, L Vandewalle, M Konstantinovic, T. Depover, K. Verbeken, Steel Research International, 2021, 2100037
- EBSD characterization of hydrogen induced blisters and internal cracks in TRIP-assisted steel, A Laureys, M. Pinson, T. Depover, R. Petrov, K. Verbeken, Materials Characterization, 159, 2020, 110029
- Critical assessment of the evaluation of thermal desorption spectroscopy data for duplex stainless steels: a combined experimental and numerical approach, L Claeys, V Cnockaert, T. Depover, I. De Graeve, K. Verbeken, Acta Materialia, 186, 2020, 190-198
- Microstructural based hydrogen diffusion and trapping models applied to Fe-C-X alloys, A Drexler, T. Depover, S Leitner, K. Verbeken, W Ecker, Journal of alloys and compounds, 826, 2020, 154057
- Qualification of the in-situ bending technique towards the evaluation of the hydrogen induced fracture mechanism of martensitic Fe-C steels, M Pinson, T. Depover, H. Springer, K. Verbeken, Materials Science and Engineering A, 792, 2020, 139754
- The detrimental effect of hydrogen at dislocations on the hydrogen embrittlement susceptibility of Fe-C-X alloys: an experimental proof of the HELP mechanism, T. Depover, K. Verbeken, International Journal of Hydrogen Energy, 43, 2018, 3050-3061
- Understanding the interaction between a steel microstructure and hydrogen, T. Depover, A Laureys, D. Perez Escobar, E. Vanden Eeckhout, E Wallaert, K. Verbeken, Materials, 11, 2018; 698
- Effect of deformation and charging conditions on crack and blister formation during electrochemical hydrogen charging, A Laureys, E Van den Eeckhout, R Petrov, K Verbeken, Acta Materialia, 127, 2017, 192-202
- Fractographic analysis of the role of hydrogen diffusion on the hydrogen embrittlement susceptibility of DP steel, T. Depover, E. Wallaert; K. Verbeken, Materials Science and Engineering A, 649, 2016, 201-208
- The effect of TiC on the hydrogen induced ductility loss and trapping behavior of Fe-C-Ti alloys, T. Depover; K. Verbeken, Corrosion Science, 112, 2016, 308-326,

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# Sustainable Systems Engineering (STEN)

## Ghent University, Faculty of Bioscience Engineering

### General expertise of the research group:

The Research Group Sustainable Systems Engineering (STEN) aims at designing and evaluating systems in a sustainability context, relying on engineering principles. Products, processes, supply chains, and production and consumption patterns are studied with:

- a focus on resources, i.e. resource footprint and resource efficiency
- a lifecycle thinking approach, e.g. operationalized through MFA and LCA
- thermodynamic principles, relying on the second law: exergy and exergetic life cycle analysis

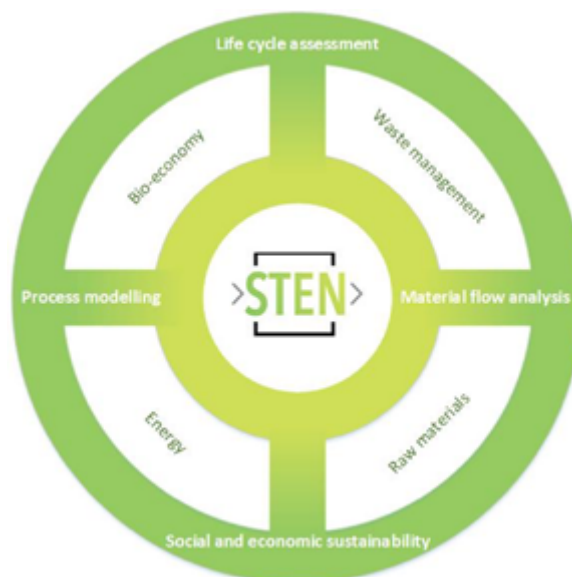
The research is in close collaboration with national and international universities, research centres, policy makers and industry in areas of the following nature: chemical, pharma, primary raw materials, waste-as-a-resource, agro-bio-food ...

### Specific hydrogen- related expertise & research topics:

- LCA of e-fuels
- resource footprint
- resource efficiency

### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- S2Chemicals (NL)
- CCU Hub
- See website: [research.ugent.be](https://research.ugent.be)



#### Main relevant publications:

- See website: [biblio.ugent.be](http://biblio.ugent.be)
- Huysman S, Sala S, Mancini L, Ardente F, Freitas de Alvarenga R, De Meester S, et al. Toward a systematized framework for resource efficiency indicators. *RESOURCES CONSERVATION AND RECYCLING*. 2015;95:68–76.
- Buchmayr A, Verhofstadt E, Van Ootegem L, Sanjuan Delmas D, Thomassen G, Dewulf J. The path to sustainable energy supply systems : proposal of an integrative sustainability assessment framework. *RENEWABLE & SUSTAINABLE ENERGY REVIEWS*. 2021;138.

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### 3.3.4. VUB

## *Mobi research centre - EVERGI*

### Vrije Universiteit Brussel - Faculty: ETEC - Electric Engineering and Energy Technology

#### General expertise of the research group

EVERGI focuses on developing holistic models that include all aspects of the energy and mobility sector for an integrated approach: ELECTRICITY, MOBILITY, HEAT, COOLING, WATER, DATA, HYDROGEN, E-FUELS ...

Sustainable Energy Communities connect renewable energy generation with advanced multi-energy systems, including storage and prosumers.

EVERGI has special attention to the inclusion of key technologies to enable the energy transition, such as electric powertrains for vehicles, automation, bidirectional charging infrastructure, digitalisation, Internet-of-Energy, artificial intelligence (machine learning) and cryptocurrency.

#### Specific hydrogen-related expertise & research topics

- Design, optimisation and techno-economic assessment of Multi-Energy Systems that include Hydrogen as an energy vector.
- Life cycle assessment, life cycle optimisation and techno-environmental evaluation of Multi-Energy Systems that include Hydrogen as an energy vector.
- Energy management systems for Multi.Energy Systems including multiple Hydrogen assets.

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- Reformers :
  - Renewable Energy Valleys to increase energy security while accelerating the green transition in Europe
  - Horizon Europe Project
  - Together with 28 European partners from 12 different countries.
  - Renewable energy valley in Alkmaar, Netherlands and 6 replication valleys in Europe.
- Smart dHYstrict :
  - Waterstof als vector in semi-autonome lokale energiesystemen
  - Interreg FL project
  - Together with WaterstofNet (NL/BE), PRIVA, Fluvius, Solhyd

#### Available equipment/tools:

- Tools:
  - Design and optimisation framework for techno-economic and environmental assessment of Multi-Energy Systems including Hydrogen as an energy vector.
- Equipment/assets to be installed:
  - Electrolyzer
  - Fuel-cell
  - Storage
  - Gas mixer

#### International collaborations:

- Ongoing joint PhD with Kobe University, Japan.
- Research ex-change with University of Zaragoza, Spain
- Inycom, Spain. Doctoral Internship.

#### Main relevant publications:

- Techno-economic assessment on hybrid energy storage systems comprising hydrogen and batteries: A case study in Belgium, A. Martinez Alonso, D. Costa, M. Messagie, T. Coosemans, International Journal of Hydrogen Energy, 2023, ISSN 0360-3199, <https://doi.org/10.1016/j.ijhydene.2023.06.282>. (<https://www.sciencedirect.com/science/article/pii/S0360319923032615>)
- Multi-state optimal power dispatch model for power-to-power systems in off-grid hybrid energy systems: A case study in Spain, A. Martinez Alonso, G. Matute, J.M. Yusta, T. Coosemans, International Journal of Hydrogen Energy, 2023, ISSN 0360-3199, <https://doi.org/10.1016/j.ijhydene.2023.06.019>. (<https://www.sciencedirect.com/science/article/pii/S036031992302832X>)
- Phasing out steam methane reformers with water electrolysis in producing renewable hydrogen and ammonia: A case study based on the Spanish energy markets, A. Martinez Alonso, N. Naval, G. Matute, T. Coosemans, J.M. Yusta, International Journal of Hydrogen Energy, 2023, ISSN 0360-3199, <https://doi.org/10.1016/j.ijhydene.2023.07.347>. (<https://www.sciencedirect.com/science/article/pii/S0360319923039009>)

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- Lennert Callebaut [lennert.callebaut@vub.be](mailto:lennert.callebaut@vub.be) – infrastructure/lab

## Department of Materials and Chemistry MACH/ Research Group Electrochemical and Surface Engineering SURF

### Vrije Universiteit Brussel, Faculty of Engineering Sciences

#### General expertise of the research group

The Electrochemical and Surface Engineering group (SURF) has a long tradition in research on electrochemical systems, and is internationally recognized for its expertise in unravelling mechanisms of electrochemical processes related with corrosion and protection, passivation of metals, localized corrosion, surface treatments and coatings. The multidisciplinary research strategy of the group is employed based on complementary macroscopic and local electrochemical methods, own developed computational software for process simulation and in-situ/ex-situ surface analytical techniques. SURF is in the unique position of having advanced research technology in-house and has own infrastructure of about 6 million €. SURF has a large network of companies supporting the research.

#### Specific hydrogen- related expertise & research topics

- Study of the hydrogen-steel interactions from a SURFACE perspective: influence of surface state, oxide types.... on the hydrogen-steel interaction mechanisms;
- Use and development of electrochemical methods to study hydrogen-metal interactions at the H-steel surface/interface, based on voltammetry, local methods (e.g. Scanning Kelvin Probe Force Microscopy) etc.;
- Electrochemical modelling of the hydrogen-steel interactions (FEM modelling, in-house developments);
- Electrochemical analysis of new electrode materials for hydrogen fuel cells.

#### International collaborations:

- Industrial:
  - APERAM
  - TOYOTA
  - AIRBUS
- Academic:
  - Prof. Frédéric Christien, Ecole des Mines, Saint-Etienne, France, for collaboration on Scanning Kelvin Probe Force Microscopy.
  - Dr. Lars Jeurgens, EMPA, Switzerland, for micro-capillary cell analysis.

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

- AVN - Association Vinçotte Nuclear, PhD projects, on Surface state impact of hydrogen-steel interactions;
- SBO project DeMoPreCi, SIM Maduros program, on electrochemical permeation modelling;
- FWO fundamental research PhD grant, on Hydrogen in Duplex SS steel.
- Industrial research with Aperam, Toyota, Airbus.

#### Available equipment/tools:

- Materials' surface analyses: XPS, FEG-AES, ToF-SIMS, FEG-SEM/EDX/WDX, Raman, Ellipsometry, FTIR, nano-IR / EIS combination, AFM
- Electrochemical experimental analyses:
  - Macroscopic: polarisation methods (OCP, CV, ...), Impedance spectroscopy (in-house developed ORP-EIS), climate chamber...
  - Microscopic: AFM, SKPFM, SVET, SECM
- Electrochemical FEM modelling (own developed approaches & expertise)

#### Main relevant publications

- B. OZDIRIK, K. BAERT, T. DEPOVER, J. VEREECKEN, K. VERBEKEN, H. TERRYN, I. DE GRAEVE, 'Development of an Electrochemical Procedure for Monitoring Hydrogen Sorption/Desorption in Steel', JOURNAL OF THE ELECTROCHEMICAL SOCIETY 164(3) (2017) C747-C757.
- B. OZDIRIK, T. DEPOVER, L. VECCHI, K. VERBEKEN, H. TERRYN, I. DE GRAEVE, 'Comparison of Electrochemical and Thermal Evaluation of Hydrogen Uptake in Steel Alloys Having Different Microstructures', JOURNAL OF THE ELECTROCHEMICAL SOCIETY 165 (11) (2018) C787-C793.
- B. OZDIRIK, T. SUTER, ULRIK HANS, T. DEPOVER, K. VERBEKEN, P. SCHMUTZ, L. P. H. JEURGENS, H. TERRYN, I. DE GRAEVE, 'Study of the hydrogen uptake in deformed steel using the microcapillary cell technique', CORROSION SCIENCE DOI:10.1016/J.CORSCI.2019.04.029.
- L. VECCHI, DARJA PEČKO, et al. H. TERRYN, 'Numerical interpretation to differentiate hydrogen trapping effects in iron alloys in the Devanathan-Stachurski permeation cell', CORROSION SCIENCE DOI:10.1016/J. CORSCI.2019.04.008.
- L. VECCHI, et al. H. TERRYN, 'Modelling of hydrogen permeation experiments in iron alloys: Characterization of the accessible parameters – Part I – The entry side', ELECTROCHIMICA ACTA 262 (2017) DOI: 10.1016/j. electacta.2017.12.172.
- L. VECCHI, et al., 'Modelling of hydrogen permeation experiments in iron alloys: Characterization of the accessible parameters – Part II – The exit side', ELECTROCHIMICA ACTA 262 (2018) 153.
- L. CLAEYS, T. DEPOVER, I. DE GRAEVE, K. VERBEKEN, 'Electrochemical hydrogen charging of duplex stainless steel', CORROSION 75(8) (2019) p.880-887.
- L. CLAEYS, I. DE GRAEVE, T. DEPOVER, K. VERBEKEN, 'Impact of hydrogen and strain rate on the martensitic transformations and mechanical properties of 304L stainless steel: hydrogen embrittlement or hydrogen enhanced ductility?', ACTA MATERIALIA accepted MSA\_140079.

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### 3.3.5. VITO

## *Techno-economic assessments and LCA analysis*

### VITO/EnergyVille – Unit SCT and SEB

#### General expertise of the research group

VITO is a leading European independent research/consultancy centre in the areas of cleantech and sustainable development, elaborating solutions for the grand societal challenges of tomorrow: climate change, food security, a sustainable energy supply, the ageing population and scarcity of resources. Within several units VITO combines the competences to perform techno-economic assessments and life cycle assessments (LCA and LCC) of the hydrogen value chain. With our developed models we can execute these assessments on the micro/meso/macro scale from a specific project/technology and upscale to the energy system covering energy supply and demand sectors.

#### Specific hydrogen- related expertise & research topics

- PhD research project (BE-HyFE) focusing on the development of an investment and operational optimization modelling framework for the future hydrogen infrastructure. The model represents the hydrogen-related supply technologies and pure hydrogen gas flows with high spatial resolution (in the level industrial clusters) to deliver some insights on the cost-optimal required hydrogen backbone capacity, and how different policies can affect the industrial hydrogen production and demand.
- The TIMES-BE model developed by VITO/EnergyVille represents the Belgian energy system including all related technologies and their corresponding material and energy flows. The model is developed in TIMES, a techno-economic energy system modelling framework. Due to its detailed system perspective, the TIMES-Be model is useful for determining hydrogen applications at system level:
  - TIMES will indicate the cost-optimal route in terms of technology investments. Due to the high level of industrial process detail, the model allows for hydrogen applications to be compared to its possible future competitors.
  - The TIMES-BE model has an integrated system approach, meaning that the interaction between sectors is considered in the analysis. The TIMES-BE model was developed under close collaboration between industry and researchers, allowing for detailed insights regarding industrial needs.

#### Available equipment/tools:

- Techno-economic assessment model developed in house
  - LCC models
  - LCA models
  - Long-term energy system optimisation model: TIMES (co-development within IEA-ETSAP technology collaboration programme)

#### International collaborations:

- VITO NDC Support Center: the NDC Support Center provides support to increase capacity of African countries to improve their National Energy Information Systems and their energy modelling expertise, to prepare climate communication and to improve policymaking in the framework of commitments as set for the Paris Agreement. The NDC Support Center is currently active in Malawi, Mozambique, Uganda, and Morocco.
- Colombia NDC Update: The World Bank's PMR fund contracted VITO's consortium in 2020 to update Colombia's NDC. The consortium, including UniAndes and the Stockholm Environmental Institute, updated & consolidated sector GHD emission scenarios and assessed associated abatement costs.
- Horizon Europe Water-Energy-Food Nexus: WEF Energy Planning and Modelling through Integrated Assessment of Climate-Land-Energy-Water Nexus in Sub-Saharan Africa: The Cases of the Volta and Tana River Basins
- The other flagship World Bank project in which VITO is leading the consortium focuses on conducting a comprehensive technical assessment of resilience to disasters, climate change risks and related GHG emissions intensity for the city of Ahmedabad and providing assistance to the Ahmedabad Municipal Corporation (AMC) in developing resilient and sustainable urban service delivery systems. This project got further extension in 2022 to also include the non-AMC (private) sectors as part of the GHG emissions inventory.

#### Participating in FL/B/EU funded projects with H<sub>2</sub> related research:

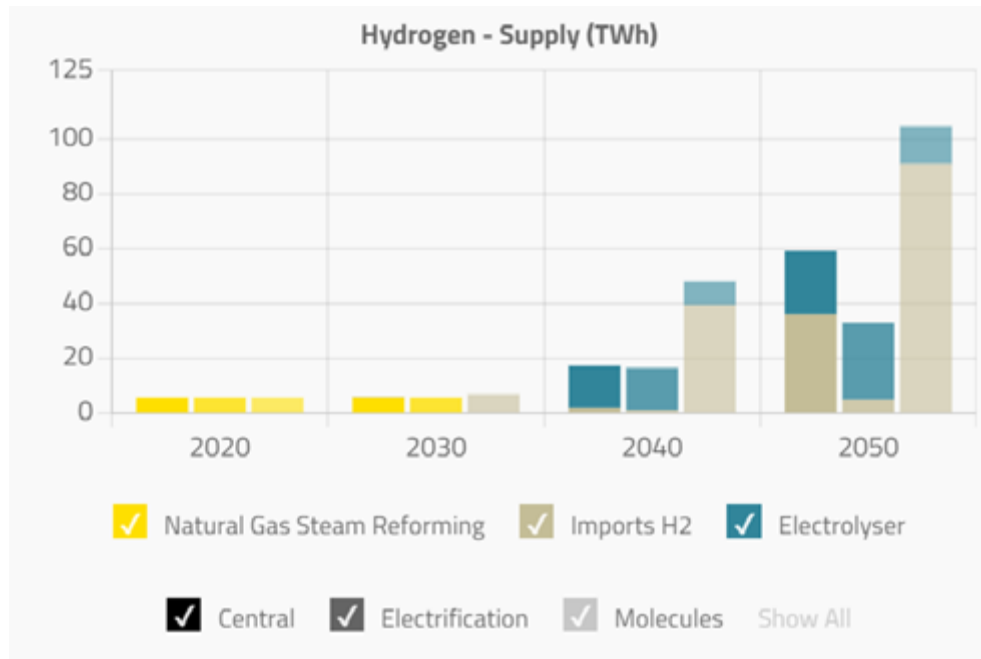
Energy transition funds projects EPOC and PROCURA focus on the role of hydrogen in the industrial and energy system. Recently, the Paths2050 study, funded by Febeliec published results on the cost optimal pathways for the Belgian energy system, including the role of hydrogen, in [www.perspective2050.energyville.be](http://www.perspective2050.energyville.be).

In addition, last year two projects were carried out for DG Reform:

- One project discussed IPCEI regulation on hydrogen networks,
- The other project investigated policies to implement RepowerEU, and an in-depth report on hydrogen regulation and impact on the federal hydrogen strategy was delivered.

In both projects Trinomics was in the lead, EnergyVille provided the hydrogen techno-economic analysis. Expected publication date is March 2023.





#### Main relevant publications

- [www.perspective2050.energyville.be](http://www.perspective2050.energyville.be) contains the most relevant TIMES related results of the past year, including a topic on hydrogen.

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