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# HydrogenDays 2023

## 13th International Conference on Hydrogen Technologies

March 29th – 31st 2023
Prague, Czech Republic

# Program & Abstracts

EUROPEAN UNION
European Regional Development Fund
Operational Programme Enterprise
and Innovations for Competitiveness

HYTEP
CZECH HYDROGEN
TECHNOLOGY PLATFORM
SINCE 2007

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TECHNOLOGY PLATFORM
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# Content

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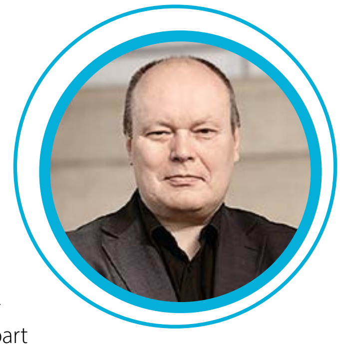
# Hydrogen – The Road to Energy Independence



**Dear Colleagues,**

We have witnessed a rapid growth of interest in hydrogen technologies during the last months. This phenomenon became even more apparent after 24th February 2022, on the day when Europe changed. It became clear that our efforts towards deployment of new clean technologies and new solutions leading to more independence in the energy sector must be accelerated. Hydrogen represents an important part of the complex plan called REPowerEU.

The main effort of this plan is to reduce the consumption of fossil fuels not only in energy but also in industry and transportation sectors. Hydrogen utilization is the final goal that helps to shield Europe from dependence on politically unstable regions.

As a lead motto, we have therefore chosen "**Hydrogen – The Road to Energy Independence**".

This motto summarises our current endeavours in the field of hydrogen technologies. It entails rapid development of hydrogen technologies and their broad introduction into practice. This is because the current interest and geopolitical situation presents not only a great opportunity, but also a strong commitment for the entire hydrogen community. Commitment to accelerate integration of hydrogen technologies into the different sectors of our economy and into our daily life. The commitment to convince the public about advantages of the hydrogen technologies and also about their technology readiness.

I hope you enjoy the conference in all its aspects. The parts focused on sharing the latest information on political and strategic plans for the implementation of hydrogen technologies, examples of large projects focused in this direction, information on recent results of research activities in different laboratories, but also sections dedicated to introduce the basics of hydrogen technologies. And I also hope that you will take this opportunity to meet and share with your peers.

**Karel Bouzek**
Chairman of the Scientific Committee

# General Information

## Scientific conference

City Conference Center
Na Strži 1702/65
140 00 Prague 4
Czech Republic

## Conference language

The conference is being held in English.
No simultaneous translation will be available.

## Student award

To encourage high-quality work amongst young researchers, on the occasion of the Hydrogen Days 2023, Student Awards will be delivered in recognition of the best student contribution. The Student Awards Committee will award 2 attendees, one for the best presentation and the other one for the best poster. The student awards are sponsored by HYTEP. **Each winner will receive a cash prize of 200 EUR**.

All student contributions will be automatically included in the contest for Student Awards, if not stated otherwise.
The student award committee will evaluate student contributions according to the following criteria

- Quality of research
- Compliance with ethical standards for publication
- Clear structure and explanation of content
- Poster resp. presentation design
- Ability of student presenter to answer questions
- Student Awards will be announced during the closing ceremony on Friday 31 March 2023

## Social programme

We are delighted to invite you to the conference dinner, which will be hosted in the Restaurace Šalanda. Come and join us to spend a pleasant evening with your colleagues and friends and taste delicious food.

**Date:** Thursday, 30 March 2023
**Time:** start at 18:30
**Venue:** Restaurace Šalanda

## Publication policy

Participants will receive the Book of Abstracts with summaries of lectures and posters presented during the conference. Authors are free to publish their papers at will after the conference. Based on authors permission, the presentation will be available at the Hydrogen Days website after the conference.

## Contact

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# Programme

Stvořeno pro život

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## Věděli jste, že...

... díky našemu senzoru BMI260 pro optickou a elektronickou stabilizaci obrazu můžete na svém smartphonu pořizovat perfektně ostré fotky a videa?

# Short Programme

## 29. 3. 2023 (Wednesday) – Empiria Hall

### Opening & Welcome

9:00–10:00

**Overview of hydrogen policies, strategies and research activities**
10:00–11:15

**Coffee Break**
11:15–11:40

**German vision for Hydrogen Implementation**
11:40–13:00

**Lunch**
13:00–14:00

**Poster Session**
14:00–14:40

**Overview of hydrogen research strategies and hydrogen activities**
14:40–16:10

**Coffee Break**
16:10–16:30

**Role of hydrogen in energy transition**
16:30–18:10

## 30. 3. 2023 (Thursday) – Scientific part – Empiria Hall

**Keynote**
9:00–9:40

**High-temperature processes for hydrogen production**
9:40–10:40

**Coffee Break**
10:40–11:20

**Alkaline Water Electrolysis**
11:20–12:40

**Lunch**
12:40–13:40

**PEM Fuel Cells & Electrolysers**
13:40–15:20

**Coffee Break**
15:20–16:00

**Economic and environmental impact of hydrogen production**
16:00–17:20

**Conference Dinner**
18:30

## 30. 3. 2023 (Thursday) – Educational part – Tower Hall

**Introduction to hydrogen technologies fundamentals**
9:40–15:40

**Cofee Break**
15:40–16:00

**Company project presentations**
16:00–16:40

**Conference Dinner**
18:30

## 31. 3. 2023 (Friday) – Empiria Hall

**Hydrogen technologies in transportation**
9:00–10:40

**Coffee Break**
10:40–11:00

**Hydrogen in commercial applications**
11:00–12:20

**Student Awards & Closing Ceremony**
12:20–12:40

**Lunch**
12:40–13:40

# Detailed Programme

## 29. 3. 2023 (Wednesday) – EMPIRIA HALL

### Overview of hydrogen policies, strategies and research activities

**Chaired by Karel Bouzek**

9:00 **Opening by conference chairman and chairman of the board of HYTEP**
Karel Bouzek, Aleš Doucek (University of Chemistry and Technology, HYTEP, CZ)

**Welcome address by the Deputy Minister for Industry & Trade**
Eduard Muřický (Ministry of Industry and Trade, CZ)

**Welcome address by the Deputy of the Cabinet Minister of Regional Development**
Radim Sršeň (Ministry of Regional Development, CZ)

**Welcome address by the Special Envoy for Science Diplomacy of the Ministry of Foreign Affairs**
Petr Kaiser (Ministry of Foreign Affairs of the CZ)

**Welcome address by the Ambassador of the Embassy of France in the Czech Republic**
Alexis Dutertre (Embassy of France in the CZ)

10:00 **Acceleration of H2 implementation for decarbonization**
Mirela Atanasiu (Clean Hydrogen Partnership, EU)

10:15 **Priorities for hydrogen R&I in Europe: The perspective of Hydrogen Europe Research**
Luigi Crema (Hydrogen Europe Research, EU)

10:30 **Status of Hydrogen Technologies and Strategy in the Czech Republic**
Petr Mervart (MIT, CZ)

10:45 **Overview of Czech hydrogen projects and outlook**
Jan Sochor (HYTEP, CZ)

11:00 **Hydrogen as alternative energy in public transport**
Karel Novák (IVECO, CZ)

11:15 **Coffee Break 11:15–11:40**

## German vision for Hydrogen Implementation

**Chaired by Karin Stehlík**

11:40 **Status of Hydrogen Technologies and Strategy in Germany**
Felix Matthes (Öko-Institut, Member of German National Hydrogen Council, D)

12:00 **Technology platform TransHyDE**
Mario Ragwitz (Institution for Energy Infrastructures and Geothermal Systems IEG, D)

12:20 **The EU's future hydrogen system: What are the needs for hydrogen infrastructure under alternative scenarios?**
Tobias Fleiter (Fraunhofer Institute for Systems and Innovation Research ISI, D)

12:40 **A system analysis of the future electrical and hydrogen sectors in Europe**
Joshua Fragoso (Fraunhofer Institute of Systems and Innovation Research ISI, D)

13:00 **Lunch 13:00–14:00**

14:00 **POSTER SESSION 14:00–14:40 (PANORAMA HALL)**

## Overview of hydrogen research strategies and hydrogen activities

**Chaired by Luigi Crema**

14:40 **Hydrogen readiness of European education systems – gap analysis**
Robert Steinberger-Wilckens (University of Birmingham, UK)

15:10 **Japan's action to promote hydrogen**
Eiji Ohira (New Energy and Industrial Technology Development Organization NEDO, J)

15:30 **Current status and developments of the hydrogen value chain in Sweden**
Vitaliy Tsvyntarnyy (Swedish Business Council, S)

15:50 **Overview of the French National Research Program on Low-Carbon hydrogen**
Abdelilah Slaoui (CNRS, F)

16:10 **Coffee Break 16:10–16:30**

## Role of hydrogen in energy transition

**Chaired by Robert Steinberger-Wilckens**

16:30 **Analysing the role of green hydrogen in Germany's energy transition**
Christoph Kiefer (Fraunhofer Institute for Systems and Innovation Research ISI, D)

16:50 **Case study GreenWilhelmshaven: Hydrogen Import & Hydrogen Production large scale**
Agnes Herdick (Uniper Hydrogen GmbH, D)

17:10 **The role of hydrogen in securing energy supply and maintaining competitiveness**
Thomas Merker (GasNet, CZ)

17:30 **H2 flows in CEE**
Michal Slabý (NET4GAS, CZ)

17:50 **A review of existing standards and regulations governing the production, storage, and transportation of hydrogen for commercial use in USA**
Edison Sripaul (Texas A&M University, USA)

# 30. 3. 2023 (Thursday) SCIENTIFIC PART – EMPIRIA HALL

**Chaired by Matthias Jahn**

9:00 **Hydrogen – A Road to the Energy Independence**
Thomas von Unwerth (TU Chemnitz, D)

## High-temperature processes for hydrogen production

9:40 **Enlarging operating conditions of solid oxide fuel cells with gaseous mixtures**
Annie Le Gal La Salle (CNRS, F)

10:00 **Design and demonstration of efficient Power-to-Liquid processes via high temperature electrolysis using SOEC technology**
Paul Adam (Fraunhofer Institute for Ceramic Technologies and Systems IKTS, D)

10:20 **Production of hydrogen and nanostructured carbon by polypropylene plastic wastes and CO2 treatment via thermal steam plasma reactor**
Jafar Fathi (Institute of Plasma Physics of the Czech Academy of Sciences, CZ)

10:40 **Coffee Break 10:40–11:20**

## Alkaline Water Electrolysis

**Chaired by Jiří Vávra**

11:20 **Modelling of Hydrogen Production by Alkaline Water Electrolysis Using Unstable Sources of Energy**
Karel Denk (University of Chemistry and Technology, Prague, CZ)

11:40 **Influence of plating conditions on properties of Ni-Fe cathode catalyst for alkaline water electrolysis**
Jana Záchenská (Slovak University of Technology, SK)

12:00 **Effect of the membrane structure on performance of the membrane-electrode assembly in an alkaline environment**
Michaela Plevová (University of Chemistry and Technology, Prague, CZ)

12:20 **Verification of the bifunctional character of Co0.83Ni0.17Se2 – a non-platinum catalyst for reversible alkaline fuel cell**
Dita Hronová (University of Chemistry and Technology, Prague, CZ)

12:40 **Lunch 12:40–13:40**

## PEM Fuel Cells & Electrolysers

**Chaired by Tomáš Němec**

13:40 **Current challenges in designing suitable inline quality control for formed metallic bipolar plates**
Leutrim Gjakova (Fraunhofer Institute for Machine Tools and Forming Technology, D)

14:00 **Diamine crosslinking of sulfonated tetrafluoroethylene based ionomers towards improve protone conductivity of proton exchange membranes for fuel cells applications**
Alba Gonda (University of the Basque Country, E)

14:20 **In situ Deposition of Pt Catalyst Layers on Gas Diffusion Electrodes for Proton Exchange Membrane Fuel Cells**
Meenakshi Seshadhri Garapati (Institute of Thermomechanics of the Czech Academy of Sciences, CZ)

14:40 **Magnetron sputtering as a viable option for preparing the low-Ir-Ru-loading catalysts for PEM-WE with detailed EIS analysis**
Tomáš Hrbek (Charles University Prague, CZ)

15:00 **TiOx support structure and galvanic applied Ir/Ru catalysts for OER in PEMEL**
Johannes Näther (University of Applied Sciences, Mittweida, D)

15:20 **Coffee Break 15:20–16:00**

15:20 **Bosch H2 Product Portfolio**
Vlastimil Šram (BOSCH)

BOSCH

## Economic and environmental impact of hydrogen production

**Chaired by Jaromír Hnát**

16:00 **Can success be planned? – China's path to technology leadership in green electricity and hydrogen**
Viktor Müller (Fraunhofer Institute for Systems and Innovation Research ISI, D)

16:20 **Blockchain Based Hydrogen Market (BBH2) – A paradigm-shifting innovative solution for climate-friendly and sustainable structural change**
Volker Wannack (University of Applied Sciences, Mittweida, D)

16:40 **Multivariate evaluation of figures of merit for renewable hydrogen production by liquid ammonia electrolysis**
Jungrok Oh (Hanyang University, ROK)

17:00 **Environmental Impacts Evaluation of Hydrogen Production and Transportation using the Life Cycle Assesment Method**
Jiří Štefanica (ÚJV Řež, a. s., CZ)

18:30 **Conference Dinner**

# 30. 3. 2023 (Thursday)
# EDUCATIONAL PART – TOWER HALL

## Introduction to hydrogen technologies fundamentals

**Chaired by Martin Paidar**

9:40 **Přehled unijních strategií a legislativy včetně jejich vývoje v oblasti vodíkového hospodářství**
Jan Sochor (HYTEP)

10:10 **Situace v ČR, legislativní a další omezení, přehled projektů**
Jan Sochor (HYTEP)

10:30 **Otázky**

10:40 **Coffee Break 10:40–11:20**

## Introduction to hydrogen technologies fundamentals

**Chaired by Jan Sochor**

11:20 **Základní vlastnosti H2**
Jaromir Hnát (VŠCHT)

11:40 **Technologie výroby vodíku – neelecktrochemické a electrochemické metody**
Martin Paidar (VŠCHT)

12:30 **Přeprava vodíku v EU**
Tomáš Lev (NET4GAS)

12:50 **Lunch 12:50–13:40**

## Introduction to hydrogen technologies fundamentals

**Chaired by Petr Krejčí**

13:40 **Základy palivových článků, druhy a příkady technologie**
Martin Paidar (VŠCHT)

14:20 **Vodíkové spalovací motory – extrémně nízké nebo nulové emise? Vztah účinnost / cena**
Jiří Vávra (ČVUT)

14:50 **Bezpečnost nově schvalovaných vozidel a vodíkových aplikací v dopravě z pohledu legislativy a využití testování pomocí akustické emise**
Luboš Trnka a Peter Palička (TÜV Süd)

15:10 **Ekonomické aspekty výroby a distribuce vodíku v ČR**
Matúš Bodnár (Linde)

15:40 **Coffee Break 15:40–16:00**

16:00 **Company project presentations 16:00–16:40**

**Chaired by Jan Sochor**

16:00 **Hydrogen train**

Dan Kurucz (Alstom)

16:20 **Budoucnost vodíku a udržitelnosti v BMW**

Maciej Galant (BMW)

18:30 **Conference Dinner**

# 31. 3. 2023 (Friday) – EMPIRIA HALL

## Hydrogen technologies in transportation

**Chaired by Thomas von Unwerth**

9:00 **Techno-economic analysis of alternate fuel sources for non-electrified rail operations: a case study in the Czech Republic**

Frederico Zenith (SINTEF, N)

9:20 **Fuel Cell Electric Vehicle optimal control: minimization of hydrogen consumption through a Dynamic Programming approach**

Edoardo Cennamo (University of Rome Tor Vergata, I)

9:40 **Driving cycle simulation of hybrid passenger cars powered with hydrogen engine**

Štěpán Kyjovský (Czech Technical University, CZ)

10:00 **Simulative sensitivity analyses of a stationary PEMFC-stack model for automotive application**

Rico Löser (Fraunhofer Institute for Machine Tools and Forming Technology, D)

10:20 **Risk analysis of the hydrogen filling station: case study**

Aleš Bernatík (VSB-Technical University of Ostrava, CZ)

10:40 **Coffee Break 10:40–11:00**

## Hydrogen in commercial applications

**Chaired by Václav Bystrianský**

11:00 **A plant-specific approach to model future hydrogen demands in energy-intensive industries**

Marius Neuwirth (Fraunhofer Institute for Systems- & Innovation Research ISI, D)

11:20 **Green hydrogen generation coupled with iron production**

Daniela Lopes (CICECO – Aveiro Institute of Materials, P)

11:40 **Climate-neutral raw material supply for refineries – opportunities for the refinery site Schwedt in Germany, Brandenburg**

Natalia Pieton (Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems IEG, D)

12:00 **Techno-economic and net energy comparative studies of Liquid Organic Hydrogen Carrier (LOHC) storage and transport**

Nomuunaa Tsogt (Inha University, ROK)

12:20 **STUDENT AWARDS & CLOSING CEREMONY 12:20–12:40**

12:40 **Lunch 12:40–13:40**

# Posters Programme

## ID – 43 Towards tailored nanomaterials for fuel-cell applications: Binary platinum-tungsten nanoalloys by spark ablation

**Nina Zábojníková** (Institute of Inorganic Chemistry, Technology and Materials, Faculty of Chemical and Food Technology, Slovak University of Technology, Slovakia.)

## ID – 51 Performance Measurement of Inkjet Printed Catalyst Layers for PEM Fuel Cells

**Miroslav Hala** (University of Chemistry and Technology Prague, Czech Republic)

## ID – 46 Development of turnkey transportable system at ICI Caldaie

**Carlo Tregambe** (ICI Caldaie SpA, Italy)

## ID – 27 Improvement of gas-diffusion electrodes for novel hybrid alkaline water electrolysis

**Marcel Kaiser** (Research Center Energy Storage Technologies / Clausthal University of Technology, Germany)

## ID – 45 Effect of alkaline electrolyte concentration and temperature on the HER and OER performance on nickel electrodes

**Kateřina Hradečná** (University of Chemistry and Technology, Czech Republic)

## ID – 39 Statistical techno-economic assessment of renewable energy supplying of water splitting in hydrogen production process (A case study of USA)

**Masoud Khaleghiabbasabadi** (Institute for Nanomaterials, Advanced Technologies and Innovations, Liberec, Czech Republic)

## ID – 12 High efficiency power electronics for direct hydrogen production from solar power

**Jonas Ott** (Deggendorf Institute of Technology, Germany)

## ID – 47 Effect of light distribution on the physiology of Chlamydomonas reinhardtii

**Çağla Yarkent** (Department of Bioengineering, Faculty of Engineering, University of Ege, Turkey)

## ID – 37 Solid state materials for deuterium storage

**Lenka Oroszová** (Institute of Materials Research, Slovak Academy of Sciences, Slovakia)

## ID – 55 Medium-entropy alloys for hydrogen solid state storage

**Karel Saksl** (Faculty of Materials, Metallurgy and Recycling Technical university of Košice, Slovakia)

## ID – 17 Risk of hydrogen embrittlement in a mixture of natural gas and hydrogen

**Klára Kuchťáková** (UCT Prague, Czech Republic)

## ID – 14 Hydrogen Utilization by Steam and Gas Turbines

**Jaroslaw Milewski** (Warsaw University of Technology, Poland)

## ID – 52 Map of ideal locations of HRS in CZ

**Bronislav Vahalík** (Transport Research Centre, Brno, Czech Republic)

## ID – 35 Viewpoints of Gaseous $H_2$ (Fuel Cell Vehicle) applications in green sustainable transportation system (A case study of California state, USA)

**Mohammad Gheibi** (Institute for Nanomaterials, Advanced Technologies and Innovation (CXI), Technical University of Liberec)

## ID – 56 Technical analysis of hydrogen production based on water electrolysis technology with storage and HRS

**Ján Vereš** (Energy Research Centre, Czech Republic)

## ID – 38 Policy-making of hydrogen energy production in countries with the application of Shlaer – Mellor technique

**Masoud Khaleghiabbasabadi** (CXI – Institute for Nanomaterials, Advanced Technologies and Innovations TUL – building L, Czech Republic)

# Abstract Orals

**ID 19**

# The EU's future hydrogen system: What are the needs for hydrogen infrastructure under alternative scenarios?

Tobias Fleiter [1]

[1] Fraunhofer ISI, Karlsruhe, Germany, e-mail: tobias.fleiter@isi.fraunhofer.de

**Keywords: Energy system; EU; Optimization; Hydrogen Transport; hydrogen demand**

## Abstract

### Introduction

The fast and comprehensive roll-out of hydrogen generation, transport and storage infrastructure has become a top-priority of the EU and its member states. At the same time, huge uncertainty still exists about future hydrogen needs and its overall role in the energy system. Thus, planning and developing hydrogen infrastructure first requires a thorough understanding of the future role of hydrogen in the energy system.

### Method

We a detailed energy systems analysis with high temporal and spatial as well as technological resolution under alternative scenarios. We use sector models for the three demand sectors that allow a detailed simulation of technology competition and consideration of the specific socio-economic drivers. We define five scenarios that range from no-regret demands in industry only to hydrogen use in all demand sectors to a large extend. Based on the demand scenarios, we use an energy system model to optimize the entire European energy system with hourly time resolution and detailed spatial consideration of renewable energy potentials. The model calculates 5 - year steps towards 2050.

### Results

Results provide insights into the regional distribution of hydrogen demands for all EU countries. Further, results give insights to the use of hydrogen in electricity generation, the need for seasonal storage, the transport capacities across countries and the needs for hydrogen imports from non-EU countries. Based on the resulting overall picture of the energy system, requirements and insights for hydrogen infrastructure are derived.

The analysis is done in the frame of the project TranshydeSYS supported by BMBF.

## ID 24

# A system analysis of the future electrical and hydrogen sectors in Europe

Joshua Fragoso Garcia [1], Benjamin Lux, Frank Sensfuß,
e-mail: joshua.fragoso.garcia@isi.fraunhofer.de

[1] Fraunhofer Institute of Systems and Innovation Research (ISI), Germany,
e-mail: joshua.fragoso.garcia@isi.fraunhofer.de

**Keywords: Renewble energy; system model; energy coupling**

### Abstract

#### Introduction

The future energy supply in Europe shall be decarbonized by the year 2050. This represents an immense challenge as a large number of renewable energy systems (RES), mainly wind and photovoltaic, need to be installed to cover the demand. Together with the RES, hydrogen will play an important part in the future European energy system. However, the extent of this participation still faces big uncertainties.

#### Methodology

To evaluate the future European energy system, we consider the demand data of different scenarios with changing hydrogen demand. The energy supply to cover the demand was determined using the model Enertile. Enertile is a linear model that optimizes the energy supply from a cost perspective. It determines the generation capacity expansion, dispatch and storage for three different energy sectors: electric, heating and hydrogen. To determine the expansion of RES, Enertile calculates the renewable energy potentials in Europe with high spatial and temporal resolution.

#### Results

The results include the RES potentials for utility-scale photovoltaic, roof-photovoltaic, wind onshore and offshore, and concentrated solar power. We provide a future picture of the electric generation capacity and the hydrogen reconversion demand included in it. The hydrogen generation locations are identified within Europe together with the non-EU hydrogen imports. The electrolysers' locations are identified as well and a first insight into the hydrogen trade within Europe is provided. The storage capacity to balance the seasonal requirements is also determined.

The analysis is done in the frame of the BMBF project TranshydeSYS.

# Current status and developments of the hydrogen value chain in Sweden

Vitaliy Tsvyntarnyy [1], Hana Burešová

[1] Business Sweden Prague, e-mail: hana.buresova@business-sweden.se

**Keywords: Sweden, hydrogen value chain, European collaboration, renewable sources, fresh water, green steel, decarbonisation**

**Abstract**

With a strong share of renewables in its energy mix and decarbonized grid, Sweden has been well on track to meet its energy and sustainability targets. The next step towards its ambition to reach climate neutrality by 2045 is to decarbonize the industrial sector. Here both electrification and hydrogen are hailed as the two most important factors that will complement each other to achieve ideal energy efficiency.

With more than 150 entities active in the Swedish hydrogen ecosystem broadly represented across the entire value chain and as a result of its experience in hard-to-decarbonize sectors such as steel, cement and chemical industry; Sweden has started profiling itself as the frontrunner in deploying innovative hydrogen projects, especially on the downstream side.

The EU also perceives Sweden as a significant upcoming contributor to fulfil its domestic renewable hydrogen production targets, thanks to the abundance of renewable sources and clean fresh water needed for electrolysis. On top of that, low electricity prices favour both off-grid and on-grid electrolysis capacities that position Sweden well in terms of additionality and to contribute to the European hydrogen economy.

**ID 29**

# Analysing the role of green hydrogen in Germany's energy transition

Christoph P. Kiefer [1]

[1] Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany,
e-mail: christoph.kiefer@isi.fraunhofer.de

**Keywords: Hydrogen, energy system modelling, European trade, security of supply**

## Abstract

A central issue for the energy transition and the future energy system is security of supply. The intermittency of renewable energy technologies (RETs) such as wind or photovoltaic, poses a critical challenge. Hydrogen is often proposed to solve such problems, because in comparison with electricity, it is much easier and cost-efficient to store. Nevertheless, the exact role of hydrogen in future energy systems is disputed.

This study systematically analyses the role of hydrogen in future integrated (sector-coupled) energy systems.

A scenario-based energy system modelling approach was chosen. A set of scenarios was defined, including an electrification and a hydrogen scenario. Within each scenario, the usage of hydrogen as an energy carrier was optimized (i. e., the use of hydrogen is a model result) from an overall system cost perspective (that was minimized). For the energy supply side, the model Enertile was chosen, as it provides a high spatial and temporal resolution of integrated energy systems. The model optimises RET and electrolysis capacity expansion, corresponding electricity and hydrogen generation and associated cost, quantifies European energy trade flows by balancing demand and supply under consideration of transport infrastructure etc. In this study, all European regions were modelled, yet the analytical focus is on Germany.

The results show that hydrogen has a very specific role in the future energy system. Hydrogen is, used where its inherent features (i. e., storability) provide most system value. This is related mostly to backup, stabilising or flexibility-providing functions. The model results also quantify future European hydrogen trade.

## ID 5

# A review of existing standards and regulations governing the production, storage, and transportation of hydrogen for commercial use in USA

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**Keywords: Hydrogen, Standards, Regulations, Saftey**

**Abstract**

Currently, the annual global hydrogen production is around 70 Mt, of which in the United States 12 Mt. With the demand for clean energy growing, the United States alone is expected to produce more than 70 Mt per year in 2050. The growing demand and recent favorable political and economic conditions will mean that along with hydrogen production the whole downstream is going to see the same growth. But this imminent growth in the hydrogen economy demands scrutiny of the underdeveloped federal government's safety regulation. Department of Energy is currently the leading authority in pushing hydrogen to be the next energy source through its investment in next-generation green energy initiatives such as electrolyzers and fuel cells. OSHA under the Occupational Health and Safety standards for hazardous materials covers multiple aspects such as storage and piping, relief devices, and assembly. EPA superficially regulates hydrogen as part of the chemical accident prevention program or Greenhouse reporting program. PHMSA regulates the 700 miles of hydrogen pipeline in the United States, but these regulations are primarily drafted based on natural gas. All these organizations currently address some of the regulatory needs, but they are more addressed incidentally by treating hydrogen as just one of the substances under their regulation. Currently, there is no comprehensive regulatory authority for overseeing hydrogen safety. This paper will evaluate the existing regulations governing the safety of hydrogen under different regulating authorities and how these regulations need to evolve in the next few decades to ensure accidents can be prevented.

# Hydrogen – A road to energy independence

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In the past decades, various drivers for the change in energy supply and use could be identified worldwide. While the finite availability of fossil fuels and their costs initially played a decisive role, the discussion was later expanded to include the effects of energy use on the global climate, i.e. ecology and sustainability. In recent times, it has also become clear that fossil energy sources in particular always give rise to dependencies in the course of advancing globalisation, which in geopolitically difficult times can lead to economic and socio-economic disadvantages for those dependent on them. As a result, in the future the focus will increasingly be on building an energy system that allows for greater geographical diversification of energy supply. Hydrogen is an energy carrier that fulfils these conditions. Produced with the help of various primary energies, it can be made emission-free and thus green, especially on the basis of solar, wind and hydropower. It can be stored both decentrally as a gas or liquid and centrally and on a large scale in caverns, or it can be transported in or on other compounds such as ammonia or methanol simultaneously with high energy densities by road, rail, gas grid or sea. It can also be used for a variety of applications with different technological approaches, such as direct hydrogen combustion, electrochemical conversion via fuel cells, use in steel production or as a raw material for chemical products. If the full potential of hydrogen as an energy carrier is utilised, it can help pave the way to greater energy independence.

**ID 40**

# Enlarging operating conditions of solid oxide fuel cells with gaseous mixtures

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**Keywords: Fuel cell, Syngas, Biomass, Gasification**

## Abstract

The "H2"PEPR is part of France's national low-carbon hydrogen strategy. It supports upstream R&D activities (TRLs 1 to 4) by exploring new directions likely to lead to breakthrough innovations of interest as regards the strategy but also as support tools for industry. One of the 7 targeted projects, FLEXISOC, is devoted to the diversification of fuels usable into solid oxide fuel cells. Indeed, if mature polymer membrane fuel cells require very high-purity hydrogen gas to produce electricity, it is not the case for high-temperature fuel cells (SOC: Solid Oxide Cell), which can operate in reversible mode alternating the functions of electrolyser and generator, and also allow the use of various fuels, such as gaseous mixtures issued from biomass.

After a brief description of the project, preliminary results obtained in our laboratory, in terms of electrical power densities and electrochemical impedance measurements, obtained with Ni-YSZ-based SOFCs fueled by various mixtures of N2, H2, CO, CO2, and CH4 will be presented. Results obtained with a gas issued from a gasifier are also presented, and emphasize issues linked to pollutants such as HCl or H2S. The influence of these pollutants depends drastically on the operation conditions but also on the composition of the gas mixture, and optimized operation conditions can be determined for each gaseous mixture. Cleaning procedures, increasing the service life, are also proposed.

Strategies used to enlarge conditions of SOC operation, by modifying cell composition, but also by adapting current collection or gas purification, are then presented.

**ID 22**

# Design and demonstration of efficient Power-to-Liquid processes via high temperature electrolysis using SOEC technology

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**Keywords: Power-to-Liquid; sector coupling; SOEC; co-electrolysis; syngas**

## Abstract

### Objectives

While the share of renewables in electricity generation is increasing, the progress in other sectors is more limited. A technology allowing for efficient sector coupling is the high temperature electrolysis (SOEC, solid oxide electrolysis cell). The unique capabilities of direct syngas production from $H_2O$ and $CO_2$ (co-electrolysis) and internal reforming of hydrocarbons are very advantageous for coupling with synthesis processes generating green fuels or bulk chemicals. The objective was therefore the development and demonstration of process concepts that utilize these beneficial capabilities.

### Methods

Several different process concepts for the implementation of Power-to-Liquid processes utilizing high temperature electrolysis were modeled using the flowsheet-based simulation package Aspen Plus to identify the most efficient plant design. Based on the modeling results demonstrators in different scale were designed, built and operated to show the advantages of Power-to-Liquid processes integrating a high temperature electrolysis.

### Results

The process modelling results showed a strong dependency of process efficiency to heat integration and by-product recirculation. Using such integration options, an energetic efficiency of $\eta_{en} > 0.55$ can be reached under realistic conditions with thermal losses considered. The advantages of the modelled process integration options could be demonstrated successfully in laboratory scale (1 kW DC) and in a containerized plant (12 kW DC).

### Conclusions

It was shown via process modelling, that implementing a high-temperature electrolysis in an integrated Power-to-Liquid process enables high efficiencies of $\eta_{en} > 0.55$. The process concepts and several advantageous process integration options were demonstrated successfully on different scale.

**ID 48**

# Production of hydrogen and nanostructured carbon by polypropylene plastic wastes and CO2 treatment via thermal steam plasma reactor

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**Keywords: power 2X, hydrogen, carbon nanostructured material, polypropylene plastic wastes treatment**

**Abstract**

For having Sustainable climate and clean energy system we need to add value to waste and control CO2 emission. The main idea of this work is converting plastic wastes and CO2 to high values material. This goal is achieved by thermal steam water plasma reactor which the reaction temperature was around 1200 °C and power of plasma system was 88 up to 109 kW. This plasma system could be run by renewable electricity sources. For this experiment, 6 kg/h polypropylene (PP) granules and various CO2 gas flow, feed to the reactor. Hydrogen, carbon monoxide and nanostructured solid carbon came out as process products. This experiment was carried on at five different condition, the best CO2 conversion rate was 98% and almost all amount of PP plastic converted to products. The maximum hydrogen concentration was 41% of output gas. produced solid nanostructured carbon material characterized via high resolution transmitting electron microscopy, scanning electron microscopy, Raman spectroscopy, X-ray photoelectron spectroscopy, energy-dispersive X-ray spectroscopy, X-ray diffraction and BET special surface area analysis. carbon particles size were from 50 nm up to 400 nm. this nanomaterial has capability to use as color pigment or rubber and tire enforcement filler. In the best condition of experiment all raw material, PP plastic and CO2 gas, converted to hydrogen and carbon monoxide and solid nanostructured products. This can be a advanced technology to convert renewable electricity to chemical energy storage in syngas form, in same time, converting of plastic waste and CO2 to high values material.

**ID 34**

# Modelling of Hydrogen Production by Alkaline Water Electrolysis Using Unstable Sources of Energy

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**Keywords: hydrogen; model; electrolysis**

## Abstract

Hydrogen is a universal energy carrier with use in broad range of technologies, from chemical industry to clean mobility. Its key advantage lies in the possibility of production without $CO_2$ emissions by water electrolysis using renewable sources of energy. Utilization of hydrogen in fuel cells or by combustion also does not produce any unwanted emissions. Furthermore, both water electrolysis and fuel cells are reasonably efficient.

Alkaline water electrolysis (AWE) is an industry-verified technology which does not utilize expensive materials such as platinum group metals. Its advanced form, membrane alkaline water electrolysis (MAWE), boasts with flexibility.

Utilizing mathematical modelling and knowledge of AWE and MAWE enables us to predict hydrogen production powered by an unstable source of energy. A mathematical model was created for assessment of hydrogen production. Input data used for the electrolyser come from an in-house device and are supplemented by literature, data for unstable power sources involve a photovoltaic power-plant and electricity recuperated by braking electric trains.

Developed tool can be used to assess optimal size of an electrolyser used for a given energy source. The output data generated by the model are estimate of total hydrogen produced and utilization of the device which is in the form of production time and the power load during production.

## Acknowledgment

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**ID 28**

# Influence of plating conditions on properties of Ni-Fe cathode catalyst for alkaline water electrolysis

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**Keywords: Ni-Fe coatings; cathode catalyst; zero gap electrolyzer; alkaline water electrolysis; load measurements**

## Abstract

Alkaline water electrolysis (AWE) in combination with renewable energy sources represents promising technology for producing green hydrogen. Many research groups have been focused on designing new catalyst with aim to increase efficiency of AWE. Ni-Fe based materials have gained much attention due to their promising properties as an effective catalyst toward both oxygen and hydrogen evolution reaction in alkaline solutions. These materials have also good stability in alkaline medium and can be easily prepared by electrodeposition. Tuning the catalyst activity can be done through optimisation of the electrodeposition conditions. The aim of this work was to find optimal electrodeposition parameters for preparation of Ni-Fe catalysts used in zero-gap electrolyzer for AWE.

Ni-Fe coatings were deposited by direct current electrodeposition on Ni substrate at 60 °C. The effect of current density and time of electrodeposition were studied. Prepared samples were investigated by several analytical and electrochemical methods. Catalysts were tested in zero-gap electrolyzer with anion-selective polymer membrane for alkaline water electrolysis. As electrolyte, solution of 10 wt.% KOH with temperature of 50 °C was used.

It was found that the plating conditions can affect electrocatalytic properties of coatings. Optimal values of current density and time were 25 $A \cdot dm^{-2}$ and 60 min, respectively. Applying higher current density results in peeling off the coating from substrate. The electrochemical studies showed possibility to improve catalytic activity for HER in an alkaline environment.

## Acknowledgement

This work was financially supported by the grant of the Slovak Scientific Grant Agency VEGA under the contract number 1/0747/21.

**ID 36**

# Effect of the membrane structure on performance of the membrane-electrode assembly in an alkaline environment

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**Keywords: Hydrogen; membrane; catalyst; electrolysis**

## Abstract

Production of green hydrogen is of critical importance to achieve full decarbonisation of the industry, transport, electricity, and heat production. Membrane alkaline water electrolysis (MAWE) could contribute to the decarbonisation as it can be powered by renewable energy, utilize low-cost electrocatalysts and other inexpensive components. But some limitations, such as power efficiency, safety and flexibility need to be resolved.

Efficiency can be improved by utilization of catalysts, preferably non-platinum. The safety and flexibility can be improved by using a highly conductive anion-selective membrane, which allows the use of diluted KOH electrolyte. The catalyst can then be deposited directly on the membrane surface (CCM – catalyst-coated membrane) which allows reduction of the catalyst loading. This approach is not used in MAWE as limited number of materials able to withstand the operation conditions is available.

The aim of this work is to verify the influence of the ultrasound technique on the homogenization of the catalyst ink and comparison of different anion-selective materials. Chloromethylated block copolymer functionalized with 1,4 - diazabicyclo [2.2.2]octane and Fumapem® membranes are compared. $NiCo_2O_4$ and $NiFe_2O_4$ are used as anode and cathode catalysts, respectively. Ultrasound bath or horn are used for ink homogenization. The obtained results show the possibility of performance improvement by using suitable membrane and ultrasonication method.

## Acknowledgments

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 875118. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe research.

**ID 26**

# Verification of the bifunctional character of $Co_{0.83}Ni_{0.17}Se_2$ – a non-platinum catalyst for reversible alkaline fuel cell

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**Keywords: reversible alkaline fuel cell, oxygen reduction reaction, oxygen evolution reaction, bifunctional catalysts**

### Abstract

One of the drawbacks of renewable sources of energy lies in their strong dependence on actual weather conditions. Possible solutions and way to increase usability represent balancing the energy output fluctuations by energy storage. Besides well-known batteries, hydrogen is considered as an option. Compared to batteries, hydrogen-based technologies are not limited by rechargeable cycles and have higher specific energy density. Hydrogen can be produced as green using renewable electricity by water electrolysis and converted back to electrical energy via fuel cells.

A reversible alkaline fuel cell (RAFC) is a device that combines a water electrolyzer and a fuel cell. The alkaline environment enables to use of a wide spectrum of materials for catalysts. The advantages of the combined energy conversion device are the high energy density and space and cost savings. However, the demands on the bifunctional catalyst materials, which are utilized in RAFC are quite high, due to the occurrence of two different half-reactions on the electrode.

Selenide-based materials represent a perspective non-platinum catalyst for the oxygen reduction reaction. Our study aims to verify the possibility to use selenides for oxygen evolution reaction, which occurs under harsher conditions. The morphology and physical properties were determined by SEM-EDS and XRD. Electrochemical properties were measured by linear sweep voltammetry and electrochemical impedance spectroscopy on rotating disk electrode.

### Acknowledgments

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under (Grant Agreement No. 875118). This work was supported by the grant of Specific university research.

**ID 18**

# Current challenges in designing suitable inline quality control for formed metallic bipolar plates

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**Keywords: Mass manufacturing; PEMFC; Quality control; Surface coverage; Multi-Sensor System**

**Abstract**

The main objective of the KontiBIP [1] project is to develop a new production chain for the manufacturing of high precision metallic bipolar plates including new tooling and automation concepts suitable for large-scale production. Although forming bipolar half-plates from thin metal sheets (sheet thickness ≤ 0.10 mm) has the potential to increase the production capacity, the inline quality control remains a bottleneck in the production chain. Due to the complex structure of the formed bipolar plates, microcracks and necking, burr formation and layer defects can occur during production. The use of defective parts would thus be associated with high follow-up costs. For this reason, automated 100 % inline control is necessary, but it is associated with many challenges. So-called inline-capable multi-sensor inspection systems are often not available as standard solutions. In addition, the inspection concept must cover the entire surface in order to monitor multiple defect classes and inspection criteria in a contactless manner. However, the impact of the defect classes in the process are not well known and a standardized defect catalog is not available. Since the defects are usually in the micrometer range, optical systems reach their technical limits (resolution, data rate). Various approaches that take the different challenges into account will be discussed in detail.

[1] The project "KontiBIP" - Hochratenfähige Herstellung metallischer Bipolarplatten mittels kontinuierlicher Fertigungstechnologie" is supported by the German Federal Ministry for Digital and Transport (BMDV) on the basis of a decision by the German Bundestag.

ID 44

# Diamine crosslinking of sulfonated tetrafluoroethylene based ionomers towards improve protone conductivity of proton exchange membranes for fuel cells applications

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**Keywords: PEMFCs; Crosslinking; Nafion®; Aquivion ®; IMMENSE M-ERA.NET EU PROJECT**

**Abstract**

Despite the wide utilization of the sulfonated tetrafluoroethylene ionomers in proton exchange membranes for fuel cells (PEMFCs) they still present certain drawbacks, which limit their full potential. The non-environmentally friendly nature of the ionomer dispersions containing organic solvents contributes to increase of volatile organic compounds release during membrane preparstion. Additionally, the membranes present a rapid decline of the proton conductivity and a performance loss at high temperatures, because of humidity lost. In this work, we overcame these limitations by creating a crosslinked sulfonated tetrafluoroethylene ionomer using diamine crosslinkers with various chain length between the amine groups. It was expected that the crosslinked structure would improve the ability of the membrane to entrap the humidity even at higher temperatures. Moreover, due to decreased solubility, the crosslinked structures created a water-based dispersion, avoiding the use of non-environmentally friendly solvents. Nafion® and Aquivion® commercial ionomers were chosen for this aim. The size of the crosslinked particles in aqueous dispersions was controlled to be in a range of 80–500 nm. Along to the characterization of the crosslinking, the film formation properties, thermal properties and proton conductivity of the new materials were determined. The obtained results have shown that the crosslinkers with larger chain length are more favorable to form better quality membrane and to increase the proton conductivity for up to an order of magnitude at 95 ºC (which is the instrument limit) and with increasing trend. This simple methodology can be a potential way of improving performance of the existing PEMFCs.

## ID 9

# In situ Deposition of Pt Catalyst Layers on Gas Diffusion Electrodes for Proton Exchange Membrane Fuel Cells

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**Keywords: Proton exchange membrane fuel cells, Oxygen reduction reaction, Membrane electrode assembly, catalyst nanoparticles, spark-discharge generator**

### Abstract

Herein, the present work focuses on the direct deposition of Pt catalyst nanoparticles on gas-diffusion electrodes (GDE) and use as the electrodes of the membrane electrode assembly (MEA) for low-temperature proton exchange membrane fuel cells (PEMFC) without any additional treatments. This in situ deposition of catalyst nanoparticles does not involve any chemicals or solvents that can damage the Nafion membrane. Pt nanoparticles have been synthesized by spark-discharge generator (SDG), a gas-phase atmospheric-pressure synthesis process. SDG produced nanoparticles were deposited by filtration on standard GDE (SIGRACET® 36 BB) placed at the outlet. By variation of the carrier gas ($N_2$ and forming gas (FG, $N_2$ 95 % + $H_2$ 5%) in the SDG, two kinds of Pt nanoparticles (Pt-$N_2$ and Pt-FG) were obtained. At first, the oxygen reduction reaction (ORR) activity and durability of both nanoparticle samples were examined by the half-cell measurements, i.e., cyclic voltammetry, rotating-disk electrode, and accelerated durability tests. For MEA fabrication, in situ deposited Pt-$N_2$ and FG catalysts on GDE (Pt loading 0.2 mg $cm^{-2}$) are used as the anode and cathode. In the single-cell studies, MEA with Pt-FG catalyst delivers a power density of 644 mW $cm^{-2}$ at 60 $^0$C and RH75%, which is higher than the Pt-N2 (500 mW $cm^{-2}$) and commercial Pt-black (320 mW $cm^{-2}$) catalysts. The performance of Pt-FG catalyst can be attributed to higher crystallinity and smaller particle size evaluated from X-ray diffraction and transmission electron microscopy measurements. Hence, the SDG technique can produce high-quality and in situ deposited PEMFC electrodes.

**ID 6**

# Magnetron sputtering as a viable option for preparing the low-Ir-Ru-loading catalysts for PEM-WE with detailed EIS analysis

Tomáš Hrbek [1], Peter Kúš, Yuliia Kosto, Miquel Rodriguez, Iva Matolínová

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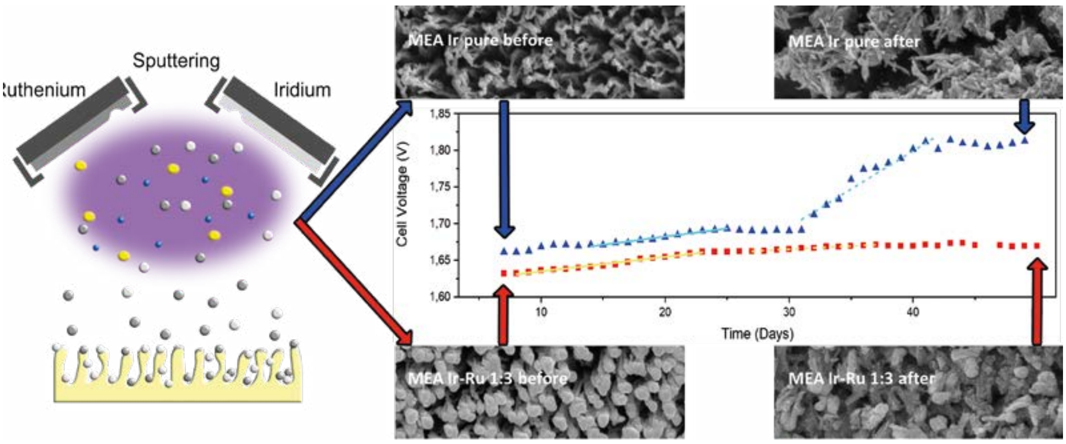
**Keywords: PEM-WE, low Ir, Ir-Ru, impedance, stability**

**Abstract**

Proton Exchange Membrane Water Electrolyzers (PEM-WEs) are entering the phase of commercial mass production. However, the issue of an iridium catalyst for the anode remains. This work presents an iridium-ruthenium-based catalyst (25% Ir = 158 µg cm-2, 75 % Ru) prepared as a thin film on the surface-enhanced-anode of PEM-WE via magnetron sputtering. Using a strictly practical single-cell approach, without any iR corrections, we show its excellent activity – 1 A cm-2 at 1.606 V, 80 °C, and stability – 1.3 µV h-1 at 1 A cm-2 for 500 hours. Together with a purely Ir-based catalyst (158 µg cm-2), we subject it to a massive electrochemical and material analysis, showing that the thickness and interconnectivity are essential for the catalyst's stability. This conclusion is based on results from single-cell galvanostatic measurements, Potential Electrochemical Impedance Spectroscopy (PEIS), Scanning Electron Micrsocopy (SEM), X-Ray Photoelectron Spectroscopy (XPS), and Energy Dispersive X-ray spectroscopy (EDX). Consequently, we believe that magnetron sputtering is currently the most perspective method for preparing low-Ir-loading catalysts. Compared to the nanoparticle approach, it allows the creation of very thin films with unprecedented interconnectivity.



**ID 21**

# $TiO_x$ support structure and galvanic applied Ir/Ru catalysts for OER in PEMEL

Johannes Näther [1], Lisa Sagewka [2], Tim Hülser [3], Frank Koester [1], Pit Podleschny [1]

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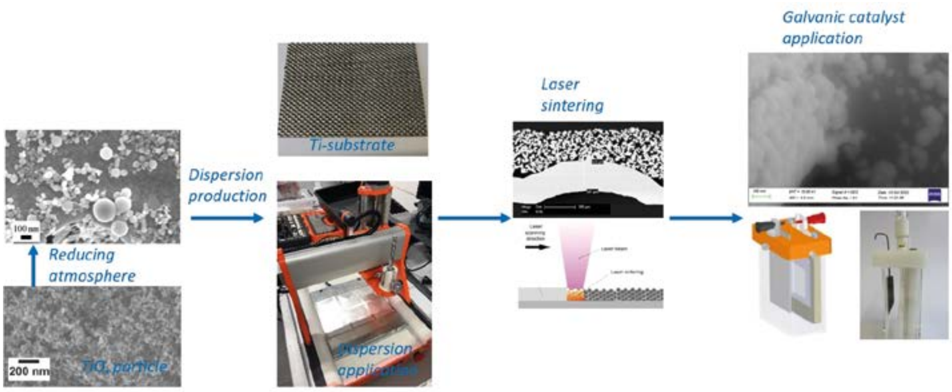
**Keywords: PEMEL; titanium PTL; catalysts for OER**

## Abstract

The current situation regarding the gas supply in Europe makes the urgency of the further development of storage technologies such as PEM electrolysis for the production of hydrogen clear. An electrode structure for PEM electrolysers is presented, which consists of a titanium carrier, a sprayed layer of conductive TiOx particles and galvanically generated catalyst particles. The particles are synthesized by sub-stoichiometric combustion of tetraisopropyl orthotitanate (TTIP) as precursor. The nanoscale titanium particles are posttreated in a reducing atmosphere after fabrication. The application to the support material is done by air-brushing under argon atmosphere. Subsequently, the surface is laser sintered to produce an oxidation-insensitive, conductive titanium suboxide phase (Magnelliphase) as a porous transport layer. A 355nm laser is used to stabilize the particles without affecting the basic structure and particle size too much. The catalyst is then applied galvanically, directly onto the structured electrolde, in order to achieve an optimal electrical connection. Due to the large geometric surface of the sintered structure, the catalyst application can be reduced to 0.2–0.5 g/cm². By using pulse plating, the distribution of the catalyst and the composition of alloy particles can be controlled in a targeted manner. Co-deposition of ruthenium to produce alloyed particles leads to higher activities in terms of OER. The complete anode structure is characterized in terms of its conductivity, surface topography, and exsitu and insitu activity for OER. For further investigations, the long-term stability of the alloy particles is of primary interest.



**ID 13**

# Can success be planned? – China's path to technology leadership in green electricity and hydrogen

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**Keywords: Renewable Electricity Technologies; International Trade; Political Drivers; Green Hydrogen Production; China**

## Abstract

Renewable electricity and green hydrogen will play a key role in the future energy system. To meet their demand, sufficient amount of production and storage units are needed. Besides local production, many countries import these units from other countries due to lower costs. International trade in these technologies has therefore increased. A quantitative analysis of export data shows that China in particular has substantially increased the number of technology components relevant to the field of renewable energies and green hydrogen that are exported with a comparative advantage. Through a qualitative literature review, the possible reasons and drivers are analysed for this development.

We identify 36 components of the four technologies: Photovoltaics, wind turbines, battery storage and water electrolysis. China has made a globally unique industrial know-how gain in this area, exporting 31 out of 36 components in 2019 with a comparative advantage, compared to only 3 out of 36 components in 1995. At the same time, a rapid increase of installed capacity in renewable technologies in China can also be observed. This was strongly driven by a series of support instruments induced by the main national policy, the Five-Year-Plans, which emphasized not only the expansion of clean energy but also its research and development. From economic perspective, the high international demand and decreasing production costs of the specific components lead to a continuous expansion of Chinese clean energy industry nationally and globally.

**ID 49**

# Blockchain Based Hydrogen Market ($BBH_2$) – A paradigm-shifting innovative solution for climate-friendly and sustainable structural change

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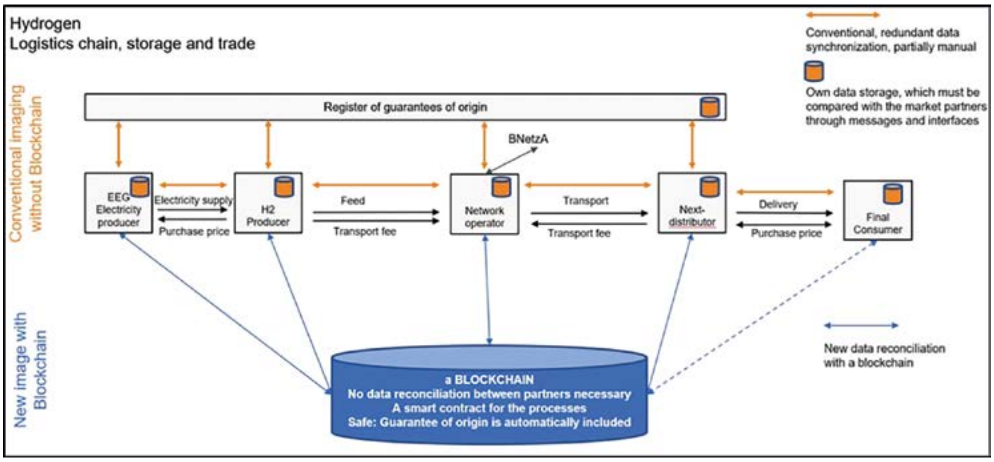
**Keywords: Hydrogen, blockchain, sustainability, innovation, structural change**


## Abstract

Until now, there has been no flawless tamper-proof verification of climate-friendly "green" hydrogen and the resulting possible tracking of its origin from the renewable energy producer to the end consumer, so that the entire supply chain of "green" hydrogen cannot be represented in terms of economic, ecological and social sustainability and mapped in a secure and transparent market. This problem can be solved with a suitable blockchain, which also offers further unprecedented added value for the supply chain of the "green" hydrogen market and for sustainable structural change as a whole, and whose development is being funded as part of the funding call "Hydrogen Technology Offensive" within the research funding of the Federal Ministry of Economics and Climate Protection in the 7th Energy Research Program of the Federal Government.

**ID 32**

# Multivariate evaluation of figures of merit for renewable hydrogen production by liquid ammonia electrolysis

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**Keywords: Multivariate evaluation; Figures of Merit; Renewable hydrogen production; Liquid ammonia; Ammonia electrolysis**

### Abstract

Multivariate evaluation of figures of merit is employed to characterize the performance of renewable hydrogen production systems. In particular, a piping and instrumentation diagram of a liquid ammonia electrolysis system is constructed on the basis of polymer electrolyte membrane water electrolysis. Then, hydrogen production cost for the liquid ammonia electrolysis with associated inputs of electricity for the electrolysis and BOP operation as well as fuel supply (i. e., figures of merit for electrochemical systems) is optimally estimated using response surface methods and compared with other clean hydrogen production systems: cost competitiveness of electrolytic hydrogen. Result shows that the liquid ammonia electrolysis system produces hydrogen in logarithmically proportional to the operating current density and, moreover, consumes approximately 30 % less electricity than the polymer electrolyte membrane water electrolysis system. This multivariate evaluation of figures of merit can be utilized to estimate hydrogen production cost and design renewable hydrogen production in the industry.

**ID 54**

# Environmental Impacts Evaluation of Hydrogen Production and Transportation using the Life Cycle Assessment Method

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**Keywords: LCA; hydrogen production; environmental impacts; climate change**

## Abstract

Current decarbonization efforts are based not only on electromobility but also on hydrogen as an alternative fuel. However, it is necessary to ensure minimal environmental impacts of hydrogen production and transportation for the efforts to achieve the intended goal. Hydrogen can be produced by different methods with different environmental impacts. Above all, the environmental impact category Climate change (also called Carbon footprint) is at the forefront, however, there are other important categories such as Particulate matter, Photochemical ozone formation, Human toxicity and others. Moreover, summary of all environmental impacts across all categories can be evaluated using normalization and weighting.

In the scope of project CK02000044.

**Progressive Development of Hydrogen Economy for Transportation** in the CZR an extensive analysis of hydrogen production technologies, its compression / liquefication and its transportation was carried out. Environmental impacts of selected technologies were evaluated using the Life Cycle Assessment (LCA) methodology and the most up to date method PEF3.0 (recommended by the European Commission). The LCA method is utilizing a holistic "cradle to grave" approach to include all related environmental impacts starting from the technology construction (including mining and processing the construction materials), operation (fuels, feedstock, energy and auxiliary materials consumption) and decommissioning (recycling, waste disposal).

The presentation will focus on the results in the impact category Climate change and on the summary of environmental impacts after normalization and weighting.

**ID 15**

# Techno-economic analysis of alternate fuel sources for non-electrified rail operations: a case study in the Czech Republic

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**Keywords: railway; technical-economic analysis; viability; simulation**

## Abstract

### Objectives

The availability of new power sources such as hydrogen and battery offers new alternatives for upgrading from ICE on non-electrified railway lines. However, the comparison of technologies requires an in-depth analysis of technical, economic and operational requirements. In this paper, we evaluate the techno-economic feasibility of different energy sources (electrification, battery, and hydrogen against ICE) for a Czech railway line.

### Methods

We establish energy requirements using single-train simulations on track models, including height profiles and models of various rollingstock using air and rolling resistance and tractive-effort curves. The different technologies are compared by benefit-cost ratio, payback period, capex/opex and annualised investment cost – based on the development in energy prices. This is an extension of previous work on freight simulations.

### Results

We show the feasibility and the benefit-cost ratio of the different alternatives, which indicates the economic viability of ICE-alternatives such as hydrogen and hydrogen-battery hybrids. As expected, catenary electrification is not competitive, even if its operating costs are lower. Battery trains are at the limit of technical feasibility with a 120 km non-electrified line, but have the best benefit-to-cost ratio; hydrogen trains can be integrated into a hydrogen distribution network supporting other forms of transport. Both would be cheaper overall than diesel.

### Conclusions

Electrification of regional trains is not only possible with new technologies such as battery and hydrogen but is also likely to be significantly cheaper than continued diesel operation. The benefit is between 20 and 50% of costs and payback times of about 2 years.

## ID 53

# Fuel Cell Electric Vehicle optimal control: minimization of hydrogen consumption through a Dynamic Programming approach

Edoardo Cennamo [1], Lorenzo Bartolucci [1], Stefano Cordiner [1], Vincenzo Mulone [1], Federico Grattarola [1], Ferdinando Pasqualini [1], Marco Aimo [2], Gabriele Giraudo [2]

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**Keywords: Sustainability; Hydrogen; Energy Management Strategy; Optimization; Fuel Cell**

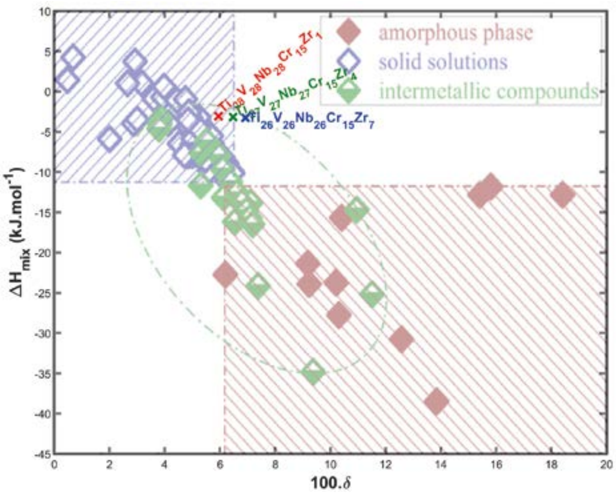
### Abstract

Modern climate change demands urgent decarbonization of human activities, and among them the transport sector is one of the most significant. Accordingly, the European Green Deal's objective is to reduce GHG emissions by 55 % by 2030 and to achieve carbon neutrality by 2050.

The international community is pushing alternative fueling vehicles replacing ICE powertrains to achieve this goal; in particular, Fuel Cell Hybrid Electric Vehicles (FCHEVs) have been demonstrating significant room for improvement, owing to short refueling times, great ranges due to the on-board high-pressurized tanks, high efficiency of powertrain components, and safe operating conditions.

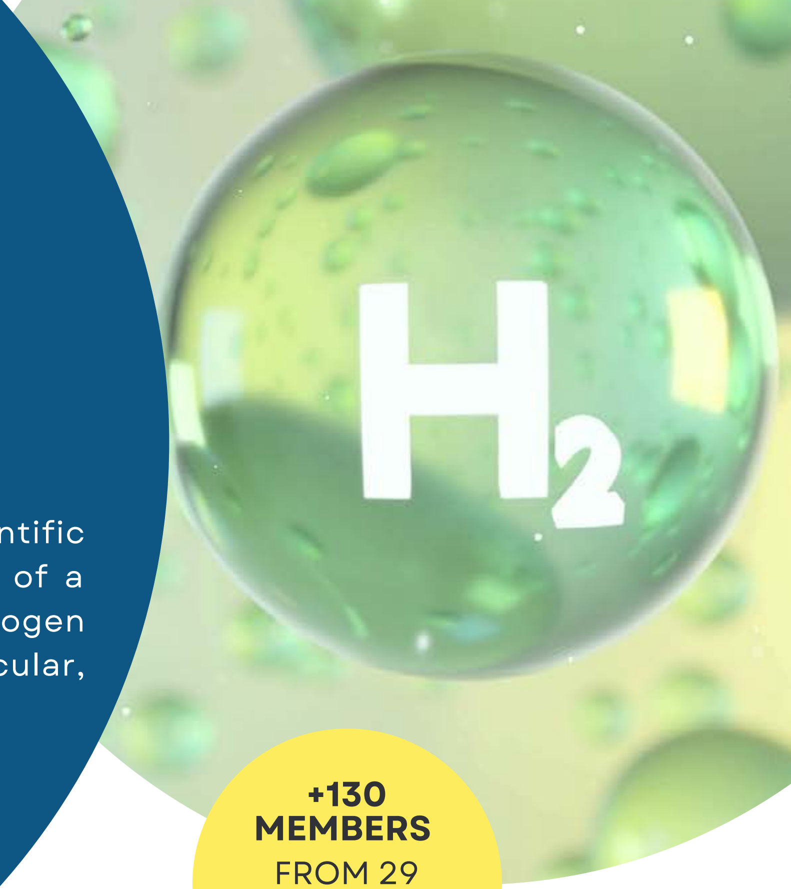
However, the design of an ad hoc Energy Management Strategy (EMS) is crucial. Rule-based approaches still represent the state-of-the-art for vehicular applications, while optimization-based ones are the most effective to enhance the global efficiency.

In this work, the optimal control of a FCHEV is proposed through an offline Dynamic Programming approach, minimizing the hydrogen consumption. The control test has been carried out through a Digital Twin, modeling in detail all the subsystems of the vehicle, including the thermal ones, thus simulating the whole Balance of Plant. The results obtained over the WLTP driving cycle show a characteristic behavior of the powertrain control actions: an initial battery charge phase at FC highest efficiency operating points is followed by a charge depleting phase, where the FC is helped by the battery to supply the requested power. Moreover, a comparison with a Range Extender strategy is proposed, showing the improvement of almost 7 % in the estimated range.



Hydrogen Europe Research

# Hydrogen Europe Research




We represent the European scientific community involved in the development of a new industrial ecosystem based on hydrogen and committed to moving towards a circular, carbon-neutral economy.

Our members are Universities and Research & Technology Organisations (RTO) active within the European hydrogen and fuel cells sector.

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## ID 7

# Driving cycle simulation of hybrid passenger cars powered with hydrogen engine

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**Keywords: Hydrogen engine; Hybrid vehicle; NOx emissions**

### Abstract

The hydrogen combustion engine (H2ICE) provides an available and mature solution to the demand for carbon neutral transportation. H2ICE doesn't produce (relevant) on-site CO2 emissions and the emitted amount of the principal pollutant (NOx) can be minimized to near zero levels using correct engine control and aftertreatment. The research objective is to evaluate the performance of H2ICE in passenger cars, accounting for current powertrain trends (downsizing, turbocharging and hybridization).

Experimental data from a single cylinder engine are used to construct an equivalent virtual 4-cylinder 1.5l engine, which is incorporated into a vehicle model. Mild hybrid vehicles, representing four segments, are then investigated through driving cycle simulations.

The subsequent virtual engine maintains very high efficiency and low NOx emissions throughout majority of its operating range, achieving peak power of 53 kW/l @4000 RPM. The predicted hydrogen consumption for a C segment vehicle in WLTC is 1.1 kgH2/100 km (4 l/100 km of gasoline equivalent), the NOx emissions are kept well below the EURO6 limit without the use of any aftertreatment (0.02 g/km) and the CO2 emissions induced by lubricant-burning amount to 0.2 g/km. With the considered storage solution, the vehicle attains a range of 480 km.

The results indicate the potential of H2ICE to decarbonize transportation and to further decrease vehicle fuel (energy) consumption while maintaining ultra-low pollutant emissions and an acceptable range.

This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres, project #TN01000026 Josef Bozek National Center of Competence for Surface Vehicles. This support is gratefully acknowledged.

**ID 23**

# Simulative sensitivity analyses of a stationary PEMFC-stack model for automotive application

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**Keywords: PEMFC; Simulation; Sensitivity analysis; Automotive; Modelling**

## Abstract

The research project 'Hzwo:FRAME Eco_CC' [1] pursued the goal of gaining new insights into PEMFC-vehicles by combining sensor data and process models in order to develop an economical and more reliable measurement and control concept for automotive applications. Another aim was to reduce sensor costs for cell monitoring and to decrease the experimental effort in the development phase.

For this purpose, a greybox model of a FC stack was developed in MATLAB/Simulink, which depicts the steady-state behavior for varied currents, different relative cell humidity, temperatures and pressures. The simulation results approximate the measured data on a test bench very well, whereby the relative deviations are normally distributed. The model was used in a sensitivity analyses considering different operating conditions and was experimentally validated. An increased sensitivity of the cell voltage to a drop in pressure and a drop in humidification in the cathode was proven. At higher current levels, the cell reacts more sensitively to a drop in humidity. In addition, a higher cooling temperature increases the drying out of the membrane, which could damage the cell. With the help of the simulation model, the negative influence of nitrogen in the anode could also be described qualitatively.

[1] The project 'Hzwo:FRAME Eco_CC' was supported by the European Regional Development Fund (ERDF) and the 'Sächsische Aufbaubank (SAB)' on the basis of a decision by the State of Saxony.

## ID 10

# Risk analysis of the hydrogen filling station: case study

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**Keywords: hydrogen; filling station; risk analysis; case study**

### Abstract

Nowadays, hydrogen technologies and their use in daily life are being worldwide developed and supported. As one of the most promising energy carriers, hydrogen should be used as an alternative energy source for vehicles. In connection with that, hydrogen filling stations and infrastructure are developed. Although hydrogen use is wide with several advantages, it still has a high risk as well.

The purpose of the present study is to summarize a risk analysis of the hydrogen filling station, where hydrogen will be produced, stored, transported, and used. The aim of the study is to assess the safety zones from the risk of fire and explosion. According to the "Purple Book" the most significant scenarios that pose the greatest risks to the physical surroundings were identified and the subsequent quantitative risk assessment was provided. The main assessed activity that will affect safety is production technology and hydrogen storage, including a pipeline and a stand for filling. These activities are given the necessary attention in the risk analysis and assessment. The following scenario, continuous leakage of hydrogen from a high-pressure vessel, dispersion to the surrounding area, and possible ignition which should lead to fire or explosion, was evaluated in detail.

According to the results, the risk in the hydrogen filling station considered is socially acceptable. Within the risk analysis, safety measures were adequately evaluated and appear to be sufficient given the results of the presented risk analysis.

## ID 20

# A plant-specific approach to model future hydrogen demands in energy-intensive industries

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**Keywords: Industry; Agent-based Modelling; Decarbonisation; Hydrogen; site-specific**

### Abstract

### Objective

High ambition in hydrogen roll – out (e. g. REPowerEU) show the need for more detailed planning. The industry sector is expected to be the most important demand sector for green hydrogen and the ramp-up of infrastructure. The integration of hydrogen into the energy-system is a major task ahead with high uncertainties and partly directly related to new processes or process designs. A better systemic understanding of the integration in the energy system requires detailed knowledge about the spatial distribution of demand potentials and the age structure of the plant-stock. This would facilitate the development of policy-strategies.

### Method

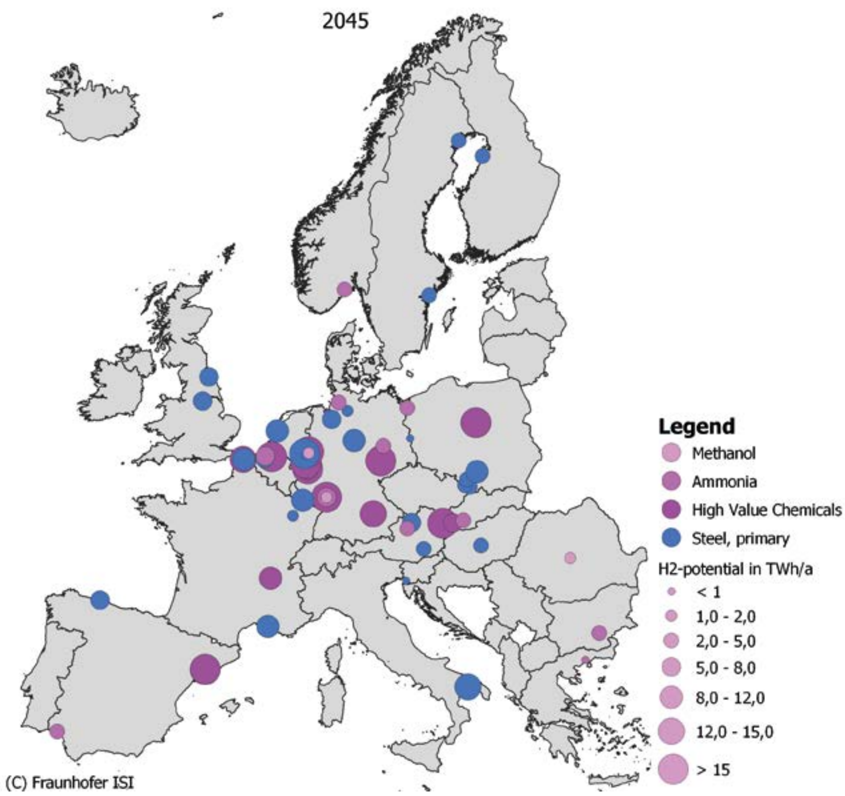
To close this gap, we present a site-specific bottom-up approach for modelling the transition of energy-intensive industries. In particular, we are taking into account the georeferenced industrial plant stock and its age distribution. This knowledge allows addressing the windows of opportunity according to natural reinvestment cycles of the industries to avoid stranded investments. The site-specific transformation through diffusion of new climate-neutral technologies is calculated using process-specific reinvestment cycles and economic indicators.

### Results/Conclusions

The presented results reflect the modelling approach and show model results for the transition towards hydrogen technologies based on the current plant age and typical reinvestment cycles per technology in the EU. Here, we are focussing on primary steel plants as well as basic chemicals (Ammonia, Methanol, HVC). This could lead to a demand of around 150 TWh in 2030 and 500 TWh in 2050 by assuming today´s industry structure.

### Acknowledgement

This work is supported by the German BMBF-project TransHyDE-Sys.


2045
Legend
Methanol
Ammonia
High Value Chemicals
Steel, primary
H2-potential in TWh/a
< 1
1,0 - 2,0
2,0 - 5,0
5,0 - 8,0
8,0 - 12,0
12,0 - 15,0
> 15
(C) Fraunhofer ISI

**ID 41**

# Green hydrogen generation coupled with iron production

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**Keywords: Water electrolysis; iron; MXene; eletrochemical reduction; HER**

## Abstract

Hydrogen production technologies have received significant attention as a supply of clean energy meeting the worldwide increasing energy consumption. Greener approaches to hydrogen production without fossil fuels dependence have opened new technology pathways. Water electrolysis represents an economical and sustainable method for this purpose [1]. Cathodes manufacturing is critical for developing water electrolysis as a suitable technology for hydrogen production. The development of ceramic iron oxide cathodes seeking Fe production for steelmaking has been successfully attempted under alkaline conditions [2], with H2 and O2 as by-products. On the other hand, promising MXenes-based cathodes showed high catalytical activity towards hydrogen evolution reaction (HER) [3]. In this scope, two types of cathodes have been designed and fabricated in the present work: i)the co-generation of H2 and Fe from hematite-based cathodes; and ii)efficient hydrogen production boosted by MXenes-containing cathodes. Hematite-based cathodes were processed using emulsification of ceramic suspensions. Ti3AlC2-MAX/Ni were synthetized by the self-propagating high-temperature synthesis and etched in NaOH (1M) for obtaining MXene. XRD/SEM/EDS studies were performed. Water splitting was performed in alkaline electrolytes (10M for i; 1M for ii)), with a Pt wire as anode and a reference electrode of Hg|HgO|NaOH (1M). The results show the contributions of HER + iron reduction, while the cathode microstructure also impacts both processes. The demonstrated approach is expected to bridge the metallurgical sector and green hydrogen production. Novel nano-Ni/Ti3C2(OH)x MXene cathodes also proved to be suitable towards efficient HER.

## References

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[3] https://doi.org/10.1002/anie.201800887

**ID 25**

# Climate-neutral raw material supply for refineries – opportunities for the refinery site Schwedt in Germany, Brandenburg

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**Keywords: Refineries; PtL; High Value Chemicals; Net Zero; 2045**

## Abstract

### Motivation and research objective

Refineries process crude oil mainly into fuels and platform chemicals. In order to achieve climate neutrality in all sectors by 2045, we need to move away from fossil fuels, become circular and electrify extensively. Therefore, the question here is whether and how refineries can be made climate neutral by 2045.

### Methodological approach

Different synthetic pathways for the production of fuels and platform chemicals are investigated and compared. Demand trends for fuels and platform chemicals are determined from German energy system studies, a potential product portfolio for a future carbon-neutral refinery Schwedt is derived. The resulting capacity is calculated, the resulting feedstock and infrastructure requirements are derived.

### Results and conclusions

The analyses have shown that refineries are indispensable industrial sites and can make a valuable contribution to the energy transition and regional structural change in the future, although capacities will probably have to be drastically reduced.

To achieve climate neutrality, the fuel production of refineries will probably be limited to kerosene and marine diesel. Fischer-Tropsch synthesis (FT synthesis) and methanol-to-synfuels pathways can be considered for synthetic fuel production (kerosene, diesel). Platform chemicals can be produced either from the co-product naphtha from FT synthesis or via the methanol-to-olefins (MtO) pathway. However, it is still unclear which part of the value creation may be outsourced to countries with high renewable potential or kept locally.

Based on: Pieton N.; Neuwirth M.; Jahn, M.; Ragwitz, M. (2022): Policy Paper zur Sicherstellung einer mittel – bis langfristigen klimaneutralen Rohstoffversorgung der Raffinerie Schwedt. doi:10.24406/publica-478.

Refineries; PtL; High Value Chemicals; Net Zero; 2045.

**ID 16**

# Techno-economic and net energy comparative studies of Liquid Organic Hydrogen Carrier (LOHC) storage and transport

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**Keywords: LOHC, LOHC Storage, Process Design, Techno-economic analysis, Net energy analysis**

**Abstract**

Hydrogen is currently utilized as one of the clean fuels and energy. Nevertheless, its low volumetric density (0.08988 g/L at 1atm) makes it difficult to store. The Liquid Organic Hydrogen Carrier (LOHC) system is an attractive option for hydrogen storage and transport. However, the selection of a suitable LOHC, its deployment in hydrogen fuel stations, and its economic viability are active areas of study. To fill this research gap, this study utilized an Aspen HYSYS simulation to investigate and compare a few representative LOHCs in cargo handling systems. We also considered the development of steady-state models for the entire cargo handling system, including storage, transportation (i.e., loading and unloading), dehydrogenation, and fuel cell-based hydrogen utilization. For the production of hydrogen from rich LOHC, a hydrogenation and dehydrogenation reactor and process simulation were conducted.

Finally, a comparison of the properties, of the LOHCs, a techno-economic evaluation, and a net energy analysis of the LOHC system were conducted. LOHC's properties were compared based on their storage capacities, energy densities, dehydrogenation temperatures, toxicities, prices, energy consumptions, and material handling. Utilizing the Aspen Capital Cost Estimator, a techno-economic evaluation is performed by estimating capital and operating costs. For the purposes of further calculation, the LOHC fuel cell integrated system is considered as a regenerative hydrogen fuel cell consisting of an electrolyzer, hydrogen storage, and fuel cell. Therefore, the electrolyzer, hydrogen compressor, hydrogen storage, and fuel cell were included in the evaluation of energy stored on investment (ESOI).

# Abstract Posters

**ID 43**

# Towards tailored nanomaterials for fuel-cell applications: Binary platinum-tungsten nanoalloys by spark ablation

Nina Zábojníková [1], Tomáš Němec [2], Meenakshi Seshadhri Garapati [2], Ján Híveš [1], Viliam Vretenár [3]

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**Keywords: nanomaterials; spark discharge generator; proton exchange membrane fuel cell**

## Abstract

Spark discharge generator (SDG) is an environmentally friendly, scalable and cost-efficient gas-phase method employing spark discharge plasmas for the production of high-purity nanoparticles with tailored properties. Approximately 80 pure elements can be converted into nanoparticles using spark ablation. The use of alloyed electrodes, sintered mixed-powder electrodes, or the setup of two electrodes from different metals in the SDG can yield mixed nanoparticles with predictable and tunable composition and size distribution. The potential for the use of nanoparticles generated by SDG is large, including materials for catalysis, lithium ion batteries, semiconductor fabrication, etc. Specifically, core-shell nanoparticles have potential applications as electrocatalysts in proton exchange membrane fuel cell (PEMFC) [1], [2].

We have synthesized binary platinum-tungsten nanoparticles by SDG both in the form of homogeneous nanoalloys and inhomogeneous core-shell-like nanosystems. Our results show how the evaporation rates for Pt-Pt, Pt-W, and W-Pt SDG electrode arrangements (anode-cathode) depend on the carrier gas employed in the process and how efficient is the nanoparticle collection by electrostatic filtering. Moreover, EDS-STEM elemental mapping and XRD characterization show a correlation of the ratio of the evaporated material from each electrode and the composition of the synthesized nanomaterials. With one of the electrode arrangements, using platinum as the anode and tungsten as the cathode, we have achieved to form core-shell nanostructures.

## References

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**ID 51**

# Performance Measurement of Inkjet Printed Catalyst Layers for PEM Fuel Cells

Miroslsv Hala [1], Martin Prokop [1], Tatiana Zubkova [2], Andreas Willert [2], Kathleen Heinrich [2], Dana Mitra [2], Martin Paidar [1], Karel Bouzek [1]

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**Keywords: PEM; fuel cells; inkjet; printing; CCM**

**Abstract**

PEM fuel cells are devices for the conversion of chemical energy, stored in hydrogen and oxygen, to electrical energy within Hydrogen economy concept. Inkjet printing of catalyst layers directly on the membrane is a fast, reliable, and precise technology, which can be used in mass production. Using this technology, 3D structured layers can be printed allowing for better utilization of the catalyst and maintaining good three-phase contact. In this work, a number of catalyst coated membranes (CCMs) with an active area of 25 $cm^2$ was prepared by inkjet printing and tested in a PEM fuel cell along with the reference CCMs prepared by ultrasonically-assisted ink deposition. After 24 hours of operation at 1 $A{\cdot}cm^{-2}$, the cells were characterized using load curves, electrochemical impedance spectroscopy, and cyclic voltammetry with pure nitrogen supplied to the cathode. The inkjet-printed CCM showed performance similar to and in some cases even better than that of the CCM prepared by sonic deposition, while having a lower platinum loading. This shows that inkjet printing is a viable technique for the preparation of CCMs which could help drive down the cost of fuel cells.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958174. This project is co-financed from the state budget by the Technology agency of the Czech Republic under the M-ERA.Net Programme, project No. TH80020006. This project is co-financed with tax funds on the basis of the budget passed by the Saxon state parliament.

**ID 46**

# Development of turnkey transportable system at ICI Caldaie

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**Keywords: Transportable System; Integration; Reactors**

**Abstract**

The continuous collaboration between ICI Caldaie (an industry active in the energy transformation sector) and international universities, has allowed a cross-fertilization between different skills allowing to accelerate the process from the conception of a new technology to its positioning on the hydrogen market sector.

**ID 27**

# Improvement of gas-diffusion electrodes for novel hybrid alkaline water electrolysis

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**Keywords: alkaline water electrolysis; anode; gas diffusion electrode; nickel iron catalyst; oxygen evolution reaction**

## Abstract

Hydrogen production via alkaline water electrolysis (AWE) is particularly economical due to the use of low-cost materials [1]. A new hybrid AWE concept with only one electrolyte cycle employing nickel-iron gas-diffusion electrodes (GDE) for oxygen evolution (OER) was proposed by Koj et al. [2]. These GDEs reached a similar performance as classical AWE electrodes at current densities of up to 400 mA cm-2 [2].

For the GDEs prepared in earlier work, iron (II) acetate as a relatively expensive component was used as iron precursor. For this reason, we evaluated two different, less expensive precursors as alternatives. Moreover, another work on silver-based GDEs used for oxygen reduction showed that the PTFE content is also an important parameter influencing the physical properties and the electrochemical performance [3, 4].

Variation of the iron precursor revealed that iron (II) gluconate is a cost-effective alternative to iron (II) acetate which leads to GDEs with comparable overpotentials and technical current densities as reported by Koj et al. [2]. With rising PTFE content in gluconate-based GDEs, the breakthrough of the electrolyte could be inhibited and the pore structure changed towards smaller pore sizes. LSV measurements carried out at room temperature and 32 wt.-% KOH showed that the overpotential of the OER decreases with the PTFE content. Consequently, an optimal PTFE content is required to operate the GDE at low overpotential without electrolyte breakthrough.

**ID 45**

# Effect of alkaline electrolyte concentration and temperature on the HER and OER performance on nickel electrodes

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**Keywords: hydrogen; alkaline water electrolysis; nickel electrode; HER activity; OER activity**

## Abstract

Nowadays, hydrogen represents feedstock for chemical industry. However, as an energy vector, it can be used for balancing the fluctuating production of electricity from renewable sources. Alkaline water electrolysis (AWE) represents an industrially established technology that is considered for hydrogen as energy vector production. In order to maximize the efficiency of energy storage, modifications of AWE like anion-exchange membrane water electrolysis (AEMWE) are being developed. AEMWE operates in zero-gap arrangement with porous electrodes pressed to the surface of the AEM. AEMWE can operate with diluted KOH solutions, however, the AEM causes temperature limitation. This change of conditions may affect the electrochemical activity of the nickel electrodes for hydrogen and oxygen evolution reactions (HER and OER).

The aim of this work is to study kinetic effect of pH and temperature on HER and OER. Rotating disc electrode measurements in KOH concentrations ranging from 0,1 mol dm-3 to 5 mol dm-3 and temperatures from 30 °C to 70 °C are used to accomplished this task. The exchange current density and Tafel slope of HER and OER were evaluated by electrochemical impedance spectroscopy and linear sweep voltammetry measurements. Results are compared with kinetic parameters of 3D electrodes made of nickel foam. Based on the results obtained, increase of Ni electrochemical activity at higher temperatures and concentrated electrolytes was observed.

## Acknowledgement

This project has received funding from the European Union's Horizon 2020 Research and innovation action under grant agreement No 862509. This work was supported by the grant of Specific university research.

ID 39

# Statistical techno-economic assessment of renewable energy supplying of water splitting in hydrogen production process (A case study of USA)

Mr Mohammad Gheibi, Masoud Khaleghiabbasabadi [1], Stanisław Wacławek, Miroslav Černík

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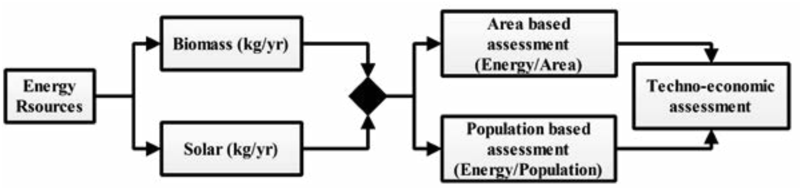
**Keywords: Biogas, Solar energy, Hydrogen, production**

### Abstract

One of the main issues for hydrogen energy production is related to the energy supply from the water-splitting process. While, applying renewable energy resources such as biogas or solar can guarantee a clean hydrogen energy production process. In the present study, the banked data is organized into two categories for solar, and biogas, containing area – and population-based assessments as per National Renewable Energy Laboratory reports in USA. According to the outcomes, it can be found that in USA, the volume of hydrogen production based on the solar system is enormously more than biomass resources. According to statistical results, it is clear that the solar system's Hydrogen Energy Production Used Area (HEPUA) (kg/yr. km2) factor is more efficient than biomass resources. Therefore, from an economic aspect, the biomass system does not have considerable performance compared to the solar system. Because, on average, 5.7 tons/yr. km2 of energy is produced per square kilometer of hydrogen energy production with the biomass system, while this amount is around 704 tons/yr. km2 for the solar system. Finally, it can be concluded that from all technical, economic and social points of view, hydrogen energy production using solar resources has higher efficiency and brings more development justifications. However, it should be noted that the production of hydrogen using biogas energy was not only from the energy supplying of water splitting and it also has an environmental purpose such as circular economy implementation.



**ID 12**

# High efficiency power electronics for direct hydrogen production from solar power

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**Keywords: power electronics, hydrogen production, solar power**

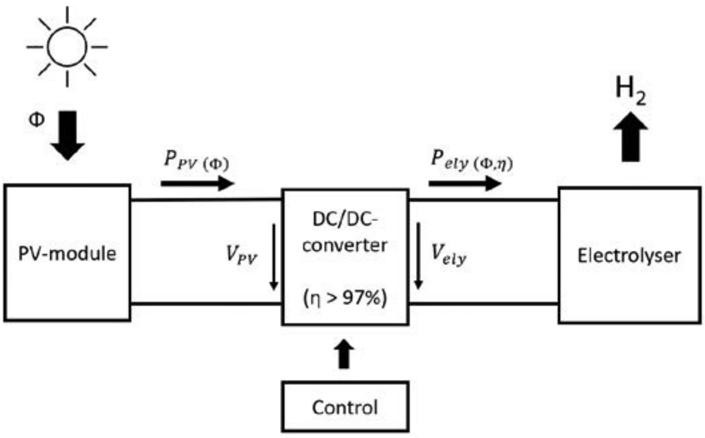
## Abstract

Power electronic devices are key components in any electrolysis and fuel cell system [1]. In order to maximize hydrogen production from renewables, the very high efficiency of more than 97 % achievable by power electronics can be a useful contribution.

Local solar power is especially suited for utilisation in electrolysis systems, since solar power is not only amongst the cheapest in the market [2], but also the DC-nature of photovoltaics benefits the efficiency and complexity of the required power electronics.

In the present work a small-scale mobile demonstrator system for hydrogen production from solar power was designed, containing solar panels with 720 Wpeak, a specially designed synchronous buck converter with maximum power point tracking controls and a PEM-Electrolyser for hydrogen production. The main focus was set to achieve a high efficiency of more than 97 % for the synchronous buck converter.

Results showed a peak conversion efficiency for the synchronous buck converter of 99.3 % while remaining above 97.5 % efficiency for the measured input power range.



ID 47

# Effect of light distribution on the physiology of Chlamydomonas reinhardtii

Çağla Yarkent [1], Ayşe Kose [1,2], Cecilia Faraloni [3], Esra Imamoglu, Murat Elibol [1], Giuseppe Torzillo [3,4], Fazilet Vardar Sukan [5,6], Suphi Ş. Oncel [1]

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**Keywords: Green hydrogen; Biohydrogen; Microalgae; Chlamydomonas reinhardtii**

**Abstract**

Global warming concerns and the problem of energy supply/demand are increasing daily. Among of energy sources, hydrogen is considered as a sustainable and renewable one. Biological hydrogen production is recognized as an exciting technology development area. In this topic, photosynthetic microorganisms, especially microalgae and cyanobacteria are preferred as light-sensitive microorganisms due to their high hydrogen yields. Considering the hydrogen producer microalgae species, **Chlamydomonas reinhardtii** has been drawn attention as a model organism. In photosynthesis, D1 protein complex has a role in electron transport system through photosystems (PSs). The main objective of the study is to investigate the effect of different distribution of high light on the growth and the physiology of **C. reinhardtii** wild type strain and **C. reinhardtii** D1 protein mutant. The findings pointed out the importance of D1 protein in responses to high light stress in C. reinhardtii, and in particular evidenced how a reduced performance of PSII, with a reduced electrons transport rate, a plastoquinone pool reduction level higher than the wild type strain, made this strain less sensitive to the high light exposure. This was showed both by the reduced decline of Chlorophyll-a fluorescence and xanthophylls cycle induction lower than in the wild type.

The authors would like to thank Institute of Ecosystem Study (now: Research Institute on Terrestrial Ecosystems) (CNR) and National Research Council of Turkey (TUBITAK) for their financial support (Bilateral Project No: 111M609).

## ID 37

# Solid state materials for deuterium storage

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**Keywords: metal hydrides; deuterium; hydrogen; storage material**

### Abstract

The utilization of hydrogen as an energy vector in the coming decades has boosted the research and enhancement of hydrogen storage procedures. Metal hydrides (MH) are a safe and manageable technology to store hydrogen at lower pressures in small systems that through chemically bonded hydrogen molecules within the metal compound structure remain stable at atmospheric pressures. The surge in the research activity of scientists worldwide can be traced back to the publication of the seminal paper in 2016 by Sahlberg et al., who reported enormous hydrogen uptake of 2.7 wt % by the TiVZrNbHf.

The R&D in the field of MH is focused on optimizing the characteristics of materials that have to exhibit not only high hydrogen capacity but also the low temperature of hydrogen release and have to be economically achievable.

Therefore here is an effort to substitute costly Hf with high mass by other chosen elements. The aim of the present work was to investigate a series of materials TiVZrNb-X (X=Cr, Ni, Fe, Ag, Ta) prepared by arc-melting and evaluate their potential for use as deuterium storage materials.

Deuterium absorption capacity was studied by the gravimetric method, which demonstrated levels of absorption ~1 D/M. The best result showed TiVZrNbCr containing 3.28 wt % of deuterium which corresponds to 1.1 D/M. Thermogravimetric analysis and high-energy in-situ XRD measurement confirmed the deuterium desorption onset temperature at 146.8 °C. Our contribution provides proof that alloys composed of intermetallic compounds have higher deuterium storage capacities compared to solid solutions.

**ID 55**

# Medium-entropy alloys for hydrogen solid state storage

Karel Saksl [1,2], Jakub Kubaško [1], Dagmara Varcholová [2,1], Jens Möllmer [3], Marcus Lange [3]

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**Keywords: medium entropy alloys; hydrogen solid state storage; hydrogen absorption; X-ray diffraction**

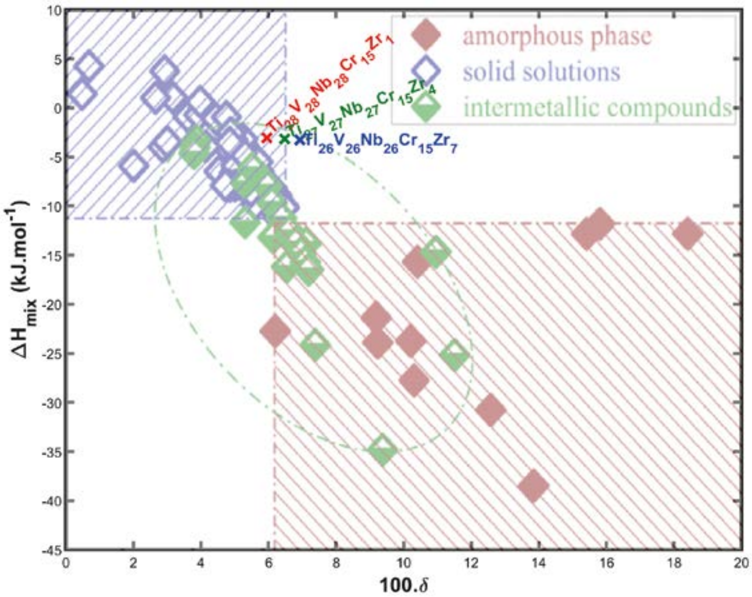
**Abstract**

Hydrogen storage in the solid state is one of the most efficient, as it allows to store more hydrogen per unit volume than in the liquid or gaseous state.

Recently, novel groups of alloys known as high entropy alloys (HEA), complex concentrated alloys (CCA), multi-principal element alloys (MPEA) or more generically multicomponent alloys were introduced by the scientific community, expanding the options of compositions to be assessed. Differently from conventional alloys, these groups are based on at least 3 elements having substantial atomic fraction, i. e., alloys belonging to the central part of multicomponent phase diagrams. Such multicomponent alloys can either form single solid solutions with simple structures, such as face-centered cubic (FCC), body-centered cubic (BCC) and hexagonal close-packed (HCP), or more complex structures combining multicomponent solid solutions and intermetallic compounds

Medium-entropy multicomponent TiVNbCr alloys have recently attracted attention of researchers, as these alloys form FCC hydrides at room temperature and achieve a maximum hydrogen absorption of 2 H/M (3.1–3.2 wt%) in a few minutes, demonstrating a fast absorption kinetics. Despite excellent absorption properties, desorption of hydrogen from these alloys takes place at very high temperatures (above 150C) while complete desorption occurs only at 450C.

In our work, we tried to lower the hydrogen desorption temperature from this high potential alloy by adding a small proportion of zirconium. We present the results of our research on Zr-doped systems from the point of view of hydrogen absorption as well as hydrogen desorption.



ID 17

# Risk of hydrogen embrittlement in a mixture of natural gas and hydrogen

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**Keywords: hydrogen embrittlement; gas grids; steel; hydrogen absorption**

## Abstract

Because there is increasing pressure on carbon neutrality, hydrogen blending into the existing natural gas system is becoming an important issue. Natural gas infrastructure is made up of a wide range of steel components that might be prone to unpredictable failures due to hydrogen embrittlement. This phenomenon may occur due to the interaction of steel with diffusible hydrogen, resulting in deterioration of the mechanical properties of steels. The steel-hydrogen interaction strongly depends on the material microstructure, surface state, and environmental parameters.

Preliminary experiments suggest that contact of steel with dry hydrogen gas at a pressure of up to 80 bars is not hazardous due to the low rate of hydrogen entry into steel. However, the combination of atomic hydrogen formed by the reduction of H+ ions accompanying steel corrosion and the dissociation of pressurized hydrogen gas can be potentially detrimental.

Steel specimens were exposed to different environments, simulating real conditions in gas industry facilities, to assess the critical environmental parameters that enhance the entry of hydrogen into steel. The amount of absorbed hydrogen was measured by thermal desorption spectroscopy. For a comprehensive understanding of the influence of different environmental factors, corrosion products formed on the surface of the exposed samples were characterized by energy dispersive X-ray spectroscopy (SEM/EDX) and X-ray diffraction spectroscopy (XRD). Particular attention was paid to clarifying the found synergy between corrosion-induced hydrogen and gaseous hydrogen. Slow-strain rate test (SSRT) was conducted to evaluate the susceptibility of industrial steels to hydrogen embrittlement.

## ID 14

# Hydrogen Utilization by Steam and Gas Turbines

Jaroslaw Milewski [1], Piotr Puszka, Andrzej Miller

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**Keywords: hydrogen, steam turbines, gas turbines, oxygen combustion**

### Abstract

The hydrogen fueled steam turbine cycles with direct firing studied as part of this research (500 MW class units) show very high thermal efficiency (up to 71%), which is far higher than the performance of known cycles. It has been fully confirmed that it is possible to achieve efficiency levels at least 10 percent points higher than the efficiency of the most efficient power units currently. Similarly, all the analyzed steam turbine cycles have very high specific power (2.2–4.7 MJ/kg), which is many times higher (in extreme cases, by an order of magnitude) than the performance of current gas or steam turbines or combined cycles.

Similarly, hydrogen fueled gas turbines were analyzed for two manufacturers: General Electric and Siemens. By using hydrogen, the efficiency is raised to almost 40% compared to natural gas as fuel, which gives 31%. Due to environmental limitations (NOx creation in combustion chambers) hydrogen needs to be mixed with steam and/or nitrogen to reduce firing temperature, but the temperature is still slightly higher than for natural gas.

**ID 52**

# Map of ideal locations of HRS in CZ

Bronislav Vahalík [1], Vojtěch Přikryl

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**Keywords: HRS location; consequences; Czechia**

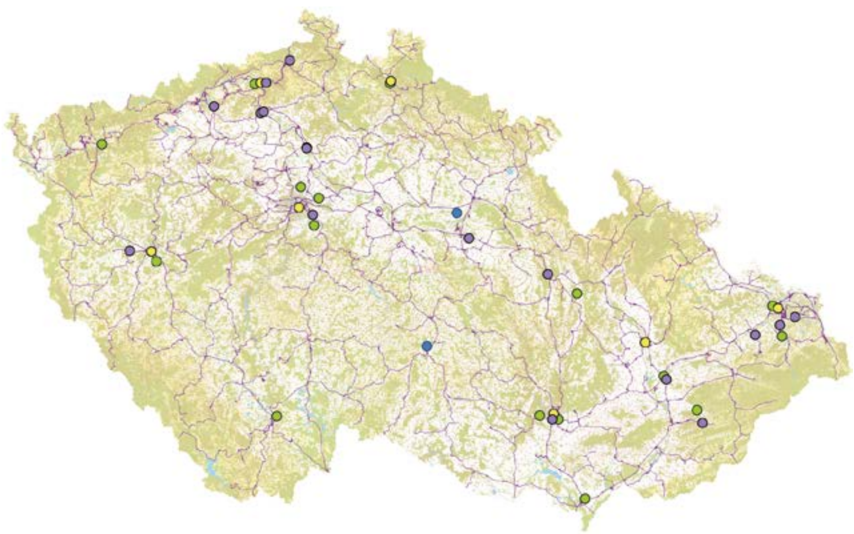
**Abstract**

The poster in a form of a map will demonstrate the ideal location of filling stations in the Czech Republic concerning:

- AFIR approved
- traffic intensity
- potential for multimodal use
- accessibility of the site for heavy-duty transport

Not every investor in hydrogen refuelling stations or subvention approval procedures is aware of the impacts of a possible traffic increase and other consequences.

The basic steps to follow for "ideal choice of location" will be introduced.



## ID 35

# Viewpoints of Gaseous $H_2$ (Fuel Cell Vehicle) applications in green sustainable transportation system (A case study of California state, USA)

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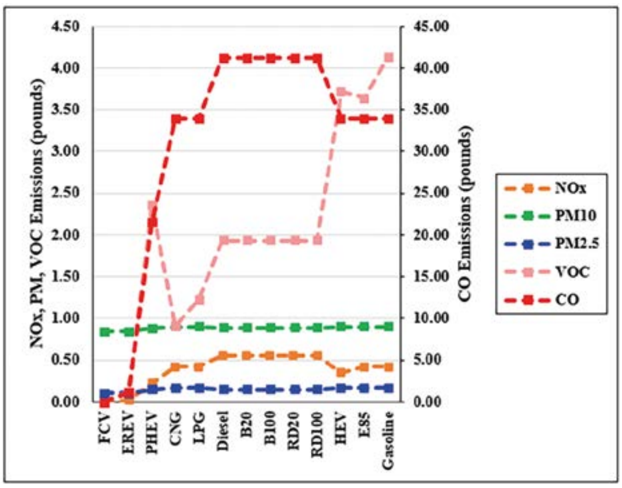
**Keywords: Gaseous $H_2$; Fuel Cell Vehicle; Green Transportation System; AFLEET simulations; Air pollution**

### Abstract

Hydrogen Energy Resource (HER) is assumed to be a green and clean technology for supplying energy in different applications such as industries, transportation systems, or household usage. In this research, the air pollution of different fuel resources is evaluated in driving cars by the application of the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool in California state, USA (12400 miles driving annually). For the comparing air pollution emission of Gaseous $H_2$ Fuel Cell Vehicles (FCV) with other resources, some different fuels such as Gasoline, Diesel, Electricity (Hybrid Electric Vehicles-HEVs), Biodiesel (B20 and B100), Renewable diesel (RD20 and RD100), Ethanol (E85), Propane, Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LNG), and Diesel Exhaust Fluid (DEF). Based on simulations, the lowest and the highest amounts of Petroleum use index for the fuel preparation are connected to FCV and Gasoline with 0.03 and 8.33, respectively. The outputs of AFLEET simulations demonstrated that FCV does not release CO, NOX, and Volatile Organic Carbon (VOC). While, in the CO and NOx emissions, the worst fuels are Diesel, B20, B100, RD20, and RD100 with 41.21 (CO) and 0.55 (NOx) pounds, similarly. Regarding VOC, the least quality fuels are HEV and E85 with 3.72 and 3.65 pounds emissions, correspondingly. Also, regarding the emission of Particle Matter (PM10 and PM2.5), FCV with 0.85 (PM10) and 0.11 (PM2.5) pounds has an ideal condition. In conclusion, it can be understood that the cleanest fuel for transportation systems is FCV based on H2 resources.



**ID 56**

# Technical analysis of hydrogen production based on water electrolysis technology with storage and HRS

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**Keywords: hydrogen; PV farm; HRS; mining dumper**

### Abstract

Hydrogen can help tackle various critical energy challenges. It offers ways to decarbonise a range of sectors – including long-haul transport, chemicals, and iron and steel – where it is proving difficult to meaningfully reduce emissions. It can also help improve air quality and strengthen energy security. Mining dumper producers are also trying to commercialize hydrogen technology that's been in development in last years, but has been held back by prohibitive costs and a lack of infrastructure. While the vast majority of heavy-duty dumpers are powered by diesel engines, manufacturers and parts suppliers have stepped up development of alternatives to comply with stricter emission rules. The purpose of the study is to present the possibility of design and implement a system for hydrogen production based on the electrolysis process, powered by a photovoltaic (PV) farm and refuelling station for the mine's internal transport vehicles. The designed system also includes battery storage, regulating the flow of power between the electrolyser and the PV farm, and pressurized hydrogen fuel storage. The research methodology was systematically designed to ensure valid and reliable results that address the research aims and objectives.

**ID 38**

# Policy-making of hydrogen energy production in countries with the application of Shlaer – Mellor technique

Mohammad Gheibi, Masoud Khaleghiabbasabadi [1], Stanisław Wacławek, Miroslav Černík

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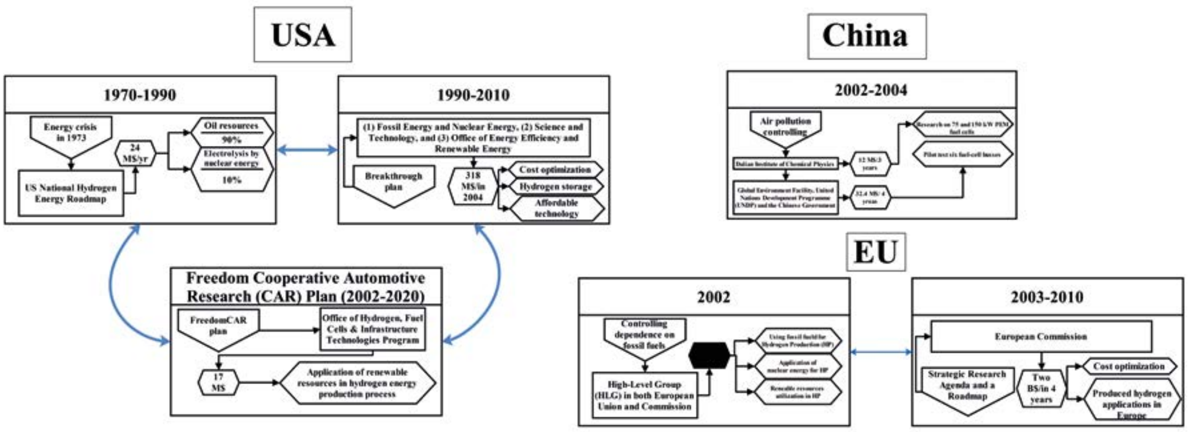
**Keywords: Hydrogen, Energy, Production, Sustainability**

## Abstract

As per the importance of hydrogen energy production as a green energy resource in different countries, the necessity of policy-making in the field is more evident than in the past. In this research section, the policies of different countries, including; China, USA, and European, for hydrogen production are evaluated. In the case of policy-making, Shlaer – Mellor method is utilized for the first time. The technique is a type of Object-Oriented Analysis (OOA) method. Based on the modeling, it can be seen that the volume of invested expenses in EU is much more than USA, with an amount equal to 2 billion US$ in a limited time. According to created conceptual models, it can be found that in the USA, policies have been based on using fossil fuels as the raw material for hydrogen energy production. This is despite the fact that after several years of exploitation and development of the mentioned clean energy, approaches have changed, and also, the volume of investments has increased more than tenfold in the second ten years. While in Europe, a large investment has been made in the production of hydrogen energy from the beginning, and the focus has been on evaluating new applications of this renewable resource in society. Finally, in China, main investments were focused on technology development for using hydrogen energy in transportation systems. The study demonstrates that by creating such start-ups to use hydrogen as an energy source, significant amounts of black carbon emissions can be reduced emission amounts, annually.



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UCT PRAGUE

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GREEN REMEDY

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ŠKODA

CHART Innovation. Experience. Performance.

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CDV CENTRUM DOPRAVNÍHO VÝZKUMU

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SOLEK New energy for your investment

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