

# HydrogenDays 2019

10<sup>th</sup> International Conference on Hydrogen Technologies



**HYTEP**

CZECH HYDROGEN  
TECHNOLOGY PLATFORM

— SINCE 2007 —

March 27-29, 2019 | Prague, Czech Republic

Through collaboration to the deployment of H<sub>2</sub> technologies

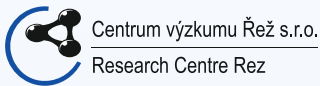


**PROGRAM  
&  
ABSTRACTS**

ORGANIZED BY



MEMBERS OF HYTEP



UNDER THE AUSPICES OF



SPONSORS & EXHIBITORS



**10<sup>th</sup> International Conference on Hydrogen Technologies**

# **HYDROGEN DAYS 2019**

Through collaboration to the  
deployment of H<sub>2</sub> technologies

Editor: Karin Stehlík

**Book of Abstracts**

**Final Program**

**List of Participants**

**March 27 – 29, 2019  
Prague, Czech Republic**

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- *Chairperson:* **Karel Bouzek**, University of Chemistry and Technology Prague, Czech Republic
- **Aleš Doucek**, ÚJV Řež, Czech Republic
- **Martin Paidar**, University of Chemistry and Technology Prague, Czech Republic
- **Karin Stehlík**, Research Centre Řež, Czech Republic
- **Jiří Vávra**, Czech Technical University, Czech Republic

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- **Matthias Jahn**, Fraunhofer IKTS, Germany
- **Federico Zenith**, SINTEF, Norway
- **Karin Stehlík**, HYTEP, Czech Republic

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## PREFACE

Dear Colleagues, Ladies and Gentlemen,

You have just opened the Book of Abstracts of the 10th international conference Hydrogen Days 2019 on hydrogen technologies and their applications. Yes, it is already the 10th edition of the event. In the early days, we hardly dared to hope that the event would be able to make a place for itself in the present world with its abundance of conferences, congresses and meetings, the world in which much larger countries and societies were significantly more advanced in recognizing the importance of hydrogen technologies and more advanced in implementing the application phase. Nevertheless, due to the well-nigh endless enthusiasm of the organizers and continuous support by our partners on a national as well as an international scale, this has become reality, and Hydrogen Days are now a well-established event in the community's calendar. Not huge, but attractive and vital. Just as hydrogen technologies are today! This is also the idea behind this year's conference motto:

**“Through collaboration to the deployment of H<sub>2</sub> technologies”**

Additionally, it is now traditional for the program of this anniversary conference to comprise two official parts and one unofficial one. The first part of the official program is represented by contributions highlighting recent advances and hydrogen technologies in selected countries. They were achieved locally, or in collaboration with other regions. The Visegrad countries and their neighbors have a special place in the program, but it is not limited to them. Their contributions will be accompanied by a presentation of selected important demonstration projects underscoring the viability and reliability of hydrogen technologies. This is all in the context of European policy, represented at the conference by Fuel Cells and Hydrogen Joint Undertaking. The second part of the official program focusses on reports on research activities addressing solutions to particular problems on a lower TRL level and preparing fundamentals for the next generation of hydrogen technologies.

The third part, as mentioned above, is the informal one, devoted to networking among the participants, discussion of new ideas, discussion of the new research findings presented, and also a discussion of new project topics, new consortia and new collaborations.

Therefore, I would like to thank all of you for joining us at this special event and for contributing to it.

I wish all of us an informative, interesting and pleasant meeting with a profusion of fruitful discussions.

Karel Bouzek

Chairman of the Scientific Committee

## GENERAL INFORMATION

### Conference venue

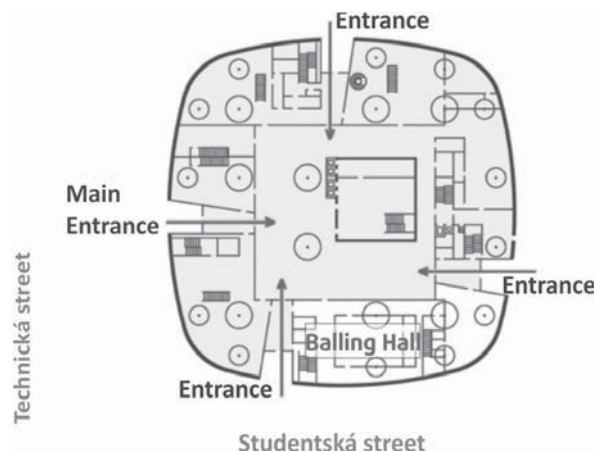
The conference will take place in the National Library of Technology (NTK, [www.techlib.cz/en](http://www.techlib.cz/en)), the largest and the oldest library of technical literature in the Czech Republic. Housed in a modern, ecological building situated in the heart of the Dejvice engineering and technology campus, NTK serves as a social and cultural centre, with frequent lectures, educational tours, events and exhibitions.

### Address

National Library of Technology  
Technická 6/2710  
160 80 Praha 6 – Dejvice  
GPS: 50.103906, 14.390751

# NTK

50°6'14.083"N, 14°23'26.365"E  
Národní technická knihovna  
National Library of Technology



### Conference language

The conference language is English. No simultaneous translation will be provided.

### Conference office and on-site registration

The Conference office in the National Library of Technology will be open for registration and information:

- Wednesday, March 27, 2019 11:00 – 18:00
- Thursday, March 28, 2019 8:30 – 13:00

### Conference Opening

The Conference will officially begin on Wednesday, March 27, 2019, at 13:00 with Opening Ceremony.

### Conference Dinner

The Conference Dinner will be held on Wednesday, March 27, 2019 in the restaurant Profesní dům, Malostranské nám. 25, 118 00 Malá Strana ([www.profesnidum.cz](http://www.profesnidum.cz))

All participants are warmly invited to join the Conference Dinner and enjoy the specific atmosphere, during the evening.

### Student Award

All student contributions will be automatically included in contest for Student Award. The best three student contributions will be evaluated. Students not wishing to participate are kindly asked to inform the Organising committee by registration upon arrival.

### Publication policy

Participants will receive the Book of Abstracts with summaries of lecture and poster contributions presented during the conference. Authors are free to publish their papers at will after the conference. On the basis of authors permission the presentations will be displayed at the Hydrogen Days website after the conference closure.

### Contacts

Czech Hydrogen Technology Platform  
Husinec-Řež 130  
250 68 Husinec-Řež, Czech Republic  
[www.hytep.cz](http://www.hytep.cz)

# UJV Group Hydrogen Technologies



## Hydrogen and services for energetics

- Turn-key implementation of systems
- Processing a case study integrating hydrogen technology into your facility or operation
- Advisory and Design services

## Hydrogen and services for transport industry

- Advice on integrating hydrogen cars and fleet buses
- Support of the development of hydrogen filling station infrastructure in the Czech Republic

## Project to store surplus energy from photovoltaic into hydrogen

- Heat and power generation from hydrogen/natural gas based on cogeneration units
- Low-emission system
- Long-term energy storage
- the system is independent of the distribution grid

## Power-box 180W

- DC power source with hydrogen fuel cell

## TriHyBus project and hydrogen filling station



# FINAL PROGRAM

## FINAL PROGRAM

### Wednesday 27.3. 2019

Balling Hall	Contribution	Speaker
11:00-13:00	Registration	
<b>Chairperson: Karel Bouzek</b>		
13:00-13:20	Welcome & opening	
13:20-13:40	Situation in Europe	Carlos Navas, <i>FCH 2 JU, BE</i>
L02 13:40-14:00	Review of world and European hydrogen initiatives in transport and energy sectors	Guy Verkoeyen, <i>Hydrogenics, USA</i>
L03 14:00-14:20	EU demonstration project - Giant Leap	Federico Zenith, <i>SINTEF, N</i>
L04 14:20-14:40	Hydrogen & Local Energy Systems, a Case Study: BIG HIT Project	Enrique Troncoso, <i>Aragon Hyd. Found., ES</i>
14:40-15:20	Coffee break + <b>Poster session</b>	
<b>Chairperson: Karin Stehlík</b>		
L05 15:20-15:40	Moravian-Silesian Region the „Hydrogen Valley“: The Beginnings	Vladimír Maryška, <i>Moravian-Silesian Region, CZ</i> Daniel Minařík, <i>city Ostrava, CZ</i>
L06 15:40-16:00	H2wo Cluster in Saxony - Fuel Cell components development for mobile applications	Thomas von Unwerth, <i>TU Chemnitz, DE</i>
16:00-16:20	United Hydrogen Group - Past, Present and Future	Martin Fišer, <i>United Hydrogen, USA</i>
L08 16:20-16:40	Current advances in the field of hydrogen technologies in PL	Marek Skrzypkiewicz, <i>IEN, Dept. of HiTEP, PL</i>
L09 16:40-17:00	Development of a High Performing Fuel Cell Drive System for Hybrid Regional Trains	Jochen Steinbauer, <i>Siemens M. GmbH, DE</i>
L10 17:00-17:20	Large-Scale Green Hydrogen Storage -The greater Picture of Sectorcoupling	Stefan Bergander, <i>HYPOS, DE</i>
17:20-18:00	Coffee break + <b>Poster session</b>	

### CONFERENCE DINNER

19:00-22:00 Restaurant Profesní dům

## Thursday 28.3. 2019

Balling Hall	Contribution	Speaker
Chairperson	Thomas von Unwerth	
L11	9:00-9:20 Towards Introduction of Hydrogen Mobility in Bulgaria	Daria Vladikova, <i>IEES BAS, BG</i>
L12	9:20-9:40 Novel Roll-Out Strategy for Hydrogen Refueling Stations, Applied to Eastern DE	Fabian Gruger, <i>RLI, FZ Julich, DE</i>
L13	9:40-10:00 HyDiesel to reduce the GHG - emissions in conventional fuels	Werner Diwald, <i>DWV, DE</i>
L14	10:00-10:20 Optimization of an FCEV shutdown strategy employing CO <sub>2</sub> monitoring via mass spectrometry	Simon Erbach, <i>Daimler AG, DE</i>
L15	10:20-10:40 Hydrogen Use in a Compression Ignition Engine - Potential for Road Transport Decarbonization	Ivan Bortel, <i>UCT Prague, CZ</i>
L16	10:40-11:00 Size optimization of supercapacitors for direct hybridization with PEM fuel cell stack for transport applications	Divyesh Arora, <i>University Lorraine, FR</i>
	11:00-11:20 Coffee break + <b>Poster session</b>	
Chairperson	Daria Vladikova	
L17	11:20-11:40 Power-to-X: A Critical Review	Rolf Schicke, <i>Renewable Energies C., DE</i>
L18	11:40-12:00 The source of renewable energy and its exploitation - an astrophysical point of view -	Robi Banerjee, <i>University of Hamburg, DE</i>
L19	12:00-12:20 Future Potentials of High-Temperature (Co-)Electrolysis Systems based on Operation Results of an Industrial Prototype System and Lab Experiments	Konstantin Schwarze <i>Sunfire GmbH, DE</i>
L20	12:20-12:40 Coupling of H <sub>2</sub> and CO generation via co-electrolysis with Fischer-Tropsch synthesis	Matthias Jahn, <i>Fraunhofer IKTS, DE</i>
L21	12:40-13:00 A study on biogas co-generation plants with different H <sub>2</sub> supply strategies to reduce hydrocarbon emissions	Florian Rau, <i>TU Freiberg, DE</i>
L22	13:00-13:20 A study on hydrogen storages in solar urban districts	Madlow Anne, <i>IWTT TU Freiberg, DE</i>
	13:20-14:30 Lunch + <b>Poster session</b>	
Chairperson	Robi Banerjee	
L23	14:30-14:50 Injecting The Hydrogen To Turkey & Natural Gas Distribution Network: Hydrogen Road Map	Ridvan Aydin, <i>Istanbul Gas Distribution Company, TR</i>
L24	14:50-15:10 Mixed catalysts based on Ni and Co for alkaline electrolysis of water	Katerina Maksimova-Dimitrova <i>BAS, BG</i>
L25	15:10-15:30 Hydrophilisation of separators for alkaline water electrolysis by plasma-induced grafting of polyacrylic acid	Michal Stano, <i>Comenius University, SK</i>
L26	15:30-15:50 Optimization of the catalyst-coated membrane assembly for alkaline water electrolysis	Michaela Plevova, <i>UCT Prague, CZ</i>
L27	15:50-16:10 Catalyst, substrate and membrane/separator in alkaline zero-gap water electrolysis – practical limitations and improvement of cell performance	Stefan Loos, <i>Fraunhofer IFAM, DE</i>
L28	16:10-16:30 Characterization of the membrane alkaline water electrolysis stack under operational conditions	Karel Denk, <i>UCT Prague, CZ</i>
	16:30-16:50 Closing ceremony	Karel Bouzek, <i>UCT Prague, CZ</i>

**Friday 29.3. 2019**

On Friday morning, March 29, three technical excursions will be arranged.

The meeting point for all excursion is outside in front of the main entrance of the National Library of Technology (NTK) at 9:00 a.m. Contact person: +420 723 252 557 Elizabeth Tien.

9:30      13:30      Technical Excursions

1) **LeanCat (Prague) 9:30 - 12:00**

Come and visit Leancat, a Czech hydrogen-driven technology startup. Our first interest was a new "lean cat-alyt", then we moved on to R&D new versions of complete PEM fuel cells for various applications. Out of need to properly test these FCs, we started to develop and sell our own sophisticated testing stations. We also develop an H<sub>2</sub> generator, a UPS, a forklift and other H<sub>2</sub> related products.

[<http://www.lean-cat.com>]

2) **UCT (Prague) 9:30 - 11:00 (including the transfer back and forth)**

University of Chemistry and Technology, Prague represents the biggest educational institution of its kind in Central Europe. UCT Prague is deeply involved into the research of hydrogen related technologies. It covers not only fuel cells and water electrolysis, but also broad spectra of related technologies, like purification, storage and safety. Excursion to UCT Prague will allow you to visit selected laboratories and to discuss with specialists involved in this interesting field of research.

[<http://uat.vscht.cz/en/research/>]

3) **UJV Řež, a.s. 9:30-13:30 (including the transfer back and forth)**

*Note: you need your passport or ID card for entrance into UJV*

UJV Řež, a.s. is a reputable, renowned scientific-research and engineering company dedicated to nuclear technologies and their application in various fields. A key field of UJV Řež's interest is energy, where special attention is given to the development of long-term sustainable energy with minimum environmental impact. One of these activities is focusing on hydrogen technologies in energy and transportation, particularly high temperature processes (SOFC, SOEC), energy storage, hydrogen-based hybrid stand-alone systems and microgrids and their integration to the distribution network.

Excursion to UJV will allow you to visit:

- Research nuclear reactor LR-0 - the reactor is a light-water, zero-power, pool-type reactor. It serves as an experimental reactor for measuring neutron-physical characteristics of VVER (Water-Water Energetic Reactor) type reactors.
- Trihybus - City bus with triple hybrid electric drive and hydrogen fuel cells
- Pilot unit of hydrogen energy storage system - the energy surplus storage system from photovoltaic panels to hydrogen
- The experimental hydrogen loop of the high-temperature electrolysis for hydrogen generation

[<https://www.ujv.cz/en/products-and-services-1/research-development/hydrogen-technology>]

## List of Posters 1/2

Topic	No.	Title	Author
CCOI	P01	TeachHy project and its implementation into the hydrogen technologies education at University of Chemistry and Technology, Prague	Martin Paidar, <i>UCT Prague, CZ</i>
CCOI	P02	Recovery of industrial waste hydrogen by membrane technology	Alfredo Ortiz, <i>University of Cantabria, ES</i>
DDES	P03	Photocatalytic Hydrogen Evolution on the Hetero-system Polypyrrol/TiO <sub>2</sub> Under Visible Light	Belabel Chemseddin, <i>Faculty of Physic USTHB, DZA</i>
DDES	P04	Hydrogen production from butyric acid photoreforming over Pt-TiO <sub>2</sub>	Gabriele Scandura, <i>Khalifa University, UAE</i>
DDES	P05	Hydrogen production and storage from hydrolysis of sodium borohydride: study of the recyclability of the by-product of reaction	Diogo Silva, <i>CEFT University of Porto, PT</i>
DDES	P06	Interplay of ions in the photocatalytic H <sub>2</sub> S splitting	Habeebllah Oladipo, <i>Khalifa University, UAE</i>
DDES	P07	Methane Decomposition over Carbon Microfibers with Ni, Co, Cu Nanoparticles Modified Catalysts to Produce Hydrogen	Katarina Sisakova, <i>UPJŠ Košice, SK</i>
DDES	P08	A new electrochemical method to estimate the active site density on metal-free carbon-based catalysts	Manoj Neergat, <i>IITB Bombay, IN</i>
DDES	P09	Determination of electrochemical active site density of MoS <sub>2</sub> catalyst for hydrogen evolution reaction	Manoj Neergat, <i>IITB Bombay, IN</i>
DDES	P10	CFD study of Ethanol Autothermal Reforming on Rh/CeO <sub>2</sub> catalyst using detailed microkinetic mechanism	Renika Baruah, <i>IITG - Gandhinagar, IN</i>
DDES	P11	Catalytic methanation of biogas for SNG production	Lukas Polak, <i>UJV Rez, CZ</i>
DDES	P12	Carbon-free membrane electrode assemblies for electrolysis cells with anion exchange membrane (AEMEC)	Galin Borisov, <i>IEES BAS, BG</i>
DDES	P13	Dissolution kinetics of Pt nanoparticles integrated into the gas-diffusion electrode at conditions corresponding to high-temperature PEM fuel cell operation	Martin Prokop, <i>UCT Prague, CZ</i>
DDES	P14	Ionic liquid modified Pt/C catalysts for proton exchange membrane fuel cell application	Huixin Zhang, <i>University of Birmingham, GB</i>
DDES	P15	Electrochemical Pressure Impedance Spectroscopy: A new way of understanding transport processes inside fuel cells	Anantrao Vijay Shirsath, <i>University Lorraine, FR</i>
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DDES	P18	Snowball-structured cathode for long-term electrochemical stability of proton conducting fuel cells	Baek Hyeon Woo, <i>Hanyang University, KR</i>
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DDES	P20	Kinetics of oxygen electrode reactions in solid oxide electrolysis cell	Michal Carda, <i>UCT Prague, CZ</i>
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DDT	P34	Methodology for construction and operation of refuelling stations for hydrogen vehicles	Filip Cesnak, <i>UJV Rez, CZ</i>
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**ABSTRACTS  
LECTURES**

## Review of World and European Hydrogen Initiatives in Transport and Energy Sector

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**Keywords:** Hydrogenics, Electrolyzers, Fuel Cells, Manufacturing, Mobility, Energy Storage, CO<sub>2</sub> reduction

In the introduction part of the presentation, it is shown what Hydrogenics is, where they are based, what they are doing, including an overview of the possibilities of Renewable Hydrogen in the world in different applications.

The next part starts with a brief overview of how hydrogen can be produced, what the costs are, and where Electrolysis fits in. An overview of the product portfolio of the Hydrogenics On-Site Generation division includes the presentation of two different technologies used for electrolysis: Pressurized Alkaline and PEM.

It is also shown what the latest developments are, and what the strategic path forward for Hydrogenics is: focus on large-scale PEM systems for Energy Storage.

The goal of this presentation is to show the audience that a lot of the good ideas have been realised already – often as subsidized Feasibility project – so that you can learn from previous projects. On top of that, it shows that Hydrogenics is one of the pioneers in the Hydrogen business, developing the market.

## The Giantleap Project: Prognostics and Control of Automotive Fuel-Cell Systems

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**Keywords:** prognostics, control, range extender, balance of plant

Giantleap is an EU-funded research and innovation project, aiming to increase the availability and reliability of hydrogen buses by means of better diagnostic, prognostic and control methods, applied to a fuel-cell range extender for battery buses.

As shown by data from previous deployments, hydrogen buses have had significant issues with **availability**, i.e. the CHIC project averaged only about 70%, compared to diesel buses' 98%; even if the price of hydrogen buses can be reduced by technological development and mass production, such low availability will not be acceptable for bus operators.

Failures were due to several factors: slow supply chain for spare parts, overly detailed feedback to drivers, vulnerable balance-of-plant components such as air compressors.

Giantleap's predecessor project, Sapphire, produced data indicating that it is possible to recover a significant part of voltage degradation by means of appropriate shutdown procedures. This cell **rejuvenation** could increase the lifetime of stacks by an order of magnitude, and has been connected with water accumulation or presence of oxygen in the catalyst layer.

A common laboratory diagnostic technique for fuel cells is **electrochemical impedance spectroscopy** (EIS), which is however not feasible in the field due to equipment cost and size. It was however found that a fuel cell's degradation state correlates very well with a specific point in the low-frequency arc of the spectrum, which can be identified with relatively simple and inexpensive equipment. The method was theoretically formalised and recently successfully tested.

A significant challenge in the project has been the absence of a sufficient body of data for long-term testing of fuel-cell *systems*, in particular for their **balance-of-plant** (BoP) components: while data for fuel cells and stacks is readily available, and while most BoP components are standard parts built for the automotive industry, there is a dearth of relevant data for these components when operated in FC systems, even though they are the most prone to fail in operation. For this reason, Giantleap ran an extensive series of tests, whose data will be made openly available. As a result of these tests, it was highlighted how compressors in a fuel-cell system would exit their normal operation envelope during operation, and often enter surging conditions during transients, contributing to gradual wear and eventual failure of the unit.

Giantleap shall also produce and demonstrate a prototype for a new concept for hydrogen buses, i.e. a fuel-cell powered **range extender** that can be connected to a battery city bus to convert it into a regional bus. This concept allows operators to have a more uniform vehicle park, with the flexibility of converting city buses into regional ones as required. This also increases availability of hydrogen buses, as keeping a spare range extender is far less onerous than a whole spare hydrogen bus.

## Hydrogen & Local Energy Systems, a Case Study: the BIG HIT Project

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**Keywords:** hydrogen territories, local energy systems, green hydrogen value chain, replication

Started in May 2016, the BIG HIT project is a six-year demonstration project deployed in the Orkney Islands of Scotland and involving 12 participants based across six EU countries. Within BIG HIT, the otherwise curtailed energy generated from tidal and wind turbines (on average more than 30% of the annual renewable output in Orkney) is being used to produce ‘green’ hydrogen from electrolysis, which is then transported across the Orkney islands and used as fuel for transport, heat and power community end-uses (Fig 1).

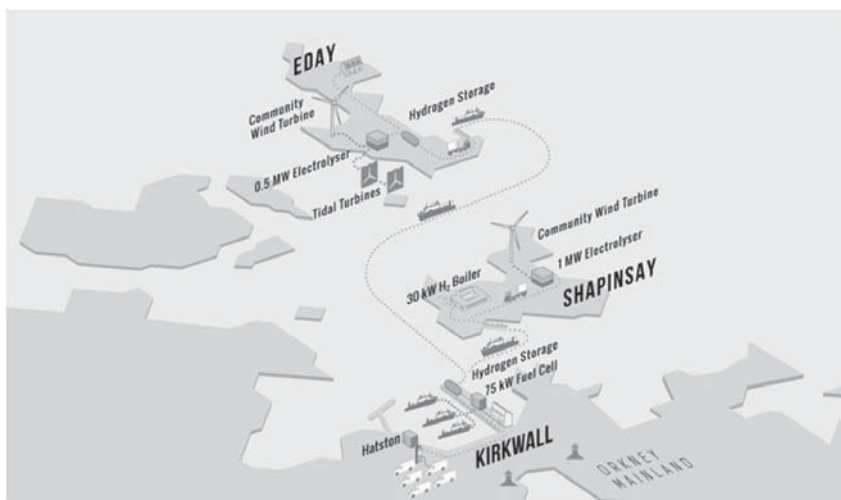


Fig. 1 Schematic of the BIG HIT Local Energy System

BIG HIT is a world-leading pilot and demonstration project, which aims to deploy an “Integrated Energy Systems Platform”, and put in place a replicable model of hydrogen production, storage, distribution and utilisation for low-carbon energy applications. The BIG HIT project is currently entering the deployment phase, along with the development of business and replication models, and the analysis of societal and environmental impacts. These are being used to verify the logistics and economic feasibility of this “Integrated Hydrogen-based Local Energy System” in the Orkney Islands. The findings set out the methodology for the replication to other island regions and remote territories. The project facilitates international cooperation on hydrogen-based energy systems through the European Commission’s Fuel Cells Hydrogen Joint Undertaking (FCH 2 JU).

## Moravian-Silesian Region the „Hydrogen Valley": The Beginnings

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**Keywords:** Hydrogen valley, Moravian-Silesian Hydrogen Region, City of Ostrava, hydrogen mobility, restructuralisation

Hydrogen technologies are a vibrant solution for future cities and regions to reduce their emission footprints and could be the most promise tool for their successful energy transition. Moravian-Silesian Region MSR with close cooperation with City of Ostrava as the regional metropole wants to implement hydrogen technologies in many areas. Historically, Ostrava, respectively whole MSR, is significantly influenced by heavy industrial production as many similar industrial zones in Europe with respect to all benefits and negatives.

Restructuralisation processes, which were started more than 20 years ago are still not fully finished and searching of new impulses for its implementation. What will be next steps of Ostrava city and MSR on the way to "hydrogen region", which projects will be support and what are the main strategic targets or opportunities with relation to current situation will be presented and discussed.

## H2wo Cluster in Saxony - Fuel Cell components development for mobile applications

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**Keywords:** Fuel Cells, Components, Powertrain, e-mobility, Cluster

The lack of cost effective components and manufacturing technologies for fuel cells and fuel cell powertrains is one of the top issues hindering a wide market introduction.

In Saxony/Germany a Network between research institutions and local enterprises has been established to work jointly on R&D projects towards a value chain for fuel cell vehicles. Knowing the drivers for electromobility and the need for emission free powertrains, they compared battery and fuel cell electric mobility regarding several parameters like efficiency, energy and power density as well as usability. While battery driven vehicles seem to be preferred because easier in design, consisting only of a battery and an e-drive, the tide turns when looking to the low achievable energy density - even with regard to newer developments - and high charging times due to less transferrable electrical power. Also Infrastructure might be more cost effective with hydrogen, because only a dedicated number of filling stations has to be installed, whilst for almost every battery vehicle on the street a specific charging station is needed, thus their number - as well as the costs - increase with the number of e-cars.

Therefrom the need for automotive fuel cell powertrains was derived and the necessary changes in the value chain coming from ICEs became obvious. While some components known from the traditional ICE powertrain can be transferred, some other have to be replaced. That means some suppliers can easily adapt their products like turbochargers, batteries, e-drives or gearboxes, others can find new business cases for new series products like e.g. bipolar plates, MEAs or GDLs. In sum that leads to the economical side-effect for protection of Jobs, but also to an increasing demand for highly specialized personnel, so some projects also deal with vocational and advanced training.

Taking all this into account, recently a Network consisting of research institutions and a number of small, medium and large Enterprises in Saxony could be installed, that under one joint roof is heading towards a value chain for fuel cell vehicles. At last, the aim is to have cost effective components for fuel cell powertrains manufactured by series suitable production processes.

## Current advances in the field of hydrogen technologies in Poland

L08

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**Keywords:** Hydrogen, Fuel Cells, Electrolysers, SOFC, SOE, Power-to-gas

Both the number and significance of projects and actions taking place in Poland during recent years in the fields related to hydrogen energy are visibly growing. Poland has already included hydrogen as an alternative fuel in newly established legislation. Policymakers have proposed the new “National energy policy until 2040” which underlines decarbonisation with the use of hydrogen technologies as one of the important paths of the Polish National Energy and Climate Plan.

The presentation presents selected advances in hydrogen-related activities in Poland with particular emphasis on high temperature fuel cells and electrolysers. Actions oriented toward construction of the first subsidized demonstrators of power-to-gas technologies are discussed. Development of materials, advanced techniques for fabrication of solid oxide cells, novel electrodes and electrolytes as well as the demonstration actions are covered to provide a general outlook. Moreover, a general view on the emerging projects coordinated by the Polish industry is given with the focus on power-to-x technologies, including R&D projects co-financed by national and international funding agencies.

## Development of a High Performing Fuel Cell Drive System for Hybrid Regional Trains

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**Keywords:** Hydrogen, Fuel Cells, Li-Ion Batteries, Mireo Plus, Cityjet Eco

Approx. 50 % of Germany's rail network is not electrified. The non-electrified tracks are mainly lines of regional and commuter traffic. In large part these tracks are currently being operated by Diesel electrical trains. In order to fulfill the future demands and requirements for emission free train operations in Europe Siemens is focusing its development on a modular and scalable traction system kit for flexible integration of fuel cells and batteries in high efficient electrical multiple units (EMU) as alternative drive technology. To achieve even these targets a deep understanding of the components and its interaction within the overall traction system will be compiled. Results obtained from this research project will be incorporated into the development of such a traction system kit and its integration in the newly developed train platform Mireo®Plus.

The core element of the hydrogen train is the next generation of fuel cell co-developed with Ballard Power (Vancouver, Canada) making the train most efficient and allowing a smoothly integrated design of the hybrid components. But only in combination with high performing batteries the use of the fuel cell is economic and provides flexibility in terms of performance to the train.

Therefore and in parallel Siemens has already integrated Li-Ion Batteries on a Siemens Desiro Main Line train operated by Austrian ÖBB. Experiences out of the battery manufacturing process, the integration design, commissioning and operation is essential for the series introduction of hybrid trains all over Europe. This Citjet eco called train owned by ÖBB is not only a demonstration train but is fully homologated acc. to European standards and foreseen for regular passenger operation.

## Large-Scale Green Hydrogen Storage – The greater Picture of Sectorcoupling

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**Keywords:** energy storage, hydrogen storage, salt cavern, electrolysis, green hydrogen, gas grid, sector coupling

Green hydrogen is a promising technology for our future energy system. Through renewable power-based electrolysis green hydrogen can maintain a substantial amount of renewable energy and operate as a subsequent seasonal storage. Further, generated green hydrogen can substitute grey hydrogen feedstock within chemical industry, refinery, mobility and other purposes. However, to decouple production and utilisation and fully develop the cross-cutting potential, a much larger network of storage capacities is necessary.

HYPOS' very own project "H2-Forschungskaverne" is about to develop, engineer and construct the single largest hydrogen storage unit in Europe. Based on an existing salt cavern filled with brine, the hydrogen storage can potentially maintain 42 mio. Nm<sup>3</sup> or 126 GWh. The cavern will be connected with a large onshore wind park and an appropriate electrolyser with 30 GW power. Located at Bad Lauchstädt in Saxony-Anhalt, the hydrogen storage is less than 20 km away from the dedicated hydrogen pipeline in Central Germany which connects hydrogen production and consumption from South of Leipzig up to Leuna and Bitterfeld-Wolfen. The distance will be bridged by an existing gas pipeline. The project is to be realised by three stages: (1) concept design and legal approval, (2) construction, (3) first filling and test schemes. While the first stage commenced in fall 2018, stage three is to be expected by 2023/24.

To support the concept design, a second project "H2-UGS" addresses geomechanical, microbiological, and thermodynamical aspects of construction and operation of hydrogen storage units based on salt caverns. The results will be integrated in the research cavern and progressively accelerate realisation of other future large-scale storage projects for different locations.

Partners of the project are VNG Gasspeicher GmbH, ONTRAS Gastransport GmbH, DBI – Gasthechnologisches Institut gGmbH Freiberg, Fraunhofer IMWS, Linde, and many more. All participants are part of the German-wide HYPOS network that includes more than a 100 partners. HYPOS is funded by the German Federal Ministry of Education and Research with 45 million Euro and has established 25 projects for green hydrogen production, transportation, storage and utilisation.

The presentation will give a more detailed analysis of the large-scale hydrogen storage and its parameters and will display first results. Secondly, aspects will be outlined to present its importance for future deployment of substantial amounts of green hydrogen and thus implicate its role model character.

## Towards Introduction of Hydrogen Mobility in Bulgaria

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**Keywords:** hydrogen mobility, hybridization fuel cell/battery, hydrogen range extender, trolleybus, legal and administrative barriers

The Energy Union is one of the 10 priorities of the Juncker Commission. It requires accelerated transition to clean and efficient energy system. Since urban transport is responsible for 23% of EU's greenhouse gas emissions, a special emphasis is given to the zero emission mobility. In this aspect hydrogen as energy storage solution emerges as a key factor with a vast potential for decarbonization of the transport system.

As a member state, Bulgaria announced the development of a low-carbon and resource-efficient economy as a priority. It is one of the 14 countries that introduced hydrogen refueling infrastructure in the National Framework Strategy for the alternative fuels market related to the implementation of Directive 94/EC/2014. However, it has to start building this infrastructure from the very beginning, since there are neither hydrogen powered vehicles, nor fueling station on the territory of the country.

In respect to the development of hydrogen technologies in Bulgaria, the Presidency (January – June 2018) and the FCH JU Hydrogen Summit (27-28 May 2018) in Sofia with a demonstration of the two hydrogen cars of the JU and the Air Liquide portable refueling station gave a strong input and increased the political and public awareness pushing forward the joint activities for the introduction of the first demonstration projects in hydrogen mobility. In September 2018 the Ministry of Education and Science granted the Distributed Infrastructure «Energy Storage and Hydrogen Technologies» aiming to ensure scientific support for the first demonstration projects implemented through the National Research Program «Low carbon Energy for the Transport and Household» (E+) which started in November 2018. They shall be supported also by Sofia Municipality, some Ministries and NGOs.

The preliminary analysis of the approaches applied in different countries (Germany, UK, France) showed that for the Bulgarian economic conditions a model with lower initial investments based on suitable market segments is more appropriate and less risky for the economy. In the field of transport the hybridization approach (battery/fuel cell) was accepted as reasonable because of its faster market introduction and smaller investments. After socio-economic analysis performed in E+ Program, the development and introduction of hydrogen powered fuel cell range extenders in the unified electric trolley system was selected. The first trolleybus belonging to Sofia Municipality is in a process of conversion. The present talk gives more details on the concept and the pathway for its realization, as well as on the legal and administrative barriers which have to be overcome.

### Acknowledgements

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## Novel Roll-Out Strategy for Hydrogen Refueling Stations, Applied to Eastern Germany

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**Keywords:** hydrogen, refueling station, infrastructure, siting, network, Germany

Currently, the number of hydrogen refueling stations (HRS) in Germany and in Europe is very low compared to the number of conventional refueling stations or infrastructure for alternative fuels like compressed natural gas. Consequently, hydrogen fueled vehicles (FCEV) cannot be used like conventional vehicles and only few people decided to buy a FCEV. On the other hand, HRS operation is not profitable because the number of FCEV is so low that HRS are underutilized. Vehicle fleets like buses or taxis do not suffer from this problem. These vehicle types are used locally and do not require nation-wide refueling infrastructure. Additionally, HRS built to supply these fleets are used to capacity because the vehicles generate a predictable, daily hydrogen demand.

This is why the presented approach focuses on bus, carsharing, and taxi fleets as well as HRS supplying them. The main research question is, whether several hydrogen “islands”, consisting of fleet vehicles and the respective HRS, can be sited and implemented in such a way, that they constitute a sensible overall HRS network.

The HRS assumed, consist of onsite electrolysis, a wind turbine, compressors, and hydrogen storages at different pressure levels as well as dispensers. In order to match the hydrogen demand of different fleet types and sizes, HRS are configured via simulation and optimization methods according to a variety of fleet combinations. Subsequently, the HRS’ profitability is evaluated. Then, a method for siting HRS and fleets is developed and applied to Eastern Germany, represented by twelve major cities. This optimization method considers different data, like population distribution, traffic flows, routes along the road network, the existing HRS network or vehicle range. Resulting network quality is evaluated by a specially developed algorithm, which determines the number of people the network enables to use FCEV.

The results show, that vehicle fleets can improve profitability of HRS. Moreover, this approach of fleet induced HRS is capable of initiating a HRS network sufficient to enable more than one million additional people in Eastern Germany to switch to FCEV. Annual costs for building and operating these HRS are relatively low, compared to other infrastructure costs. Although this approach was applied to Eastern Germany, it can be adapted to any other region or country.

## HyDiesel to reduce the GHG-emissions in conventional fuels

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Deutsche Wasserstoff- und Brennstoffzellen-Verband e. V., Germany

The Renewable Directive II (RED II) will allow for the inclusion of co-processed hydrogen obtained from renewable energy sources ("green hydrogen" or "electricity-based renewable gases and liquids") as of 01/01/2021 on the renewable targets in the fuel sector. The creation of this imputation option on the mandatory reduction of greenhouse gases from marketed fuels opens up a market economy market for green hydrogen in the fuel sector without further support. Overall, this results in a direct sales market in the refinery sector of more than 2,000 MW of electrolysis power in Germany, without this causing additional costs for the consumer compared to other solution options.

Especially against the background of the existing market penetration of diesel vehicles, renewable hydrogen, which is co-processed in the refineries in the production of diesel, will provide an economical solution for reducing emissions in traffic in the next few years.

The use of renewable liquid and gaseous fuels of non-biological origin (also known as "storage gas, power-to-hydrogen, green hydrogen or RE-hydrogen" as well as "power-based fuels") in the transport sector offers significant advantages regarding climate protection when compared to conventional technologies. Its usage reduces the dependence on fossil fuels in ever more complex geopolitical situations and furthermore adds quality of life in the transition to zero emission drivetrains. Moreover, compared to pure electricity storage, power-to-hydrogen allows for higher flexibility with regard to the economically viable usage of energy infrastructures. Therefore, provisions concerning green hydrogen applications in European law should be designed in a manner that is technology- open and non-discriminatory.

By setting the right legal framework for green hydrogen, i.e. allowing the accounting of green hydrogen towards the target share of renewable fuels, the EU could realize an industrial market potential of some 10,000 MW electrolysis capacity amounting to several billion euros (double-digits).

Hydrogen mobility in combination with intelligent sectoral integration represents an enormous opportunity for European industries and secures employment and wealth for our citizens in the future. Consequently, Europe has to act before this window of opportunity closes. A forward-looking energy market design must be taken into account in both European and national political concepts.

McKinsey's November 2017 Hydrogen Scaling Up study found that over 30 million new jobs will be generated in the hydrogen production and efficient hydrogen use segment. The annual business volume is estimated at over 2,000 billion EUR. For the German market alone, electrolysers with a capacity of 7 GW and a sales volume of more than EUR 5 billion should be produced annually from 2030 at the latest, in order to meet the German demand of at least 100 GW in 2050.

HyDiesel could be the door opener for a new defossilized economic epoch.

## Optimization of an FCEV shutdown strategy employing CO<sub>2</sub> monitoring via mass spectrometry

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**Keywords:** PEMFC, FCEV, carbon dioxide, degradation, carbon corrosion, operating strategy, shutdown strategy

Fuel cell electric vehicles (FCEVs) offer a modern approach to mobility with local zero emission of greenhouse gases and toxic gases. Low catalyst loadings of costly precious group metals such as platinum promise decent prices for FCEVs. However a trade off is to be found between catalyst loadings and lifetime goals, in which the operating and shutdown strategy of the fuel cell system (FCS) plays an important role. Employing an anode recirculation loop comes along with optimized strategies for safety, humidification and fuel efficiency including low operating costs for mobility. Nevertheless crossing over gases from cathode to anode can accumulate in the previously mentioned loop and bring along negative effects on the FCS performance. Previous works revealed the concentrations of inert gases and carbon dioxide (CO<sub>2</sub>) in recently released Mercedes-Benz GLC F-Cell. The concentration of CO<sub>2</sub> in such an automotive anode loop was found to be around an average value of 200 ppm throughout the whole operating range of the FCEV being partly electrochemically reduced to carbon monoxide (CO), which strongly adsorbs on platinum and blocks its surface. In consequence, under certain conditions the performance is decreasing and treatment might be necessary to maintain the FCEV's power.

Next to known CO-poisoning treatments of the anode catalyst with introduction of small amounts of air to the anode side ("air bleed") another treatment during shutdown could offer a viable release of blocked catalyst sites. This strategy contains crossover of air through the membrane after depletion of the remaining reactants on the electrodes under controlled conditions to avoid or at least mitigate the effect of carbon corrosion which causes permanent degradation due to catalyst support loss. Analyses of the gas composition on the electrodes via mass spectrometry reveal reactions during the shutdown of the FCS and offer monitoring options to improve the shutdown of the system.

This research demonstrates an optimized shutdown strategy including oxidation of species that block the anode catalyst under controlled conditions to mitigate permanent degradation effects that might affect the FCEVs lifetime.

## Hydrogen Use in a Compression Ignition Engine - Potential for Road Transport Decarbonization

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**Keywords:** combustion engine, dual fuel, compression ignition, diesel fuel, hydrogen, decarbonization

Combustion engines are the most widespread transportation power units all over the world. It is reasonable to consider the use of them as energy convertors for the use of hydrogen as a transportation fuel at least for the initial phase of the introduction of hydrogen into the market. The efficiency of the conversion of fuel energy to mechanical power of compression ignition engines at high load approaches that of a highly loaded fuel cell. Optimized hydrogen fuelled compression ignition engines might be one of the means for achieving transport decarbonisation targets as they were ratified in the COP21 Paris agreement.

This contribution presents experimental investigations of hydrogen utilisation as a main fuel for a compression ignition engine with a pilot injection of a small quantity of diesel fuel. The experiments were performed on a single cylinder research compression ignition engine with a bore of 85 mm and piston stroke of 90 mm, coupled with an electric dynamometer. The engine was equipped with a diesel fuel direct injection common rail system. A homogeneous mixture of air and hydrogen was formed using a port fuel injection. The engine was boosted with externally driven compressor. Realistic efficiency of the fictitious exhaust turbocharger was emulated by exhaust throttling.

An influence of hydrogen share on the total fuel energy was systematically investigated between the limits given by the pure diesel operation and the maximum share of hydrogen, approximately 98% by energy content. The tested hydrogen share was constrained by practical limits of poor combustion at low load (4 bar of IMEP) and by a limit of maximum pressure and preignition (up to 16 bar of IMEP) at engine speed up to 3200 rpm. It was observed that increase in hydrogen share reduces emissions of particles and CO<sub>2</sub> proportionally to the decrease in the carbon content in the fuel. Engine-out NO<sub>x</sub> emissions remained more or less the same for both diesel and hydrogen fuelling.

Based on experimental results steady state performance and emissions maps of a turbocharged four cylinder hydrogen – diesel dual fueled engine were compiled. A particular implementation of a dual fuel H<sub>2</sub> – diesel engine in a passenger van in a WLTP driving cycle was simulated. Two fueling strategies were compared. The simulations showed a potential of almost 70 percent reduction of the driving cycle CO<sub>2</sub> emissions for the strategy using the highest hydrogen share, compared to the pure diesel operation.

### Acknowledgment

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## Size optimization of supercapacitors for direct hybridization with PEM fuel cell stack for transport applications

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**Keywords:** PEMFCs, supercapacitors, direct hybridization, optimization, hydrogen saving

PEM fuel cell (FC) technology is gaining adequate interest by the transport applications in order to reduce greenhouse gases emissions. However, PEMFC has some limitations of too long response at the demand of high current. This limitation can be mitigated by hybridization of PEMFC with energy storage devices such as batteries or supercapacitors (SC). Direct hybridization (without power converters) has shown higher durability and reduction in the demand for fuel, i.e. hydrogen [1] in view to transported applications, i.e. with a regular change in power demand. In a previous work, we have shown that direct hybridization of a single cell with a stack of SC was beneficial in terms of H<sub>2</sub> feed and durability [1].

Yet, for transportation applications, higher voltages are usually required. Because a single PEMFC has a voltage below 1 V, a stack of FCs in series is generally considered to reach the suitable voltage. In this regard, the present study details the feasibility of coupling of the PEMFC stack with different sizes of the SC during cycling tests, using Fuel Cell Dynamic Load Cycling (FC-DLC) [2].

Thus, a progressive investigation was conducted by (i) performing FC-DLC profiles to an unhybridized stack of three 100 cm<sup>2</sup> single cells, (ii) performing comparable cycling tests with hybridization with varying size of supercapacitors to investigate the hydrogen demand per cycle, (iii) examining the influence of supercapacitor sizing on FC efficiency, and (iv) optimizing the size of the hybrid source in terms of mass, volume, efficiency and cost.

In Figure 1, with increasing size of SC, the hydrogen feed decreases due to the smoothing effect provided by the SC to the FC current. The FC yield is defined as the electrical energy produced per cycle over the hydrogen feed. The energy of the FC increases since the losses associated with FC and SC internal connections reduce, and as shown before, hydrogen feed decreases, thus the FC stack increases. From Figure 1, in these working conditions, the 3 cell stack coupled with 3 kF seems to be a more advantageous size for the current transport application in terms of hydrogen saving and increasing FC yield.

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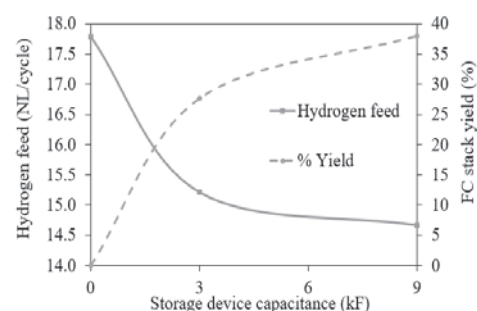


Figure 1: Hydrogen feed and FC yield vs storage device capacitance

## Power-to-X: A Critical Review

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**Keywords:** energy transition, P2X, CCU (carbon capture and usage), liquid energy carriers

In the context of the so-called “Energy Transition” one of the most often presented ideas is to produce hydrogen via electrolysis, electricity taken from renewables like wind and / or solar (PV) plants, and then combining with carbon dioxide (preferibly from concentrated sources like flue gas, waste gas streams from cement works, bioethanol plants (where CO<sub>2</sub> is a by-product of the fermentation process and usually vented into the ambient atmosphere) or biogas plants, more specifically biomethane production plants where CO<sub>2</sub> has to be separated from the raw biogas before injecting the remaining methane into the grid) to produce methane.

While this concept, at first glance, appears rather attractive because it allows for energy fluxes from the electricity grid into the natural gas grid, and vice versa, and it enables to make use of the large energy storage capacities for natural gas (in Germany alone some 250 TWh), it also does have a number of disadvantages including relatively poor overall / roundtrip efficiency (power to power) and even less efficiency when making use of this SNG (synthetic natural gas) for low temperature heat production (room heating and the like) which is still the major part of natural gas consumption. In addition, projected production costs for larger plants are in the range of 15 to 30 €ct / kWh<sub>HHV</sub>, the lower number related to biological methanation, the higher figure related to the Sabatier process. On the other hand, the market price of natural gas today (in Germany) is around 2.2 €ct per kWh<sub>HHV</sub>, i.e. considerably below the production costs of SNG. The question then is: where is a market for SNG? On the background of the German EEG (renewable energy law / feed-in tariffs) any subsidies from the government will definitely not be accepted by the public.

But, fortunately, there are other ways of making use of both waste CO<sub>2</sub> and, on the other hand, renewable energy / hydrogen from wind and solar energy. Also by no means being new technologies (for instance, the carmaker VW made field tests with regard to “M 15” (blends of 15 % methanol and (fossil) gasoline) some 35 years ago) it is only recent, that these technologies (Fischer-Tropsch fuels including kerosene, methanol etc. (DME, MTBE, OME)) apparently come into play again.

In this presentation, a number of examples will be presented, and also a comparison of the different versions of “power-to-x” with respect to their efficient / inefficient application to meet the energy demands of the various sectors (electricity, heat, mobility / traffic etc.).

A general discussion with regard to the further / future demand of renewable energy sources / systems to meet the overall (all sectors) energy demand of industrialised countries is included indicating that even extremely ambitious goals of certain countries cannot be reached without massive international collaboration.

## The source of renewable energy and its exploitation - an astrophysical point of view -

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**Keywords:** renewable energy, solar power, wind power, hydrogen, cross-sector utilisation

We are living in dramatic times of climate change and its impact on the Earth's environment, on our quality of life and on global migration of humans. Hence, it is about highest time to change - at least - our way of energy consumption and switch to CO<sub>2</sub>-free energy sources.

The most powerful and reliable energy source, which we could easily tap, is the Sun. The Sun delivers the world primary energy demand for an entire year just within about 45 minutes; that includes goods production, electric power, fuel for transportation/mobility and heating/cooling for the whole world. The technical equipment to exploit the Sun's power and to satisfy the energy demand of humans are long known, well developed and at some locations largely in use: photovoltaics, solar heat and on-/offshore wind parks.

An issue which is often raised when it comes to the large-scale usage of renewable energy sources is transportation and storage as those sources are highly local and time dependent. Nevertheless even here, the technical solution - apart from dense, wide-area power grids - is ready to use: H<sub>2</sub>. Hydrogen is easily produced with electric power from water via electrolysis and reusable via fuel cells or direct burning (by now there are very efficient stackable electrolyser and fuel cells on the market). Large-scale storage, on the other hand, can be operated via already existing gas and oil pipelines as well as underground cavities, storage stacks and mobility tanks. Hence, we are ready to switch to a carbon-free economy; the problems ahead are *not* of technical origin but are due to the will of humans.

In this talk, I'll give an overview of how to realistically install a Sun-based energy economy and discuss the next steps we have to take to be successful.

## Future Potentials of High-Temperature (Co-)Electrolysis Systems based on Operation Results of an Industrial Prototype System and Lab Experiments

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**Keywords:** High temperature electrolysis (HTE/SOC), Sector coupling, Syngas, Grid services, Load management, Co-electrolysis, Power-to-X

The integration of renewable energy sources into industrial processes has a high potential for moving to a competitive low-carbon economy in 2050 as targeted by the European Commission. The vision of Sunfire is to provide 'green' fuels and chemicals – e.g. hydrogen or syngas – via high temperature electrolysis using renewable electricity for various applications like iron-and-steel works, fueling stations and diverse applications in the chemical industry.

A first industrial scale proof-of-concept prototype for this vision was implemented within the GrInHy project (Green Industrial Hydrogen via Reversible High-Temperature Electrolysis). The prototype provides 'green' hydrogen via electrolysis using renewable electricity and provides grid management services as reversible generator in the iron-and-steel works of Salzgitter Flachstahl GmbH (Germany). It has a nominal electrolyser power consumption of 150 kW<sub>AC</sub> respectively 30 kW<sub>AC</sub> fuel cell power output. In fuel cell operation the system is able to operate on hydrogen or natural gas. Findings and results from 8,500+ hours of operation are presented. In fuel cell operation 1,300 hours were run mostly in steady state with natural gas. During that period the load was varied between 20 kW<sub>AC</sub> and 25 kW<sub>AC</sub> power output at which the RSOC achieved an AC efficiency higher than 50 %<sub>LHV</sub>. Electrolysis mode was operated for more than 2,400 hours at production rates from 20 Nm<sup>3</sup>/h to 45 Nm<sup>3</sup>/h hydrogen. In the given range of load at steady state the RSOC AC efficiency was higher than 75 %<sub>LHV</sub>.

The produced hydrogen was injected into the local pipeline and used in downstream processes of the iron-and-steel works. During operation the SOC degradation was determined approximately every thousand hours. After 7 thermo-cycles and 220 load cycles under rather harsh testing conditions the mean degradation was determined to 21 mΩcm<sup>2</sup>/kh (0.8 %/kh), which is well below the project target. Furthermore an outlook is given on the potentials of high-temperature electrolysers including their scale-up to the multi-MW level and their application for grid balancing services and direct syngas production. The outlook is based scale-up studies and on recent lab tests with a large stack unit consisting of 24 stacks. The tests proofed high load following capabilities of the Sunfire SOC systems in electrolysis operation (< 5 min from hot standby to full load) and the possibility of fast RSOC cycling (< 15 min from full load electrolysis to full load fuel cell operation). In addition results from a 10 kW scale co-electrolysis test system will be shown. The test system was implemented within the framework of the Kopernikus project and demonstrates the direct syngas production with an adjustable product composition (hydrogen to carbon-monoxide ratio) by co-electrolysis. This enables the design of new Power-to-X processes without a dedicated syngas generation step promising higher overall process efficiencies at lower total capital costs. The presentation sums up the latest advancements of Sunfire's high-temperatures electrolysers and gives insight on the upcoming development and the next generation products.

## Coupling of H<sub>2</sub> and CO generation via co-electrolysis with Fischer-Tropsch synthesis

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**Keywords:** co-electrolysis, SOEC, Power-to-X, Fischer-Tropsch synthesis, process modeling

Energy transition and sector coupling have become frequently used terms in recent times. It is generally agreed that electrolysis will play an important role in a future energy system [1,2]. A technology with promising prospects for applications in this very context is the co-electrolysis in solid oxide electrolysis cells (SOEC) [3]. The co-electrolysis allows for the direct generation of syngas from CO<sub>2</sub> and H<sub>2</sub>O. Together with the advantage of SOEC technology to use high temperature heat as energy input for the electrolysis reaction, it offers excellent properties for the development of processes consisting of an electrolysis and a synthesis step [4]. Coupling of co-electrolysis and Fischer-Tropsch synthesis allows for achieving high energetic efficiencies for stand-alone processes as well as for a deep integration into CO<sub>2</sub>-emitting industrial processes. Process modeling was applied to design a highly-efficient process for the production of waxes and liquid hydrocarbons from CO<sub>2</sub> and H<sub>2</sub>O. Based on the results, a first lab-scale prototype of such a coupled process was built. For the application at a lime plant it was shown that the proposed concept allows for the utilization of a fluctuating electricity input at constant synthesis operation together with a significant reduction of CO<sub>2</sub> emissions of this plant. The results of this study will be presented and discussed.

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## A study on biogas co-generation plants with different hydrogen supply strategies to reduce hydrocarbon emissions

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**Keywords:** Life cycle assessment, biogas, combined heat and power, formaldehyde, emission reduction

Biogas CHP (combined heat and power) plants have a significant contribution to reduce anthropogenic carbon dioxide emissions by increasing the share of renewable energy sources in the heat section as well as in the electricity section. The annual carbon dioxide reduction of about 9,000 installed biogas plants in Germany amounts to about 21 million tons per year. Currently, the limits for emissions from biogas CHP plants are massively tightened by the revision of dedicated laws. An upcoming challenge is the reduction of the allowed formaldehyde emissions to 20 mg/m<sup>3</sup> for 2020. Actual studies showed emissions of formaldehyde from 5 mg/m<sup>3</sup> to 230 mg/m<sup>3</sup> with an average value of 75 mg/m<sup>3</sup>. Therefore excessive emissions are already obvious at the present time, so that the problem already applies to many existing plants.

The high methane and formaldehyde emissions from CHP plants are indicators for incomplete combustion of the biogas. Currently, these emissions are reduced by two complex exhaust gas aftertreatment processes (oxidation catalyst, thermal afterburning). The new emission limits require technical innovations at the biogas plants and has the consequence that these might no longer be operated economically. This may lead to the dismantling of the plant.

In order to counteract this problem, the reduction of the emissions with a simultaneous efficiency advantage is examined by the addition of a combustion moderator into the internal combustion (IC) engine. As combustion moderator hydrogen is used in terms of a biogas CHP plant due to the special combustion properties. The high burning velocity, the small gap width and the high thermal conductivity favour a complete conversion of the fuel-air mixture in the cylinder, which significantly reduces the occurrence of formaldehyde and unburnt hydrocarbons in the exhaust gas.

Hydrogen can be produced either by the separation of the stages of the fermentation process (separate hydrolysis) or by the conversion of the biogas into a hydrogen-rich gas by the utilization of the waste heat of the IC engine on site (thermochemical recuperation). In addition, hydrogen can be obtained by water electrolysis.

A life cycle assessment (LCA) is performed to evaluate the favoured production path for hydrogen at the biogas plant side. The assessment includes three operating CHP plants with electrical outputs from 75 kW to 360 kW. Two of the investigated CHP plants have gasoline engines one with an oxidation catalyst. The third plant has a pilot injection engine. The assessment is supported by measurements of the emissions of the three CHP plant as well as the effect of hydrogen addition on several exhaust species.

## A study on hydrogen storages in solar urban districts

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**Keywords:** local heating network, multi-objective optimization, urban district, pareto front, multi-criteria decision making

In the course of the "Energy Concept 2050" for the reduction of greenhouse gases the energy supply systems in Germany are currently being restructured over a large area. Regarding the building sector, the German Federal Government set the goal of having a nearly climate-neutral building stock by 2050. According to this, the energy requirement of the buildings should be reduced to a minimum and the remaining share should be covered by renewable energies. In particular, the energetic renovation of existing buildings faces several challenges: As examples, the compliance with the temperature level of the heating system, low intervention in the building structure and an acceptable economic effort may be mentioned here. One possible solution to solve this problem is on the one the energetic networking of existing buildings within urban districts and on the other hand the use of a clean energy carrier such as hydrogen.

For the conception and dimensioning of energy supply systems in such districts a variety of conventional as well as innovative technologies are available. In the present concept the existing buildings are connected to a local heating network which is provided by a combination of solar thermal systems and a hydrogen burner. The solar thermal heat provided is fed to the heat storage on a central level which supplies the consumers connected to the heating network. The hydrogen burner ensures the supply of the heating network and the provision of the required temperature level. The hydrogen is locally stored in a pressure tank and produced by an electrolysis system which is feed by a photovoltaic system. To compensate deficits in hydrogen production, the connection to a hydrogen grid is assumed.

When dimensioning the system, the question arises as to which sizes for heat storage and for the gas storage are preferred from an energetic, ecological or economic point of view. In order to determine the optimal system size, a multi-objective optimization is performed using a detailed physical model of the proposed energy supply system. The model is created in Matlab / Simulink with the aid of the self-programmed EDGAR (Energy System Design with Genetic Algorithms) toolbox for a model region consisting of five buildings. A complete year is calculated with a temporal resolution of 15 minutes per simulation step. The presented system should show the highest possible share of renewable energies in a simultaneously economic and ecological operation. Based on this goal, the degree of self-sufficiency, the global warming potential as well as the total annuity are chosen as objective function.

The genetic algorithm NSGA-II is selected for the optimization that is performed with 51 individuals per population and 100 generations. Among all solution a set of individuals are selected whose fulfill the requirements of pareto dominance. The selection of a final plant configuration is made by using a multi-criteria decision making technique.

## Injecting The Hydrogen To Turkey's Natural Gas Distribution Network: Hydrogen Road Map

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**Keywords:** energy productivity, sustainability, natural gas, power expander, hydrogen, hythane.

The Turkey, as with most other countries around the world, recognises the importance of meeting the challenge of climate change and has determined to reduce carbon emissions under the terms of the National Climate Change Adaptation Strategy and Action Plan<sup>1</sup>. Turkey with 54 bcm of annual gas consumption is one of Europe's largest consumer<sup>2</sup>. Natural gas, the lowest carbon dioxide emitter per unit of energy of any fossil fuel whereas hydrogen emits zero.

Hydrogen Roadmap Project is a study with the aim of reduces carbon emissions by ensuring supply security and energy efficiency in Turkey. In this context, electricity will be produced by renewable and low opex cost methods including power expander (energy production from gas pressure difference with zero operating cost), solar and wind at IGDAS Hydrogen Center in RMS (Gas Pressure Regulating and Metering Station).

With this electricity, hydrogen will be produced by electrolysis method and the composite fuel called hythane will be formed by injecting the produced hydrogen to the natural gas pipelines. It was seen in the laboratory that up to 30% hydrogen in the mixture was possible. Hythane can be stored or used in cooker, boiler, combined cycle power plant, geyser etc.

In this way, the amount of natural gas imports will decrease and thermal heat of gas supplied to the customer will be increase.

This study will be a first in Turkey where uses natural gas in all provinces and will be used as an important R&D center for hydrogen research. The proposed implementation will present the results of the first phase of the field work as well as an outlook for a beneficial investment.

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## Mixed catalysts based on Ni and Co for alkaline electrolysis of water

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**Keywords:** catalyst, hydrogen production, alkaline electrolysis of water, anion exchange membrane, AEM water electrolysis

Hydrogen production through water electrolysis is an environmentally friendly technology that occupies an essential place in the "Green Energy Cycle" for generating electricity from renewable energy worldwide. The main goal of the researchers in the field is to reduce the cost of hydrogen production by developing and introducing innovative cells, electrodes, and catalysts to improve the electrolysis technology. The present work is focused on the synthesis, characterization and testing of new generation catalysts based on nickel and cobalt in alkaline electrolysis cells. Nanoparticles of Ni and Co are deposited on a non-stoichiometric titanium oxide ( $Ti_nO_{2n-1}$ ) known as Magnelli Phase Titanium Oxide. The metal content of the catalysts is varied in the range of 20% to 60% by weight. Nanoparticles of both metals without a carrier are also prepared and tested. The composition, surface structure and morphology are studied by Elemental Dispersion Analysis (EDX), Scanning Electron Microscopy (SEM) and X-Ray Diffraction analysis (XRD). It is found that the composite catalysts possess electrochemical stability and catalytic activity in aqueous alkaline water electrolysis. The cobalt based catalysts are more active with respect to the oxygen evolution reaction, while the nickel based ones demonstrate higher activity towards the hydrogen evolution reaction. When integrated in membrane electrode assemblies with anion exchange membrane (AEM) electrolyte the catalysts show stable electrochemical behavior with no evidence of degradation or reduction of catalytic activity in a 240 hour long experiment at cell voltage of 2.0 V. Based on the obtained performance characteristics the synthesized composite nanomaterials are considered as promising cost-efficient catalysts for generation of pure hydrogen via AEM water electrolysis.

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## Hydrophilisation of separators for alkaline water electrolysis by plasma-induced grafting of polyacrylic acid

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**Keywords:** alkaline water electrolysis, separator membrane, acrylic acid, grafting, plasma

Wettability of porous inter-electrode separators by the electrolyte is essential in alkaline water electrolysis. In this work we report on development of highly hydrophilic separator membranes based on porous polypropylene (PP) grafted by polyacrylic acid (pAAc). PP is a widely used polyolefin with reasonable mechanical properties and chemical stability in aqueous solutions of KOH. Similarly to high-performance plastics like polysulfones, PEEK or PTFE, it has a low surface energy and poor wettability by polar liquids. Grafting of pAAc results in highly hydrophilic surface without notable loss of mechanical strength of the initial porous structure. This approach has been successfully applied on separators for alkaline Ni-Cd batteries by Gancarz and coworkers [1]. Their membranes showed high conductivity although the pores were filled by pAAc. We assume that filling of the pores by pAAc may notably reduce diffusion of H<sub>2</sub> and O<sub>2</sub> gases through the membrane and make such membrane suitable for inter-electrode separator in alkaline water electrolysis.

Membranes of various thickness and pore size were activated by a low-pressure capacitively-coupled symmetrical RF discharge at 13.5 MHz in oxygen. The plasma activation was optimized for production of hydroperoxides, which are suitable for initiation of AAc graft polymerization. Concentration of hydroperoxides after plasma activation was determined by a reaction with 2,2-diphenyl-1-picrylhydrazyl (DPPH) [2]. The concentration of hydroperoxides on the surface were up to  $1.5 \times 10^{-8}$  mol/cm<sup>2</sup>. Graft polymerization on activated membranes was conducted in 20% deaerated aqueous solution of acrylic acid. Presence of carboxyl groups after grafting was confirmed by ATR-FTIR. Surface and cross-section of the membranes was studied by SEM. Grafting degree was determined gravimetrically. Ageing of the surface modification was examined in 30 wt. % solution of KOH. The modification was observed to be stable at ambient temperature over period of several months while certain mass depletion took place at 60 °C.

### Acknowledgement

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## Optimization of the catalyst-coated membrane assembly for alkaline water electrolysis

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**Keywords:** Alkaline water electrolysis, non-Pt catalyst, catalyst coated membrane, hydrogen production

Hydrogen represents an energy carrier which can be produced by water electrolysis using the solar or wind electricity. The biggest advantage of water electrolysis over the technologies that produce hydrogen from fossil fuels is that it doesn't produce CO<sub>2</sub>, which is considered the main greenhouse gas. It is possible to distinguish three types of water electrolysis from which the most developed is alkaline water electrolysis (AWE). Compared to the other technologies, AWE has relatively low capital expenses because of the use of abundant materials. Separation of the electrodes by a porous inorganic diaphragm represents the main disadvantage. The diaphragm limits the flexibility of the current AWE which is, however, the vital parameter when the renewable sources are the source of the electricity. Solution of this problem is replacing the diaphragm with a dense anion selective polymer membrane. This also involves the possibility of applying the catalyst directly onto the membrane surface (CCM). This arrangement is advantageous due to better contact between the catalyst and the membrane, which leads to considerably more efficient use of the catalyst. This has been demonstrated in the case of competing water electrolysis technologies (e.g. PEM). In an alkaline environment, this approach is not yet applied due to the absence of suitable polymeric materials.

In this work, we study CCMs with various compositions of the catalyst layer. Air brush spraying at elevated temperature (50 °C) was chosen as a preparation method. The NiCo<sub>2</sub>O<sub>4</sub> and NiFe<sub>2</sub>O<sub>4</sub> were used as anode and cathode catalysts respectively with load 2.5 mg cm<sup>-2</sup> which resulted in the thickness of the catalyst layer approximately 30 μm. Block copolymer polystyrene-ethylene-butylene-styrene (PSEBS) with 1,4-diazabicyclo[2.2.2]octane (DABCO) functional groups was used as the membrane and polymer binder of the catalyst layer. Performance of the alkaline water electrolysis in the form of the load curves was measured for all prepared samples with different potassium hydroxide concentrations (1, 5, 10 and 15 wt. % KOH) at temperature (50 °C). Electrochemical impedance spectroscopy (EIS) was used to evaluate the ohmic and polarization resistances of the system and SEM was used to observe the morphology of prepared CCMs. Finally, a mid-term stability test was conducted in a single cell alkaline electrolyser. The obtained results show the possibility to achieve the high current densities with lower catalyst load and sufficient stability in mid-term experiments. CCM thus represents a promising way of improving the alkaline water electrolysis technology.

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## Catalyst, substrate and membrane/separator in alkaline zero-gap water electrolysis – practical limitations and improvement of cell performance

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**Keywords:** electrocatalysis, electrolysis, anion exchange membrane, Raney-Ni, cell tests

Water electrolysis is considered to be a key technology in the global effort to reduce CO<sub>2</sub>-emissions stemming from the burning of fossil fuels as it provides an option for chemical storage of renewable energy.<sup>[1]</sup> Implementation of such technologies on an industrial scale is mandatory<sup>[2]</sup> and high power densities are desired.

Striving for an improvement of alkaline electrolysis, catalyst development and zero gap technology enable higher current densities at reasonably low cell potentials<sup>[3]</sup>, without use of noble metal catalysts.<sup>[4]</sup> AEM-development might support a deployment of alkaline water electrolysis without corrosive caustic liquid electrolyte on a large scale getting closer to the high performance and compact design of the PEM-technology.<sup>[5]</sup> A successful AEM-technology requires convenient fabrication, scalability and durability of all components, in particular the membrane electrode assembly (catalysts with membrane/separator and support), gas bubble management and mechanical stability.

In order to identify limitations and challenges, different combinations of non-noble metal nickel based catalysts (Raney-Ni on the cathode, binary Ni-alloys on the anode), substrates (foam, mesh, fiber) and membranes/separators (FAA-3-PK-75 from Fumatech, Sustainion®, Zirfon®) are investigated in the alkaline regime on the electrolyzer cell level (5 cm<sup>2</sup>) using cyclic voltammetry, electrochemical impedance spectroscopy, steady state Tafel analysis and galvanostatic stability tests. Thereby, it turns out that 3D-porous electrode materials (foam, mesh, fiber) are well suited to achieve high current densities and stable operation conditions - particularly a combination of Raney-Ni and NiMn-alloy is very promising. However, the membrane as a limiting factor is equally important. In practical terms, the use of a diaphragm (Zirfon) instead of an AEM at the current stage is superior in handling and upscaling. Finally, a recommendation for materials to be used in alkaline zero gap water electrolysis is suggested.

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## Characterization of the membrane alkaline water electrolysis stack under operational conditions

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**Keywords:** alkaline water electrolysis, stack, DABCO, anion-selective membrane

Membrane alkaline water electrolysis (MAWE) represents a promising technology for hydrogen production and subsequent storing. In combination with renewable energy sources, it can serve as a clean hydrogen source. The use of non-platinum catalysts ensures low capital cost while substitution of an inorganic diaphragm with a membrane enables achieving higher current densities, higher gas purities and asymmetric pressure operation.

In diaphragm alkaline water electrolysis, purity of the produced gasses is lower than in membrane (PEM) electrolysis. This can be improved by replacing the porous diaphragm by a dense anion selective membrane. Permeation of the gases through the membrane is an attribute of the membrane independent on the current density. On the other hand, the amount of produced gasses follows the Faraday's law and it is therefore controlled by current density. Thus, at low current densities, the fraction of hydrogen in the oxygen stream can exceed safety limits. Therefore, the purity of the produced gasses rises with the use of higher current loads. The use of membranes also affects energy demand of the whole process by allowing the so called zero-gap cell setup in which the electrodes are pressed directly to the surface of the membrane and the ohmic resistance between the electrodes is minimized.

In this work, we characterized a MAWE stack consisting of three cells with nickel-foam electrodes and nickel sheet current collectors. The anion-selective membranes were made of poly(styrene-ethylene-butylene-styrene) functionalized by 1,4-diazabicyclo[2.2.2]octane (DABCO). The active area of each cell was 78.5 cm<sup>2</sup>. Potassium hydroxide was used as the electrolyte in different concentrations (1, 5, 10 and 15 wt.%).

As for the characterization methods, linear sweep voltammetry was used to obtain the load curves for performance characterization. The current efficiency was evaluated based on produced gas flow rate measurement. Given these results, energy efficiency was calculated. Electrochemical impedance spectroscopy was used to determine the resistance of the stack and gas chromatography was used to find out the gas purities under different operational conditions.

In MAWE, gas purities depend mostly on the efficiency of used gas separators. With the rising electrolyte concentration, the stack performance improved due to the higher conductivity. Nevertheless, while remaining required characteristics, anion-selective membranes enabled using lower electrolyte concentration (*e.g.* 10 wt.% KOH) instead of highly concentrated (25-30 wt.% KOH) electrolyte. This increased ohmic resistance of the distribution channels, thus minimized parasitic currents.

### Acknowledgment:

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**ABSTRACTS**  
**POSTERS**

## TeachHy project and its implementation into the hydrogen technologies education at University of Chemistry and Technology, Prague

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**Keywords:** fuel cell and hydrogen technologies, M.Sc. study program, TeachHy, European curricula, study materials.

Already running changes in energy production technologies and rising need of energy storage brings about also new requirements on employees working in the energy sector. Mainly increasing usage of renewable, weather dependent sources strongly requires development of supporting technologies capable to store energy in a suitable form. Hydrogen is nowadays accepted as one promising alternative. Its high versatility as an energy vector leads to a number of technologies based on different chemical principles. Thus, well-educated experts knowing advantages and disadvantages of these technologies are necessary for their effective implementation and utilisation.

Currently hydrogen is mainly used in chemical industry as a raw material for ammonia production and in petrochemistry. It is clear that usage of hydrogen for energy storage and in chemical industry will exist concurrently. Education thus has to consider both sectors. Nowadays the students have the opportunity to get into the contact with chemical sector, like hydrogen production from fossil fuels and from chlor-alkali industry. Access to these technologies is restricted only on qualified operators. It is in contrast to the foreseen applications of hydrogen in energy sector. Here wide public is expected to have an access to selected technologies, e.g. to car fuelling or residential applications. New safety standards, handling and maintenance are prerequisites for implementation of hydrogen fuel to the energy sector. It at the same time creates new jobs for experts, technicians, etc. having corresponding knowledge on hydrogen technologies. University of Chemistry and Technology, Prague (UCTP) pays high attention to this trend and implemented hydrogen technologies into its study programs portfolio.

To support rapid implementation of the hydrogen technologies, intensive collaboration between the universities and industry across the Europe is necessary. This allows not only sharing experience and expertise between academic partners, but also reflecting the needs of industry sector and of end-users. The international consortium of 12 educational institutions was established in the framework of TeachHy project granted by FCH JU to address this issue. The main aim is to develop a complex course, including study materials, covering all aspect of hydrogen economy helping to introduce high quality education in hydrogen technologies among the Europe. The course focuses primarily on the master students but also technicians are considered within a framework of Life-Long-Learning scheme. Once finished, significant part of the course will also be implemented to the existing UCTP education scheme.

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## Recovery of industrial waste hydrogen by membrane technology

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**Keywords:** hydrogen recovery, surplus hydrogen, multicomponent gas separation, gas permeation, hydrogen-selective membranes

Industrial waste streams with hydrogen content higher than 50% are considered potential and promising sources for hydrogen recovery using separation techniques. It has been estimated that the price of recovered hydrogen could be 1.5 to 2 times lower than the price of hydrogen from natural gas reforming [1]. The advantages of membrane separation technologies over other existing mass separation processes, such as high selectivity, low energy consumption, small footprint, moderate cost to performance ratio and compact and modular design, especially in small to medium plants, have been widely reported, and thus, motivate their application to hydrogen upgrading [2]

The purpose of this work was to carry out the assessment of membrane technology for hydrogen separation from multicomponent waste gaseous streams in order to obtain high quality hydrogen to feed fuel cells. Therefore, in a lab-scale prototype, commercial flat hydrogen-selective membranes based on non-porous polymeric materials were tested using a gas permeation set-up with the aim of recovering hydrogen from three of most suitable industrial H<sub>2</sub>-rich waste gases: coke oven gas (COG), ammonia purge gas (APG) and methanol purge gas (MPG) [3]. The permeation and separation properties of the membranes were examined using the steady-state permeation method with synthetic gas mixtures. Due to their high hydrogen selectivity to CO<sub>2</sub>, N<sub>2</sub>, CH<sub>4</sub> and CO, we decided to choose the following commercial polymeric membranes: polyimide (PI), polyetherimide (PEI), polyethersulfone (PES) and polybenzimidazole (PBI). In addition, the influence of temperature and pressure on gas permeation was examined in a temperature range from 25 °C to 45 °C and at partial pressure gradient of up to 7 bar, at predetermined gas concentrations and flow rate levels.

The results of experimental tests indicated that there is a trade-off in the state-of-the-art membranes so as to keep balance between permeability and the hydrogen product purity. Although the hydrogen purity obtained was higher than 90%vol. H<sub>2</sub> from all gas mixtures, it would be necessary further upgrading to the required quality (>99.9%vol. H<sub>2</sub>) by increasing membrane stages or coupling the membrane separation with conventional separation processes such as PSA.

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## Photocatalytic Hydrogen Evolution on the Hetero-system Polypyrrol/TiO<sub>2</sub> Under Visible Light

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**Keywords:** Polypyrrol (PPy), TiO<sub>2</sub>, hydrogen.

The semiconducting properties of the hetero-system polypyrrol (PPy)/TiO<sub>2</sub> are investigated for the first time to assess its photo catalytic hydrogen evolution under visible light. The hetero-system PPy/TiO<sub>2</sub> is stable up to ~ 70 °C, with a weight loss accounting for ~ 1.2 %. The X-ray diffraction shows mixed phases with the rutile TiO<sub>2</sub> variety. Optical transitions of 0.42 and 3.01 eV, directly allowed, are determined for PPy and TiO<sub>2</sub> respectively. The *p*-type conductivity of PPy is evidenced from the Mott-Schottky plot. In neutral solution, a flat band potential of 0.11 V<sub>SCE</sub> and a holes density of 4.57×10<sup>21</sup> cm<sup>-3</sup> are obtained. The electrochemical impedance spectroscopy, measured over a wide frequency range (1 mHz-10<sup>5</sup> Hz), reveals the contribution of the bulk and grain boundaries with a constant phase element (CPE). The energetic diagram predicts the electron injection from PPy into TiO<sub>2</sub> and the best photocatalytic performance is achieved at pH ~ 7 in presence S<sub>2</sub>O<sub>3</sub><sup>2-</sup> as hole scavenger. A hydrogen liberation rate of 0.43 cm<sup>3</sup> mn<sup>-1</sup> (g catalyst)<sup>-1</sup> and a quantum efficiency of 0.17% under full light (29 mW cm<sup>-2</sup>) are determined. The photoactivity is completely restored during the second cycle.

## Hydrogen production from butyric acid photoreforming over Pt-TiO<sub>2</sub>

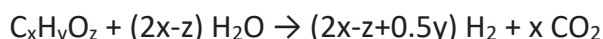
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**Keywords:** Hydrogen production, Photoreforming, Titanium oxide, Butyric acid, Platinum deposition, kinetic mechanism.

Currently, 95% of the total hydrogen (H<sub>2</sub>) supply is provided from fossil fuels,<sup>1</sup> worldwide reserves of which are reducing. Thus, developing a process for energy production built on renewable resources is of utmost importance. Solar energy, the largest renewable and 'infinite' resource, provides more energy in one hour to our planet than the total energy consumed by humans in one year and therefore it represents a reasonable choice.<sup>2</sup>

Photocatalytic H<sub>2</sub> production from water is an interesting and challenging approach because it takes advantage of solar energy and it operates under ambient pressure and temperature. However, the direct photosplitting of water (WS) has thermodynamic and kinetic limitations which can be overcome by adding oxygenated organic substrates ('sacrificial agent') which act as water reductants. This process, operating under anaerobic conditions, is called photoreforming (PR) and the overall reaction can be schematized as follows:



Compared to other organic fatty acids (e.g. acetic acid), butyric acid (BA) present in wastewater is more toxic to bacteria and difficult to degrade by biological process.<sup>3</sup> Thus, it is essential to explore the possibility of using BA as sacrificial agent in the photocatalytic production of hydrogen and, potentially, of alkanes.

In this work, photoreforming of butyric acid in aqueous suspensions of platinum-titanium oxide nanotubes (Pt-TNT) has been investigated with particular emphasis on the kinetic mechanism. The photocatalyst has been characterized by different techniques such as XRD, TEM, EDX, DRS and PL.

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## Hydrogen production and storage from hydrolysis of sodium borohydride: study of the recyclability of the by-product of reaction

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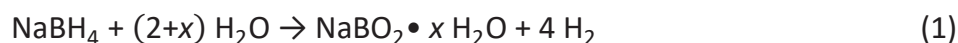
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**Keywords:** Hydrogen, hydrolysis of sodium borohydride, additives, recyclability of by-product, clean energy

Hydrogen is one of the most valuable alternatives to fossil fuels to produce energy. However, although it is abundant in the universe and has the highest gravimetric density, it is difficult to obtain and store in its molecular form and in safe conditions. One alternative to the conventional hydrogen storage is to use the high hydrogen content (10.66 wt. %) of sodium borohydride to, simultaneously, produce and store it <sup>[1]</sup>. Hydrogen can be obtained at room temperature and pressure by hydrolysis of sodium borohydride, as described in Equation 1,



where  $x$  is the hydration factor. Excess of water is necessary since the by-product of reaction, sodium metaborate, retains typically 2 or 4 water molecules, decreasing the hydrogen yield and generation rate <sup>[1]</sup>. Thus, additives can be added to alter this reaction, for example, sodium carboxymethyl cellulose (CMC). Ferreira et al. <sup>[2]</sup> observed the rearrangement of the sodium metaborate molecules when additive CMC was used in the hydrolysis of sodium borohydride. This way, sodium boron hydroxide was formed, a compound that does not retain water molecules and it is easier to recycle than sodium metaborate. Due to the cost of sodium borohydride, its regeneration is essential to implement a circular economy in a system that aims the production of *green* hydrogen for energy applications. Overall, this work focuses on the by-product of sodium borohydride hydrolysis: additives were used to observe its composition and a new method to regenerate sodium borohydride was developed.

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## Interplay of ions in the photocatalytic H<sub>2</sub>S splitting

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**Keywords:** Photocatalysis, Hydrogen production, N-TiO<sub>2</sub>-rGO/Pt, Bisulfide ion, Langmuir-Hinshelwood kinetics

Aqueous phase hydrogen sulfide conversion to hydrogen was studied in a batch reactor with a novel platinum decorated nitrogen doped multiphase titanium dioxide grown on graphene. The hydrogen generation reaction followed a zero order kinetics. Bisulfide ion had a positive influence on the pseudo-zero order rate constant up to HS<sup>-</sup> concentration of 0.059 mol/dm<sup>3</sup>, after which further increase in HS<sup>-</sup> concentration became detrimental to the reaction rate. Langmuir-Hinshelwood kinetics adequately fitted the experimentally obtained reaction rates for HS<sup>-</sup> concentrations below 0.059 mol/dm<sup>3</sup> and the obtained adsorption constants for S<sup>2-</sup> and HS<sup>-</sup> were 0 dm<sup>3</sup>/mol and 30.7 dm<sup>3</sup>/mol respectively. However, the rate of hydrogen generation was found to be independent of the concentration of hydrogen ion in the aqueous solution.

## Methane Decomposition over Carbon Microfibers with Ni, Co, Cu Nanoparticles Modified Catalysts to Produce Hydrogen

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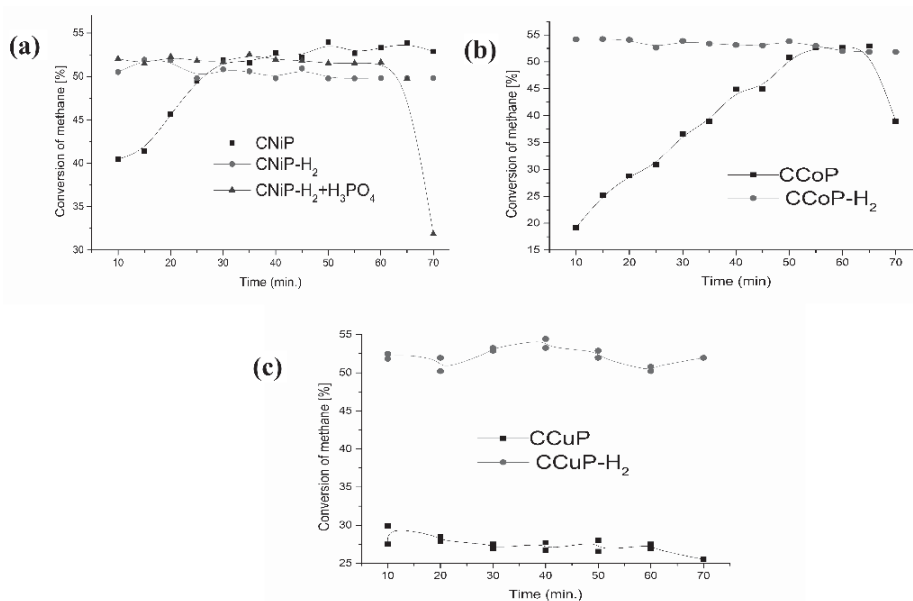
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**Keywords:** hydrogen, pyrolysis, catalysts, methane, carbon microfibers

Thermal decomposition of methane is ecologically advantageous as no carbon oxides arise. In addition, as a by-product, solid carbon is produced which can be further utilized.



The structure of nascent carbon depends on the experimental conditions and the type of catalyst which was used. Phosphides are suitable catalysts due to their catalytic properties. Their properties can be improved by an appropriate support such as a carbon microfiber. Carbon microfiber is due to its great features such as a low density, a high strength and a high electrical conducting a suitable adept. Catalyzed thermal decomposition of methane to produce hydrogen was studied. As the novel catalysts, carbon microfiber was doped with Ni, Cu and Co metal phosphides. Catalysts were prepared by needleless electrospinning. The efficiency of these catalysts was studied by the Py-GC method. The experiment was carried out in the temperature range from 700 to 800 °C. Kinetic parameters were calculated based on the Demitcheli kinetic model. The highest conversion rates were achieved using carbon microfibers doped with cobalt in a hydrogen reduction atmosphere and nickel-doped carbon microfibers sintered only under argon atmosphere – about 54%. This value corresponded with the lowest value of the carbon deposition rate, the highest metal content, and were also the most stable.



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## A new electrochemical method to estimate the active site density on metal-free carbon-based catalysts

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**Keywords:** active site density; adsorption; nitrogen-doped carbon; oxygen reduction reaction; turnover frequency

The precious metal catalysts, predominantly platinum and its alloy nanoparticles, are conventionally used in fuel cell, metal-air battery etc. Method for the estimation of their active site density is well documented in the literature. For platinum nanoparticles, the active site density is usually calculated from the  $H_{\text{upd}}$  or  $Cu_{\text{upd}}$  charge and it is correlated with their catalytic activity, for example, the ORR activity.<sup>1,2</sup> As no  $H_{\text{upd}}$  peak is observed with nonprecious metal catalysts (NPMCs), unlike that with platinum or palladium, the electrochemical estimation of active site density of NPMCs is challenging. Malko et al. and Sahraie et al. recently used nitrite ions and CO as probe molecules for estimation of the active sites on Fe-N/C catalyst.<sup>3,4</sup>

Though such methods are recently reported, it is not yet established with the carbon or nitrogen-doped carbon materials, though they are active towards ORR, HER and OER.

Therefore, an electrochemical method to estimate the active site density of carbon and nitrogen-doped carbon will be presented. In our previous work, the adsorption property of the catechol molecule was used towards estimating the active site density of metal-free porous carbon and nitrogen-doped carbon samples.<sup>5</sup> The adsorption of a unique organic molecule will be presented to estimate the active site density of nitrogen-doped carbon and carbon samples. Moreover, the difficulty in interpreting the catechol adsorption data will be discussed. The adsorption charge will be used to estimate the turnover frequency of the catalysts towards ORR, HER and OER.

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## Determination of electrochemical active site density of MoS<sub>2</sub> catalyst for hydrogen evolution reaction

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**Keywords:** active site density; adsorption; ESA; HER; MoS<sub>2</sub>

Precious metal catalysts, such as platinum and palladium are used as conventional HER catalysts. Estimation methods of active site density of platinum or palladium are well established and well documented in the literature. For both metals, active site density is estimated through H<sub>upd</sub>, CO<sub>stripping</sub> or Cu<sub>stripping</sub> and it is correlated with the catalytic activity.<sup>1, 2</sup>

For non-precious metal catalysts like MoS<sub>2</sub>, graphene, etc., no hydrogen adsorption/desorption peaks are observed in their voltammograms. Thus, estimation of electrochemical active site density is imperative. An electrochemical estimation method of active site density has been recently proposed for nitrogen-doped carbon and carbon catalysts using catechol as a probe molecule.<sup>3</sup> Based on that, the active site density of MoS<sub>2</sub> is calculated using another organic molecule.

Different MoS<sub>2</sub> catalysts are synthesized at different temperatures using hydrothermal method. The surface morphology and structures are confirmed by XPS, SEM and XRD. HER activity of the catalysts is measured in acidic medium.<sup>4</sup> HER activity increases with increase in synthesis temperature. To compare the activity, further comparison is done by calculating the electrochemical surface area (ESA) and the active site density on the surface. An organic molecule is allowed to adsorb on the MoS<sub>2</sub> surface and from the adsorption charge, totals ESA and number of active sites are calculated. It is observed that HER activity increases with the number of active sites.

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## CFD study of Ethanol Autothermal Reforming on Rh/CeO<sub>2</sub> catalyst using detailed microkinetic mechanism

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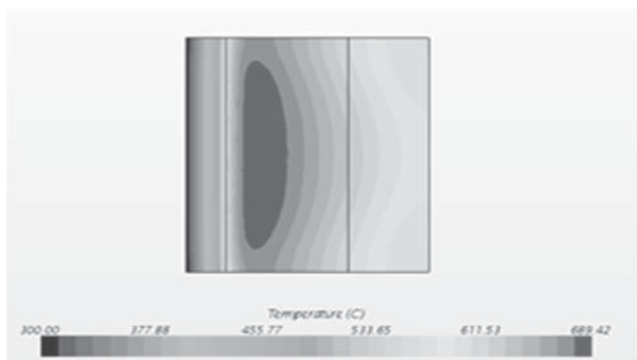
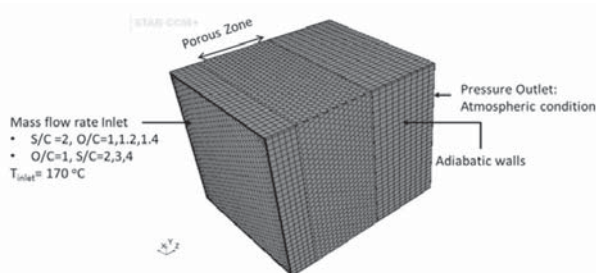
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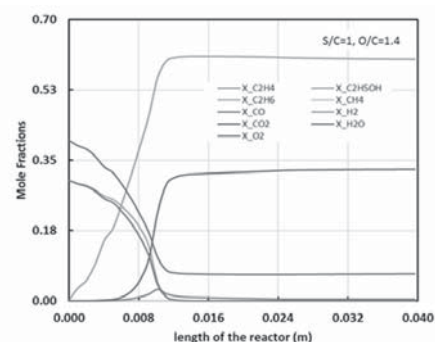
**Keywords:** Ethanol, autothermal reforming, microkinetic mechanism, CFD, monolith reactor

Computational fluid dynamic (CFD) models at reformer level incorporating detailed microkinetic mechanism are crucial to the understanding of fuel processing systems (FPS), and can contribute to improving the overall control strategies of small, autonomous fuel cell systems subjected to variable-load conditions. However, there are very few studies that incorporate detailed heterogeneous microkinetic mechanisms into their flow model. Moreover, a detailed microkinetic mechanism for Ethanol autothermal reforming (ATR) on Rh catalyst is missing from the literature. In this study a novel microkinetic mechanism is incorporated into a 3D CFD model to simulate Ethanol ATR on Rh/CeO<sub>2</sub> coated monolith reactor.

To reduce computational effort, the ceramic monolith reactor with washcoated channels is assumed to be a homogenous porous media with equivalent catalytic surface area and thermal properties. Simulations were run for wide range of steam/ethanol (2, 3 and 4) and oxygen/ethanol ratios (1, 1.2 and 1.4), while keeping the ethanol feed flow rate constant at 0.5 g/min. The inlet temperature is fixed at 300 °C and uniform mixing is assumed at the entry of the reformer. Using this model, we were able to predict the product composition and temperature profiles at various locations for different operating conditions. Preliminary results from the CFD show good agreement with experiment data. Further validation of the model in transient conditions will make it more useful as a tool to implement model-predictive control strategies.



Temperature profile along the reactor length



Product composition along the reactor length

## Catalytic methanation of biogas for SNG production

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**Keywords:** methanation, Sabatier process, hydrogen, carbon dioxide, biogas, synthetic natural gas

Today, carbon dioxide separation is used for upgrading biogas to biomethane. When compared to biogas, biomethane offer an increased higher heating value and further utilization as synthetic natural gas (SNG). The most commonly used methods for carbon dioxide separation are physical and chemical adsorption (processes like Rectisol, Purisol, etc.), adsorption (i.e. Pressure Swing Adsorption), membrane or cryogenic separation. Significant investments and higher operating expenditures are typical for all the separation methods mentioned above and limit SNG production in the Czech Republic. Also, emissions of carbon dioxide separated via biomethane production are an environment problem, which should be solved to make the SNG production reasonable. As a possible solution direct biogas methanation can be used.

Nowadays, the Power-to-Gas concept is often mentioned. An excess of electricity from renewable sources (i.e. solar or wind power plants) can be easily converted to hydrogen by different types of water electrolysis (i.e. PEM, alkali or high-temperature electrolysis). The produced hydrogen can be subsequently added in a proper ratio to precleaned biogas. Carbon dioxide present in biogas is than catalytically converted to methane via Sabatier's process. The biogas upgraded by methanation, commonly called synthetic, renewable or substitute natural gas, can be injected into the gas distribution network and used in the same way as conventional natural gas by means of its transport, storage and final utilization.

An experimental unit for direct catalytic methanation of biogas has been designed and constructed in ÚJV Řež, Czech Republic. This unit with photovoltaic powered electrolytic hydrogen production and an externally cooled fixed-bed catalytic reactor allows to perform long-term experiments with pressures up to 1,5 MPa and temperatures up to 350 °C. Main experiments focus on evaluation of different methane and water concentration on the methanation reaction. Also, different catalysts, pressure and temperature conditions are going to be tested with goal to produce gas with the high methane concentration. Finally, non-steady state operation following green hydrogen production from photovoltaics is planned to be faced with focus on successful heat management operation.

## Carbon-free Membrane Electrode Assemblies for Electrolysis Cells With Anion Exchange Membrane (AEMEC)

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**Keywords:** Hydrogen, AEM water electrolysis, Catalyst

The AEM water electrolysis based on alkali-doped polymer electrolyte membrane is an efficient method to produce hydrogen with higher purity, which offers several advantages over the traditional technologies: higher current density, low ohmic resistance, possibility to operate at higher working pressure, as well as usage of platinum free electrocatalysts. The technology still has some problems such as non-sufficient stability of the polymer electrolyte at elevated temperature, low conductivity of the commercially available membranes, and intensive corrosion on the bipolar plates of the cell. This work presents a research on development of MEA with carbon free electrodes, non-noble metal catalysts and commercially available AB-PBI anion exchange membrane, activated directly into a self-designed electrolysis cell. It is found that to achieve an optimal doping of the membrane it is necessary to apply a current density of  $1 \text{ A}\cdot\text{cm}^{-2}$  for 45 minutes at room temperature. The electrochemical performance of thus activated MEA shows low over potentials concerning both partial reactions and a stable behavior at elevated temperature of  $80 \text{ }^\circ\text{C}$ , namely current density of  $200 \text{ mA}\cdot\text{cm}^{-2}$  at cell voltage of  $2.0 \text{ V}$ . The enhanced efficiency of the electrolysis is explained with the observed homogeneous distribution of the nano-sized catalysts crystallites on the non-carbon carrier, combined with high anion conductivity of the used polymer electrolyte membrane.

### Acknowledgments:

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## Dissolution kinetics of Pt nanoparticles integrated into the gas-diffusion electrode at conditions corresponding to high-temperature PEM fuel cell operation

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**Keywords:** high temperature PEM fuel cell, Pt dissolution, nanoparticle coarsening, degradation kinetics, mathematical modelling

High-temperature fuel cell with proton-exchange membrane (HT PEM FC) is one of the promising hydrogen-operating PEM FC types. It utilizes Pt/C catalyst integrated into the gas-diffusion electrodes and membranes based on polybenzimidazole and/or pyridine-type polymers doped with  $\text{H}_3\text{PO}_4$ . Due to its operating temperature range of 120–180 °C, resistance against CO poisoning is greatly enhanced. However, degradation processes are enhanced as well.

To push HT PEM FC commercialization forward, a significant optimization of operating conditions and membrane-electrode assembly materials has to be performed. One of the most troublesome degradation processes is coarsening of Pt nanoparticles, resulting in Pt surface area decrease. Coarsening is mainly caused by the dissolution of smaller Pt nanoparticles and redepositing of dissolved  $\text{Pt}^{2+}$  on larger nanoparticles, i.e. Ostwald ripening. Dissolution of Pt nanoparticles is a critical step of Ostwald ripening. Nevertheless, detailed description of Pt dissolution mechanism and kinetics at conditions corresponding to HT PEM FC operation is still insufficient, if not entirely absent in the literature.

The goal of this work was to determine Pt dissolution kinetics in concentrated  $\text{H}_3\text{PO}_4$  at temperature of 160 °C (conditions typical for HT PEM FC) and predict catalyst degradation extent at various electrode potentials. In order to accomplish this goal, potentiostatic polarisation experiments with gas-diffusion electrodes were performed. Studied parameters of GDEs included electrochemically-active surface area, total amount of Pt and average Pt crystallite size. Experimental results were analysed using 1D mathematical model of Pt dissolution on gas-diffusion electrode. This model was built on the basis of previous works [1, 2] focused on degradation of low-temperature PEM FC and modified according to conditions used in our experimental system. Model exhibited reasonable reliability and provided useful insight into HT PEM FC degradation problematic.

### Acknowledgements

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## Ionic liquid modified Pt/C catalysts for proton exchange membrane fuel cell application

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**Keywords:** ionic liquid (IL), oxygen reduction reaction (ORR), catalyst, proton exchange membrane fuel cell (PEMFC), kinetics, adsorption

During the reaction in PEMFCs, the electrode surface, oxygen, water and other species closely interact with surface sites of the electrode material and their properties are strongly interrelated. The adsorption of active sites by nonreactive oxygenated species and the sluggish oxygen reduction reaction (ORR) kinetics on the Pt catalysts have impaired catalytical performance and caused poor durability of the Pt-catalysts. Although lots achievements have been obtained towards to enhancing ORR kinetics by application of Pt alloy and non-Pt metal catalysts, the instability of surface structures during ORR process was also identified for these emerging catalysts [1]. The relatively high ionic conductivity, wide electrochemical windows and thermal stability endow protic ionic liquids (ILs) a high potential to enhance the electrode performance in PEMFCs [2-5]. In this research, we study the coating of superhydrophobic IL on Pt/C nanoparticle catalysts. The adsorption parameters and operation are investigated. Ex-situ half-cell liquid electrolyte measurement and in-situ fuel cell test are employed to understand their influences on catalyst performance. The experimental results show that the coating of ionic liquid improves both catalytic activities and stability of catalysts, but there is an optimum value for IL addition, and the behaviour is different between nanoparticles and nanowires for which the mechanisms are further explored.

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## Electrochemical Pressure Impedance Spectroscopy: A new way of understanding transport processes inside fuel cells

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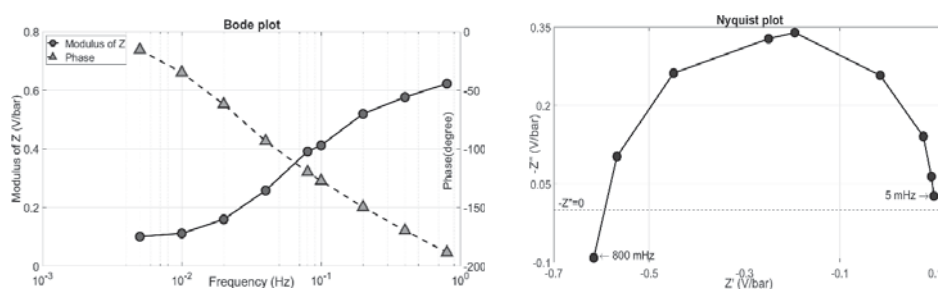
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**Keywords:** EIS, EPIS, PEM fuel cell, transport phenomena, diagnosis.

Even though a polymer electrolyte membrane fuel cell (PEMFC) is a simple power device, complex and coupled transport processes occur inside it, playing vital role in performance and durability [1]. The popular technique for PEMFC diagnosis is electrochemical impedance spectroscopy (EIS), which uses dynamics of current and voltage for evidencing source of performance loss. However, it fails marginally to comment on and distinguish between various transfer processes [2,3].

Nevertheless, fuel cells with gaseous reactants and products offer valuable non-electric variable to observe, i.e. gas pressures. When combined with current and/or voltage (keeping either constant), it gives us additional definitions for the impedance, termed as electrochemical pressure impedance [3]. The analysis of current or voltage vs pressure in harmonic conditions is termed as electrochemical pressure impedance spectroscopy (EPIS) [3,4].

In the present work, the focus is on applying EPIS to PEMFC, to develop it for gaining better understanding about the transfer processes inside a PEMFC and verify it as an approach that is more sensitive than EIS at low frequency. A sinusoidal variation in the cathode backpressure is applied using a pressure regulator to record the voltage response of the fuel cell at constant current. Impedance results obtained are quite fascinating;  $Z$  (ratio of  $V_{\text{cell}}$  and  $P_{\text{outlet}}$ ) is found to be in the range of 0.1 to 0.7 V/bar, for the frequency range, 5 to 800 mHz. In addition, the phase angle varies largely which appears promising in the valuable information to be gained on mass transport inside the fuel cell in the lower frequency range where EIS has its limitations.



### Acknowledgement:

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## Application of porous polypropylene membranes grafted by polyacrylic acid as interelectrode separators in alkaline water electrolysis cell

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**Keywords:** alkaline electrolysis, membrane separator, acrylic acid, grafting, plasma

Connection of alkaline water electrolyzers with intermittent renewable energy sources in power-to-gas applications sets high requirements on inter-electrode separator. In order to operate safely even at low current density, permeation of the produced hydrogen and oxygen gases through the separator must be minimized [1]. To achieve this, high wettability of separator membrane by the electrolyte is necessary.

In this work we evaluate performance of porous polypropylene (PP) membranes grafted by polyacrylic acid (pAAc) as inter-electrode separators in alkaline water electrolyser. The grafting technique modifies only the very top surface layer of material, providing high wettability without deterioration of mechanical properties of the substrate. Membranes with various thickness and average pore size were activated in low-pressure capacitively-coupled radio-frequency (RF) discharge in oxygen atmosphere and graft polymerization was subsequently performed in aqueous solution of AAc monomer. The modified membranes were applied in alkaline water electrolyser to determine their specific resistance and the purity of gases produced at cell current densities up to  $0.4 \text{ kAm}^{-2}$ .

The results show that despite of partial or complete filling of pores by pAAc, the membranes remain electrically conductive with reasonable ohmic resistances ranging from  $30 \text{ m}\Omega\text{cm}^2$  to  $250 \text{ m}\Omega\text{cm}^2$ , depending on the initial membrane structure and the achieved grafting degree. At current density of  $0.1 \text{ kAm}^{-2}$ , hydrogen purity of over 99.95 % was achieved by using PP membrane of  $450 \mu\text{m}$  thickness,  $1 \mu\text{m}$  average pore size and gravimetric grafting degree of about 45 %. Low gas permeability due to the formation of pAAc hydrogel allows us to assume that this approach can be applicable for production of alkaline electrolyser separators.

### Acknowledgement

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## Nanocrystalline Ni-W alloy catalyst for alkaline water electrolysis

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**Keywords:** HER; Ni-W alloys; electrocatalytic properties; "zero-gap" electrolyser

The cathode reaction catalysts for hydrogen evolution reaction (HER) were tested in alkaline electrolyte. The cathode reaction catalysts were prepared on mild steel mesh substrate covered by Ni-W electrodeposited coatings. Pulse electrodeposition was applied to reach nanocrystalline coatings with high surface area.

The prepared electrodes were characterized using different methods. Material characterization was realized by EDX, XRD and SEM methods. Electrochemical characterization was made by chronopotentiometry, potentiodynamic polarization, and cyclic voltammetry.

The individual coatings were identified as Ni-0W, Ni-23W and Ni-32W, numbers meaning the amount of alloying element in the coating. Alloying element contributes to the grain size of the coating.

The electrocatalytic parameters for HER (exchange current density, the overpotential necessary to achieve the required current density and stability) were determined on the steel sheet (Fig.1). In all cases, the best values showed the Ni-32W coating. The results of the electrocatalytic measurements were subsequently verified in a "Zero-gap" electrolyser for alkaline water electrolysis. Measurements were performed on a steel mesh in a solution of 10 wt. % KOH. The results for steel mesh correspond to the results of the electrocatalytic measurements.

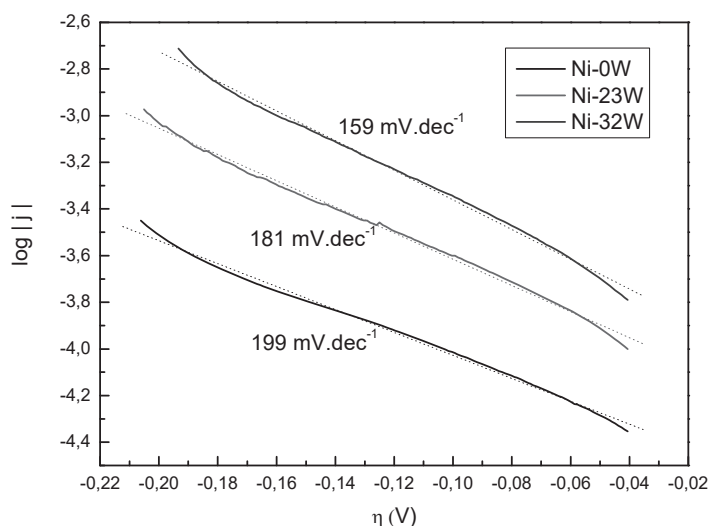


Fig. 1 Tafel slopes for the electrodes having coatings of different compositions.

### Acknowledgement.

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## Snowball-structured cathode for long-term electrochemical stability of proton conducting fuel cells

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**Keywords:** Proton conducting oxide fuel cells (PCFC), Long-term stability, Cathode, Snow ball, Electrostatic slurry spray deposition (ESSD)

Proton-conducting fuel cells (PCFCs) have attracted massive attentions due to their relatively low operating temperatures. However, in the case of PCFC, the water vapor, which is a redox product, is generated at the cathode side, so that cathode degradation by side reactions occurs more easily. This is a critical problem in long-term operation, causing a setback for entering the market with a high volume and industrial scale. To overcome this problem, the snowball-structured cathode we propose in this work has a potential to resolve the above-mentioned problem. To elaborate, the snowball has a nanoscale porous surface, while the configuration of snowball units represents microscale porous structure, building a highly porous cathode layer, so called 'dual porosity structured cathode'. With this extraordinary cathode, both the condensation of the vapor phase and the formation of undesirable secondary phases are effectively inhibited thanks to sufficient ventilation of the vapor. Consequently, a cathode degradation is expected to be suppressed, providing an enhanced long-term stability. To our knowledge, few literatures are reported on this subject, so it is worthy of investigation.

In this work, to improve electrochemical stability of cathode, snowball-structured PBSCF ( $\text{PrBa}_{0.5}\text{Sr}_{0.5}\text{Co}_{1.5}\text{Fe}_{0.5}$ ) is employed. The PBSCF powders were synthesized by modified citric-nitrate method. Taking several slurry properties such as viscosity, particle size and binder ratio into account, the PBSCF snowball was successfully by electrostatic slurry spray deposition (ESSD) technique. Microstructural analysis of the snowball was carried out by scanning electron microscope (SEM). Phase development of powders was identified by X-ray diffractometer (XRD). The I-V curves and impedance spectra of the single cell containing snowball cathode, were measured in the range of  $550^{\circ}\text{C} \sim 700^{\circ}\text{C}$ . In addition, a short-term analysis (100 hours) under specific conditions was conducted to evaluate the electrochemical stability of the snowball-structured cathode.

## New Generation Reversible Solid Oxide Fuel Cell

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**Keywords:** dual membrane fuel cell, solid oxide fuel cells, proton conductivity, mixed ionic conductivity, reversible mode, electrolyzer, separate water compartment

A promising direction in the development of solid oxide fuel cells (SOFC) is the reversible approach in which the device operates as fuel cell, producing electricity and heat, and as electrolyzer (SOEC), producing the hydrogen fuel. Reversibility strongly increases the device efficiency. It is very convenient for coupling with Renewable Energy Sources and for off grid applications. Although being very important, this direction of SOFC development still needs serious research efforts. The main problems come from the asymmetry of the system when operating in the two modes, which strongly hinders the reversibility optimization. For instance the high current density associated with a large amount of water in the fuel electrode for SOEL compared to SOFC increases the polarization resistance, the constraints on the interconnects and the overall degradation rate in that mode of operation.

The present SoA shows that in electrolyzer mode the degradation is much higher - about 2-5% after 1000h of operation, which is behind the commercialization thresholds. In this respect special measures are taken for improvement of the electrodes performance and stability.

A definitive breakthrough is the separation of the water production/consumption from the two electrodes. For fuel cell mode this idea has been proved in an innovative concept named dual membrane fuel cell (dmFC). It is based on a new design that offers three independent chambers for hydrogen, oxygen and water, which can be separately optimized. This talk presents the development of the next generation of a dmFC adapted to operate in a reverse mode. The approach is scientifically ambitious and offers a radically new solution in respect to the state of the art reversible systems. It demonstrates additional advantages as fast switching between fuel cell and electrolyzer mode, improved durability, simplified interconnects. On this stage the technology readiness level is between 2 and 3. For accelerated further development towards higher TRLs we are looking for industrial partner.

### Acknowledgements

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## Kinetics of oxygen electrode reactions in solid oxide electrolysis cell

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**Keywords:** SOEC, SOFC, H<sub>2</sub>O, electrode degradation, solid oxide cells

Today an efficient technology for intermittent energy storage is needed in order to fully utilize renewable energy resources with unstable power output over time. This obstacle can be solved by the conversion of electric energy to chemical energy of hydrogen. Among others the high-temperature approach with the so called solid oxide cells (SOCs), offers significant advantages for intermittent energy storage. This is mainly the consequence of high operating temperature (700 – 900 °C), which leads to fast electrodes kinetics, the possibility to operate in reversible modes (electrolysis – EC or fuel cell – FC) within single cell; however, the high temperature also enhances degradation processes. Particularly the interface contact degradation of electron/ion conductive phase contact at oxygen electrode has a great impact on SOCs overall performance. However, because the oxygen evolution or reduction reaction (OER/ORR) is predominantly responsible for cell activation losses, it is important to minimize activation and ohmic losses at the oxygen electrode. Therefore, a thorough understanding of the electrochemical reaction and structural characteristics of the oxygen electrode-electrolyte interface is needed. Electrode conductive material (La<sub>0.8</sub>Sr<sub>0.2</sub>)<sub>0.95</sub>MnO<sub>3-x</sub> (LSM) and ion conductive material ZrO<sub>2</sub> – 8 mol.% Y<sub>2</sub>O<sub>3</sub> (YSZ) are commonly used materials as oxygen electrode in SOCs. Hence, series of SOC cells with YSZ electrolytes with screen printed LSM electrode and Ni based hydrogen electrode were prepared. To investigate initial up-to date SOCs systems stability, each LSM-YSZ-Ni cell was tested at first in FC and then in EC mode for 300 h in potentiostatic mode. After several days in either mode a degradation of cell was observed. Therefore, symmetrical LSM-YSZ-LSM cells were prepared to examine degradation mechanisms and kinetics of OER and ORR under different O<sub>2</sub> partial pressures and temperatures. Each cell was examined by various electrochemical methods and the structural changes at the interface were examined by postmortem SEM and XRD analysis. During operation at 700 °C only a slight increase in polarization and ohmic losses was observed; however, at 800 °C the ohmic losses increased rapidly. SEM analysis suggested no visible morphological changes at the interface; however, XRD analysis showed development of new nonconductive phase at the interface. Overall, our results broaden the knowledge of OER and ORR kinetics at LSM electrode and long-term tests indicate loss of LSM-YSZ interface.

### Acknowledgements

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## Characteristics of hybrid glass seals applied in SOC stacks

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**Keywords:** solid oxide cell, SOC, SOFC, SOE, seals, stack

Solid oxide cells (SOC) are gaining popularity as an alternative way of producing energy due to their high electric efficiency and an environmentally-friendly nature. Electrochemical cell (SOFC), that generates electricity while fuel and oxidant are consumed, can be reversed during operation, which means that it can be converted into solid oxide electrolyser (SOE) which produce hydrogen and by-product oxygen. One of the most important obstacle to overcome while designing SOC units is the need for reliable sealing technology. The main demands for the seals are long-term stability in the high temperature SOFC/SOE environment (600-800°C) and the value of thermal expansion coefficient of the seal material has to be compatible with the steel and ceramic components of the unit.

The study was focused on manufacturing and testing ceramic (glass) and hybrid (glass-mica) seals whose main task is to prevent the air and fuel from mixing during operation in high temperature and low overpressure. The manufactured seals were finally applied in a SOFC stack designed at the Institute of Power Engineering. For this experiment, 3 anode supported cells of 100x100 mm size were used and the stack was operated in 650°C with the supply of air and fuel. This experiment confirmed that the application of the manufactured seals ensured very high gas-tightness that allowed to reach desired effect.

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## Experiments exploring hydrogen combustion modes for energy recovery from PEMFC anode exhaust

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**Keywords:** PEM fuel cell, hydrogen combustion, metal honeycomb catalyst, energy recovery, hydrogen safety

In a hydrocarbon-based fuel cell system, the anode exhaust gas from the fuel cell stack is typically composed of hydrogen, water vapor, carbon dioxide and traces of carbon monoxide. This experimental investigation studies the combinations of homogenous and heterogeneous hydrogen combustion modes, which can be used for heat recovery. Primary combinations of these combustion modes are- Catalytically Supported Thermal combustion (CST mode), in which gas phase combustion follows catalytic combustion, and inverse-CST (or iCST) mode in which catalytic combustion follows gas phase combustion. These modes have been experimentally investigated at multiple fuel-air ratios up to pressures of 3 kg/cm<sup>2</sup>. Heterogeneous combustion was performed using platinum coated on a stainless steel honeycomb structure, with  $\gamma$ -alumina as the catalyst support. Auto-ignition of hydrogen was observed during combustion at equivalence ratios between  $\phi=0.3$  and 3.0. This trend of auto-ignition was also observed during CST mode of combustion. As reported in the literature, super-adiabatic catalyst temperatures were attained during lean-CST combustion. On the other hand, rich-CST combustion with rich catalytic combustion and lean gas phase combustion showed no such activity, since oxygen becomes the limiting reagent in this mode. We expect this study to be useful in the design and development of an anode exhaust gas burner for heat recovery in hydrocarbon-based fuel cell systems.

## Optimization of multi-nozzle hydrogen flame burner for low NO<sub>x</sub> emissions

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**Keywords:** hydrogen, flame, combustion, nitrogen oxides, emissions

Hydrogen is a clean fuel with water being the only product of its combustion. However, high-temperature combustion in flames results in formation of nitrogen oxides due to a reaction of atmospheric nitrogen and oxygen. Both NO and NO<sub>2</sub>, commonly referred to as NO<sub>x</sub>, are harmful to human health and their formation in all combustion processes should be minimized. This is especially important in indoor applications like stoves.

In the present work we investigate formation of NO and NO<sub>2</sub> in partially- and fully-premixed flames of hydrogen in air on multi-nozzle burners with various geometry. Flue gases were analyzed by continuous gas sampling. Concentrations of NO and NO<sub>2</sub> were measured by electrochemical gas sensors and formation of both oxides was evaluated in mg/kWh of the released heat. We studied effect of burner and flame parameters like nozzle diameter, gap between nozzles, power density and air to fuel equivalence ratio  $\lambda$ . In addition, burner temperature and traces of unburnt hydrogen were monitored as well. We observed that formation of NO can be strongly suppressed at  $\lambda > 0.7$  while formation of NO<sub>2</sub> is less sensitive to variation of  $\lambda$ . In general, the NO<sub>x</sub> emissions could be reduced by decreasing power density and nozzle diameter and by increasing the gap between nozzles. Under most of the studied conditions, the emission of NO<sub>x</sub>, expressed as NO<sub>2</sub>, were below 56 mg/kWh required by the regulation No 813/2013 of the EU Commission for fuel boiler space heaters and fuel boiler combination heaters using gaseous fuels.

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## TVHT-reactor with Pebble Fuel Elements to Produce Hydrogen

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**Keywords:** Desalination, HTR, VHTR, THTR, Pebble Fuel Elements, inherent safety, Thorium, hydrogen.

Large scale production of hydrogen is one of the most important tasks for developing worldwide non-industrialized regions and has the potential for high economic impact. The condensation of sea- or wastewater is the best technology for desalination, but so far is very costly. Many chemical processes need high temperatures above 600 degree Celsius. One of them is the hydration of coal or CO<sub>2</sub> into car fuel

High temperature by nuclear energy is the most economical technology to lower the cost for these applications. When combined, the production of heat and electric power can minimize the cost for all secondary production processes.

This paper presents experiences and conclusions for the main design features of thorium very high temperature (TVHTR) power plants. These were gained from about 25 years of operations with the two German HTR-pebble bed reactors. The AVR experimental reactor (15 MWe/46 MWth) in Juelich and the THTR demonstration plant (300 MWe/750 MWth) in Hamm are the basic for the proposed design of future VHTR power plants.

The inherent safety-by-design of the pebble bed technology was demonstrated three times. In Juelich, Germany two tests of maximal credible accident (MCA) were successful in the 60ies and 70ies. In 2007 this was repeated at Tsinghua University, China, with the HTR-10, which is similar to the AVR. At these tests a total loss of coolant was initiated, all safety equipment was blocked, and no human intervention was allowed. No other nuclear power stations worldwide were even tried to stand a similar test.

This is why this technology is ideal to co-generate electricity and drinking water and/or Hydrogen – even in threshold countries and urban agglomerations. The HTR-PM in China (210 MWe) currently being built is a confirmation of this technology (which was unfortunately abandoned in Germany together with all other nuclear efforts). HTR power stations up to high capacities attain the best possible thermodynamic efficiency when high temperature is used for both: generation of electricity and subsequent processes. Cost for these processes are optimized with extracted pressures at various levels.

- When used for water desalination, the nuclear heat can be supplemented by solar energy to increase profitability.
- When used for hydrogen production, the well-established but expensive electrolytic process can be drastically lowered in cost.
- When used for car fuel production, the proven Fischer –Tropsch technology yields various synthetic fuels e.g. Ethanol, Methanol, Gasoline, Diesel, Kerosene, Hydrazine etc. One enormous advantage of these is the continued use of today's supply logistic.
- Other extractions from the temperature scale can be used for industrial gases, in the steel making process, remote heating of habitations, agricultural greenhouses etc.

## Pebble Technology for HT Nuclear-Reactors to generate Heat for Industrial Processes and Electric Power – current status

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**Keywords:** HTR, Hydrogen, synfuel, synthetic gas, pebble-bed, fuel elements, inherently safe, Thorium, , Fischer-Tropsch, Bergius-Pier, biowaste, CO<sub>2</sub>, Ethanol, Methanol

Hydrogen days cover a vast spectrum of H topics. Conversion, use and distribution take a large share. This focuses the generation of H, which needs much energy for most of the processes like reforming, partial oxidation, pyrolysis, electrolysis, thermocatalytics etc. The input is mostly steam, fossil or water. Also the final use is important: Hydrogen direct for fuel cell, for hydrogenation of car fuel or else.

The widely preferred electrolytic generation from water needs lots of cheap electricity. It is known, that nuclear can be the cheapest and stablest source for electric power. It is less known for high temperature. Nuclear has a certain reputation of being dangerous, because of the three main accidents everybody knows. But fossil generating electric power also causes many fatalities. The WHO speaks of 7 Million deaths per annum, much more than all nuclear caused ones.

The way in between these challenges is a nuclear plant with pebble bed technology. This avoids meltdown, MCA, LOCA and other radiological accidents. It is reliable and independent of mechanic or human action. It works by natural laws, wisely applied. Not only promised but proven.

Pebble bed technology, originally developed in Germany and now realized in China shows a special approach in the application of physics. Witnessed test- and demonstration examples in Germany and China showed three times its inherent safety. In Juelich, Germany two tests of maximal credible accident (MCA) were successful in the 60ies and 70ies. In 2007 this was repeated at Tsinghua University, China. These three “Meltdown-Tests” have proven, that overheating leads to “peaceful” shutdown rather than explosion and contamination.

Other benefits of this technology are:

- Lower construction cost because almost no need for safety mechanisms
- Much less electronics/ digitized apparatus reduce need for highly trained personnel
- Proliferation of PU is prevented, because there is no attraction for terrorists
- Pebble fuel elements carry their own long-term storage with them after burn-up
- Distributed small safe reactors avoid large overland electricity networks
- Insurability by commercial policies rather than leaving the risk to the public
- high temperature allows multiple use for various purposes, e.g.:
  - Hydrogenation of car fuel
  - Hydrogen production
  - Seawater desalination
  - Electric power Generation
  - Remote heating for agriculture and urban areas

A special look to the car fuel production shows the following benefits:

- Proven technology (e.g. Fischer-Tropsch) can be used and be further optimized
- Continued use of the existing car fuel logistics (vs. electro mobility)
- Preserving todays car and motor production including jobs, because currents motors need minimal adjustments for ethanol fuels
- Main feed stock will first be coal, then bio-waste and even CO<sub>2</sub>

## Gemini plus: Design of high-temperature nuclear co-generation and hydrogen production

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**Keywords:** hydrogen production, high-temperature electrolysis, Gemini plus, NC2I, NGNP Industrial alliance

Gemini plus is a H2020 project, in which the European Nuclear Cogeneration Industrial Initiative NC2I and the US Next Generation Nuclear Plant NGNP Industrial Alliance are cooperating. The objective is to investigate high-temperature nuclear technology for co-generation with industrial processes.

The proposed modular high-temperature gas-cooled reactor HTGR will allow industrial cogeneration, operational flexibility, robustness and simple design enabling further applications within small isolated electric grids, electric grids with increasing proportion of fluctuant renewable energy sources and to new nuclear countries.

The contribution of Research Center Rez to this project is also in the field of hydrogen production by the high temperature electrolysis process as an example of high temperature heat utilisation. CVR operates a high-temperature electrolysis loop with 1kW electrolysis stack. The loop is rather flexible facility, where material degradation of construction materials as well as different stack degradation in dependence of operation parameters, fuel cell and reversible mode can be investigated. Within the Gemini plus project, experiments will focus on the suitability of the high-temperature electrolysis for peak shaving.

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## Portable DC power supply with hydrogen fuel cell

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**Keywords:** hydrogen, power supply, fuel cell

This paper introduces a portable DC power sources with hydrogen fuel cell, which is called Power-box. Power-box was designed and built by ÚJV Řež, a.s. in cooperation with the University of Chemistry and Technology in Prague. The fuel cell serves as a source of electricity and the fluctuations in consumption are compensated by using accumulators. The hydrogen pressure cylinder is located next to the unit.

Power-Box is designed for rescue and safety services in emergency situations where the public distribution network cannot be used. It is used to power command stations, mobile laboratories and field units that require more than one hour of power supply. The unit is also suitable for power and telecom companies, for operation in closed spaces, as a backup source for field hospitals, to power communication and monitoring devices and for charging caravan and yacht batteries.

## Economic analysis of electrolyser deployment in CCGT power plant in Počerady

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**Keywords:** Economic analysis, energy storage, electrolysis, sector coupling, hydrogen, gas turbine

Due to environmental aspects European Union set up targets for emission reduction and share of renewable sources in gross energy consumption to 32% in 2030 and 60% in 2050. This large share of renewable sources will lead to several issues in industrial sectors which has to be solved. Hydrogen technologies could facilitate integration of high share of renewable energy with grid and end-users via connecting electricity, heating, mobility and chemical sector.

Scope of this work is economical evaluation of electrolyser potential deployment in combined cycle gas turbine (CCGT) in Počerady. Design optimization of electrolyser and few possible utilizations are considered, such as: hydrogen independence providing hydrogen to cover demand for cooling electric generators; storage and burning of hydrogen in CCGT to lower the natural gas costs and the CO<sub>2</sub> allowances (EEA); usage of electrolyser as flexible compensation of volatile electricity prices; production of hydrogen as intermediate product for further treatment in chemical sector and finally co-combustion of hydrogen in diesel engine in locomotive.

Presented work is based on information from several electrolyser companies, project reports and available literature. Deployment of the unit was investigated considering potential hydrogen consumption, storage capacity and investment costs. Sensitivity analysis of hydrogen specific price were conducted on electricity price, natural gas price, CO<sub>2</sub> EEA price, electrolyser utilization rate and hydrogen demand. Economical results are evaluated via payback period however other benefits of deployment are also considered.

Sensitivity analysis shows that project is economically feasible under certain parameters and have reasonable potential for further analysis.

## Assessment of hydrogen potential of co-gasification of municipal solid waste and biomass in a downdraft gasifier

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**Keywords:** Hydrogen production, Biomass gasification, Municipal Solid Waste, Syngas, Co-gasification

In this study, gasification performance and importance of hydrogen production using municipal solid waste and biomass were evaluated. A mathematical model was developed for a gasification system. The model has been validated against a commercial-scale 100 kg/h downdraft gasifier's data given in the literature for syngas composition for three different co-gasification ratios of 0, 20 and 40%. Results of this study show that it is important to convert biomass waste into a clean energy source of hydrogen to minimize its environmental impact.

## The viability of hydrogen to the transportation sector

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Hydrogen is an energy vector that can be used as an energy source or for storage. The conversion into electricity or heat may be done using fuel-cells or combustion motors.

Hydrogen is part of the energy mix and presents high potential to contribute to the energy transition towards a cleaner system. It is key to understand the technical and economical impacts related to the introduction of this energy vector into the transportation system.

Research and development allowed so far a reduction of 60% on the fuel-cells costs. Also, the robustness of the materials is multiplied by four.

In the study we will demonstrate the state of the play of hydrogen to transport as compared with internal combustion vehicles.

## Inertization of PEM fuel cell by nitrogen generated using membrane gas separation module

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**Keywords:** inertization, nitrogen purity, fuel cell lifetime, membrane module

PEM fuel cells represents a promising device for efficient conversion of chemical energy carried by fuel into electrical energy. Performance and efficiency of the energy conversion depends on many aspects, like activity of catalyst, degree of its utilization, homogeneity of the fuel distribution, ohmic resistance of all components etc. Main part of ohmic resistance of fuel cell is determined by proton exchange membrane. Effort to reduce this loss leads to using as thin membrane as possible. Permeability of membrane to hydrogen, however, increases with decrease of its thickness. Permeation of hydrogen to the cathode compartment has, beside efficiency loss, also secondary negative effect. It consists in formation of aggressive species, especially inside catalytic layer, during fuel cell off period. This results in accelerated degradation processes. Solution of this problem represents cell inertization by an inert media during the switching off process.

The gas traditionally used for fuel cell inertization is nitrogen. It can be stored in a high pressure cylinders integrated into the fuel cell system. Such solution, however, is demanding due to the several reasons, increased complexity and weight of the system to be mentioned as the main ones. At the same time, total volume of gas in cylinder is limited and sufficient just for a limited number of inertization cycles before replacement or refilling is required. It makes the process complicated also from the logistic point of view. An alternative solution represents production of nitrogen of sufficient purity on-site, preferably from air by means of membrane separation modules. In combination with corresponding air compressing unit it represents inexhaustible source of nitrogen. Unfortunately, the membrane module is not able to produce nitrogen at purity higher than 99.9 %. Residual oxygen represents main impurity in the produced nitrogen stream. Information available in literature on the impact of traces of oxygen in an inertization gas on the fuel cell lifetime and performance is, however, not sufficient.

Main aim the present contribution is to determine impact of the oxygen content in an inertization nitrogen stream on commercial available MEA (SC-200, Horizon Fuel cell) lifetime. Accelerated test used to obtain information on this aspect consists of 1 thousand “switch on – load for 30 minutes – switch off” cycles. Impact of nitrogen containing 0 to 20 % of oxygen was studied.

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## PEM fuel cells under cyclic exposure of frost in the worst-case scenario

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**Keywords:** PEMFC, freeze-thaw attack, cyclic frost exposure, subfreezing temperatures, damage analysis, different types of MEA

Proton exchange membrane (PEM) fuel cells (FC) are electrochemical energy converting devices which are considered one of the most promising technologies for solving the environmental problems of the future. In spite that this technology has been around for almost 180 years now, only during the past few decades intensive research and development have established PEMFCs as competitive among other comparable types of power applications. One of the biggest of those is the transportation sector where this environment friendly technology constantly attempts to offer an efficient alternative for internal combustion engines. Yet even despite the ongoing commercialization of the FCEVs, further advancements in performance, durability and cost reduction are necessary for its continuing expansion. In order for this to happen, a number of technical challenges have still to be overcome before allowing its wider use and prove its advantageousness over other types of power applications. In this context, freeze-thaw effects within PEMFC single cells and stacks have been studied in present work.

Under sub-freezing temperatures, the residual water that is present within different FC stack components can freeze causing ice formation. This simple fact leads to the various local mechanical issues due to the volume expansion of ice. Because of the cyclic exposure to such temperatures as well as associated with it corresponding volumetric changes, various damaging processes of the layered MEA systems set in, which in turn can result in the unrecoverable degradation of the PEMFC performance. A better understanding of the failure models and degradation phenomena as well as their underlying mechanisms should help to identify the origin of the problems and the most appropriate methods to prevent them. Based on findings made on other porous materials such as concrete or cementitious materials under freeze-thaw exposure during decades of research work, the damage and transport mechanisms within the porous MEA components could be explained. In general, the physical background is similar for any type of solid porous materials [1].

In addition, according to the Department of Energy (DOE) targets of 2016, the fuel cell power systems should maintain its functional capability over a broad range of external environmental conditions, which extends from  $-40^{\circ}\text{C}$  to  $+40^{\circ}\text{C}$ . To address this matter while modeling the worst-case scenario, the temperature range of the freeze-thaw cycles has been adjusted to the lowest required value of  $-40^{\circ}\text{C}$ . For this purpose, the present study is a part of the ongoing research effort to investigate the damage behavior of membrane electrode assemblies of PEMFC under cyclic freeze-thaw attack.

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## Effect of fuel concentration and cell design on the performance of a passive Direct Methanol Fuel Cell

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**Keywords:** Passive direct methanol fuel cell, methanol concentration, design, electrochemical impedance spectroscopy, optimization, power output

Nowadays, the demand of alternative energy production technologies is mandatory, mainly due to the negative environmental impacts of fossil fuels. The direct methanol fuel cells (DMFCs) appear as a promising alternative solution due to their high efficiency, simplicity, low environmental impacts and quick refuelling. Moreover, passive DMFCs (pDMFCs) have potential to replace the conventional lithium batteries in portable applications, such as hearing aids. This technology converts the chemical energy of a fuel, alcohol, directly into electrical energy [1]. However, these systems present some obstacles, which hinder its massive use, such as slow anode kinetics, methanol crossover, which not only lowers the fuel utilization but also degrades the cathode performance and generates extra heat, higher costs and lower lifetimes. Therefore, it is needed a deep research on this field to solve these issues and to optimize these devices.

In the present work, it was studied the effect of different methanol concentrations and design parameters on the cell performance towards an increase of its power output with attractive costs and lifetime. The pDMFC performance was evaluated through the polarization curves and the electrochemical impedance spectroscopy (EIS) data. EIS is a complementary diagnostic tool used to analyse the fuel cell performance since it allows the identification and quantification of the individual contributions of each component and process occurring in a working fuel cell. More specifically, it allows the quantification of the losses that negatively affect the passive DMFC performance (activation, charge and mass transfer losses) [2]. Towards that, the EIS data was fitted with an in-house developed equivalent electric circuit (EEC), which showed a good agreement with the experimental data, therefore reproduces with accuracy the system under study.

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## Methodology for construction and operation of refuelling stations for hydrogen vehicles

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**Keywords:** hydrogen, refuelling station, certified methodology, clean mobility, infrastructure

Advancement of clean mobility is dependent not only on the development of new vehicles, but also on the existence of sufficient infrastructure for refuelling of vehicles with compressed hydrogen, or their charging. Construction and operation of compressed hydrogen refuelling stations are dependent on adhering to technical standards and security norms, which aren't yet unified on the global or European level. Globally recognized standards are gradually being prepared and subsequently adopted by individual countries. Czech Republic has also accepted the standards in their original English form, and with their use, they may be therefore subject to misinterpretation. Construction of refuelling stations in Czech Republic has to be agreement with Czech legislation and accepted standards; therefore, it is not easy to execute their construction.

A certified methodology "Methodology for construction and operation of refuelling stations for hydrogen vehicles" was prepared based on own experiences from the for now sole compressed hydrogen refuelling station located in Neratovice, international standards and similar directives for refuelling of CNG and LNG. This methodology was consulted with independent and government organizations and industrial stakeholders. The contribution presents a unified overview of all aspects, which need to be adhered to, in order to facilitate the process of project development, placement, construction, operation and maintenance of compressed hydrogen refuelling stations. Operation characteristics and individual components enabling the storage, compression, and refuelling of hydrogen along with necessary equipment ensuring safe operation are also specified in the contribution.

## Future European Fuel Cell Technology: Fit for Automatic Manufacturing and Assembly

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**Keywords:** clean vehicles; mass production; cleantech; automation; PEMFC stack; MEA; bipolar plate

Submitted within the call H2020-JTI-FCH-2016-1, the Fit-4-AMandA project aims to establish a technological roadmap to scale up from less than hundred stacks/year to 50,000 stacks/year in 2020 and beyond. Existing MEA and stack were redesigned/adapted for manufacturability and automation. Fast in-line non-destructive quality assurance methods for automated production of MEAs and stack assembly are being developed and implemented. The technology and machine system for the automated assembly of PEMFC stacks are being developed, manufactured and tested.

The designs, hardware, tools and software for the automated production of MEAs and stack assembly will be validated. One of the prototype stacks manufactured by the automated processes will be integrated into a light commercial vehicle provided by UPS and field-tested.



### Acknowledgements



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## SOFC applications in Unmanned Underwater Vehicles (UUV)

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**Keywords:** UUV, fuel cells system, hydrogen/oxygen storage, li-ion battery, SOFC

Unmanned Underwater Vehicles (UUVs) provide an operational platform for long periods of deployment (on the order of hours) and in depths that are too dangerous for divers. The main purpose of using a UUV is to protect human from the dangers of the submarine environment and reduce the cost of underwater exploration. These vehicles can be subdivided into two categories: remote operator-controlled underwater vehicle (ROV-remotely operated vehicle) and autonomous underwater vehicles (AUVs), which operate directly from the human input.

In today's technology, UUVs are operated by lithium-ion batteries. The UUVs need to be increased in order to reach their maturity level. Fuel cell power systems have been described as an effective tool in ensuring this durability. Fuel cells look attractive as an underwater power source due to their high efficiency, quiet operation, lack of moving parts, compact and easy maintenance.

In this study, fuel cell technologies used in UUVs have been investigated and studies in recent years are summarized. In this context, prototypes and conceptual designs of UUVs working with SOFCs were examined. Current solutions in oxygen and hydrogen storage systems are reviewed.

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## Research Centre Řež focuses on research, development and innovations in the field of power generation, especially (but not only) nuclear.

**Research Centre Řež is part of the ÚJV Group, owned by ÚJV Řež, a. s. and is knowledge-oriented organization which is – thanks to its unique research infrastructure – the largest complex research centre in Central Europe. The combination of research reactors, technological experimental loops, hot cells and material laboratories at one site is really exceptional.**

Two nuclear research reactors and experimental loops simulating operation parameters of PWR, BWR, SCWR, MSR; hot cells; severe accidents laboratories (e.g. cold crucible, LOCA device); material laboratories; microstructural and microchemical laboratories; NDT laboratories.

Within the field of hydrogen technologies, the focus is on its production by high-temperature electrolysis for co-generation applications. For this purpose, a dedicated loop was developed, as well as a test bench. The test bench serves for testing of different single cells for research and development. High-temperature electrolysis loop is used for a demonstration of hydrogen production via co-generation and testing of system components.



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Centrum výzkumu Řež s.r.o.

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## UNITED HYDROGEN, a. s. was founded in 2007 and now it is a member of the international group UNITED HYDROGEN GROUP.

In the company, UNITED HYDROGEN, a. s., the main objective is to become an important player in the area of production of high-quality hydrogen and to take an active part in the development of the hydrogen industry in the Czech Republic and the European Union. United Hydrogen Group (UHG) producing hydrogen since 2009. Production is CO<sub>2</sub> neutral and UHG provides complex hydrogen business – gas, liquid, new technologies, filling stations.

### United Hydrogen Group Operating Companies:

- United Hydrogen of Tennessee – Gaseous hydrogen production and distribution
- United Hydrogen Cryogenics – Liquid hydrogen distribution
- United Hydrogen Fuels – H<sub>2</sub> fuel stations for car and fuel cell applications
- United Hydrogen Solutions – H<sub>2</sub> producer, Application of LOHC and Power to Gas technology on US market
- United Hydrogen, a. s. – UHG Representative for Europe

United Hydrogen Group plans to build total 26 mil. kg / year and UHG plans to build 10 hydrogen filling stations, in North East region of USA. Future target is share of UHG on USA H<sub>2</sub> market of 10–20 %.

United Hydrogen Group mission is broad participation in the hydrogen economy through reliable, low cost production and distribution of hydrogen, meeting objectives of clean environment and lesser dependence on foreign oil.



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## A Fuel Cell Technology Company

**Our first interest was a new “lean cat-alyt”, then we moved on to R&D new versions of complete PM fuel cells for various applications. Out of need to properly test these FCs, we started to develop and sell our own sophisticated testing stations. We also develop an H<sub>2</sub> generator, a UPS and a forklift. We are LEANCAT.**

### We innovate

Leancat is a small innovative company, founded thanks to a close cooperation between the Department of Surface and Plasma Physics at the Faculty of Mathematics and Physics, Charles University in Prague, and a Czech technology group JABLOTRON. The founder and co-owner of the company, Professor Vladimír Matolin, gathered around him a team of enthusiastic and dedicated young researchers and technicians who are trying to transform the theoretical knowledge from the field of hydrogen technology into meaningful products.

### We produce

We manufacture professional and fully customized test stations for hydrogen fuel cells up to 10 kW. We have also started with H<sub>2</sub> generators and UPSs for industrial and residential applications, single cells and custom-made mixing stations for technical gases. With company Belet a. s. we are preparing the first Czech hydrogen-powered forklift.

### We love hydrogen

We are trying to absorb everything interesting in the field, and we are moving fuel cells forward.

### We go worldwide

For example, we supplied test stations to the European Synchrotron Radiation Facility (ESRF) in Grenoble, to Hochschule Rhein-Waal (GER) or Manchester University (UK). You will also find our equipment in prestigious institutes in China and India.



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LEANCAT  
FUEL CELL TECHNOLOGY

## We make things happen.

**The Unipetrol Group is the largest refinery and petrochemical company in the Czech Republic. It focuses primarily on crude oil processing, distribution and sale of fuel and petrochemical products – particularly plastics and fertilisers. In all these fields, the group is a key player on both the Czech and Central European market. The Unipetrol Group includes refineries and production plants in Litvínov and Kralupy nad Vltavou, Paramo with the Mogul brand in Pardubice and Kolín, Spolana in Neratovice, and two research centres in Litvínov and Brno as well as rail and road carriers. Unipetrol also owns the Benzina network of petrol stations with 409 stations, which is the largest chain in the Czech Republic. Unipetrol is one of the largest companies in the Czech Republic in terms of turnover. The group created revenue of over CZK 130 billion last year and employs more than 4 700 people. In 2005, Unipetrol became part of the PKN Orlen Group.**

### Unipetrol Group operates

- 2 refineries with an annual conversion capacity of 8.7 million tons of crude oil
- 3 polyolefin units with an annual capacity of 595,000 tons
- 1 steam cracker with an annual capacity of 544,000 tons of ethylene
- 409 filling stations and 23,2 % of the Czech Republic's market share

### Main products

- diesel
- automotive gasoline
- aviation fuels (jet)
- motor and fuel oils
- LPG
- petrochemicals (ethylene, propylene, C4 fractions, benzene, butadiene)
- plastics (polyethylene, polypropylene)
- asphalts
- ammonia

### Unipetrol and hydrogen

Unipetrol, as a traditional hydrogen producer, sees the future in this gas through gradual replacement of conventional fuels in transport. Unipetrol's representatives engage in platforms supporting development of hydrogen use. It cooperates both with state and non-state institutions as well as automotive producers to promote its use. The chemical industry already has surpluses of hydrogen today. Its use in transport would therefore be beneficial to all parties. We are currently producing hydrogen especially in our Litvínov Refinery. Approximately half of the hydrogen produced is used for the production of ammonia, feedstock for the production of fertilizers. The other half is used for hydrocracking of vacuum distillates and hydrotreating of motor fuels. We plan to produce hydrogen that can be used also in transport. In the near future, we plan to extend two existing filling stations to hydrogen filling stations in Barrandov (Prague) and Litvínov.



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## University of Chemistry and Technology, Prague

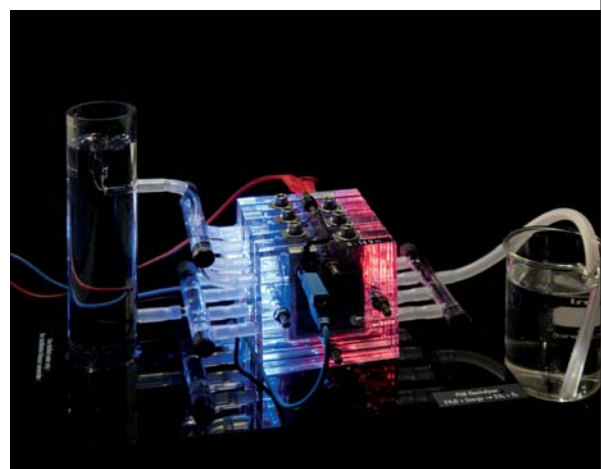
**The University of Chemistry and Technology, Prague (UCTP) is a typical research university, providing a top-class education in the fields of chemistry, materials chemistry, biochemistry and related technologies. It is one of the largest educational and research establishments in these fields in Europe.**

UCTP closely collaborates with the industrial sector and is committed not only to the publication of the results achieved, but also to their practical implementation. Research activities conducted at UCTP have the advantage of a robust infrastructure consisting of a technical library, central laboratories equipped with state-of-the-art equipment, as well as a publishing house specialising in chemistry and related fields. Besides the permanent staff, the students of PhD and MSc programmes are intensively involved in the research activities.

The broad range of specialisations includes "Hydrogen and membrane technologies" which trains specialists to operate, maintain and develop hydrogen-related technologies. The establishment of this program was motivated by the UCTP tradition of following and supporting the philosophy of sustainable development. This also covers renewable energy production, conversion and storage.

The Technical Electrochemistry research group responsible for carrying out this program has many years of experience in fuel cell and hydrogen research. Its current research activities cover the fields of material (catalyst, membranes, etc.) development and testing, cell set-up and optimisation as well as system design. The focus is on low-temperature PEM and alkaline systems and also SOFC/SOEC systems. The unique advantage of our research is the direct connection between experimental work and mathematical modelling. The mathematical modelling laboratory uses a broad portfolio of software tools (MatLab, COMSOL, Fluent, ASPEN plus, etc.) to understand and describe fundamental phenomena as well as to design the related technologies.

The UCTP research activities in the field of hydrogen technologies are currently funded by national bodies (Grant Agency of the Czech Republic, Technology Agency of the Czech Republic, Ministry of Industry and Trade of the Czech Republic and Ministry of Interior of the Czech Republic) as well as by the European Union. On the European level, the support of research and development in the field of hydrogen technologies is provided exclusively by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). UCTP is the only member representing the Czech Republic in FCH JU. It is a member of the Hydrogen Europe Research (former N.ERGHY) grouping.



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**GREEN REMEDY is a private company developing a complex design of Hydrogen Economy to cover the entire spectrum of its usage and applications. We believe in the future of hydrogen as an alternative to carbon energies and one of key energy carrier in near future.**

**GREEN REMEDY is working on a project for complex implementation of hydrogen economy, which aims to create a system to enable hydrogen technologies to be used in the full spectrum of its options – power storage, clean mobility, electricity production, etc. The key benefit will be innovative and entrepreneurial joining of the technologies that are now still in different stages of development or commercialization into a functionally optimized whole, with the widest use of IT technology.**

## **GREEN REMEDY Goals**

The goal is to produce a model system of hydrogen management using hydrogen technologies in connection with a solar power plant and hydrogen storage in a real-world environment to demonstrate the potential of hydrogen technology in the following areas:

- Accumulation of surplus electricity into hydrogen
- Utilization of stored energy in hydrogen as
  - a back-up power supply for power generation in the event of a power failure
  - for system services of the transmission system (peak alignment)
  - as a fuel for a passenger hydrogen car (later also hydrogen bus) – a general solution to hydrogen pumping station and pure mobility
- Data collection from the entire system and it's evaluation for continuous optimization of the system

## **The Model of Hydrogen Management System**

The Model of Hydrogen Management System will serve to verify the functionality of the system, optimize it, and help create a kit that will be commercially available as a "modular" solution.



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## The Czech Gas Association (CGA) brings together businesses, scientific, research and educational institutions, and experts operating in the gas and related industries.

**The CGA follows up on the traditions established in 1919 by the Czechoslovak Gas and Water Association and it is a founding member of the International Gas Union (IGU) (1931). The CGA's mission is to work for the benefit of the Czech gas industry's professional interests and needs; help to raise its levels of expertise; and represent the Czech gas industry at the international level.**

The CGA is a member of the IGU, Eurogas, Marcogaz and NGVA Europe, i.e. major international gas associations. The CGA facilitates the transmission of gas industry information from these associations, and through its activities in their bodies and structures represents the Czech gas industry at the international level.

The CGA paves the way for broad-ranging exchanges of information in the Czech gas industry. It uses such information for drafting and commenting on international and national legislation and technical regulations; it is a partner of the Czech Office for Standards, Metrology and Testing in the harmonisation of the national technical legislation with the relevant EU regulations. In this respect, the CGA also works with the Chamber of Commerce of the Czech Republic.

In pursuing its mission, the CGA also operates in technical education, organising international conferences and a number of technical training courses for both its members and outside experts.

The CGA supports and actively promotes increased use of natural gas, biomethane and SNG as green fuels that can be utilised most efficiently.



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## **HYTEP – Czech Hydrogen Technology Platform is a grouping of commercial, scientific, research and educational entities active in the field of advanced hydrogen and related technologies, with more than 15 members.**

**HYTEP was created on the initiative of the Ministry of Industry and Trade of the Czech Republic in 2007.**

### **HYTEP enables effective involvement**

of its members entities in national and European energy and research policies with the aim to increase national competitiveness in the field of power engineering technologies.

### **HYTEP supports effective communication**

between different entities, effective cooperation in dealing with projects of research, development and innovation, as well as activities within the framework of the implementation of hydrogen technologies into current power engineering and other industries.

### **HYTEP defines, represents, defends**

and promotes the legitimate common interests of its members in order to create a suitable environment for the application of modern technologies in sustainable energy development.

### **HYTEP organizes international conferences**

on hydrogen technologies in Central Europe. HYTEP organized the World Hydrogen Technology Convention WHTC 2017 and brought, for the first time, a big hydrogen event to the Czech Republic and Central Europe. HYTEP also organizes every year in spring the international conference Hydrogen Days.

### **HYTEP is an association open to other businesses**

and entities that are actively engaged or wish to engage in the issues of innovative power engineering technologies; for those, who want to participate in the Czech Republic's involvement in research, development, and application of hydrogen technologies and other supporting activities in the area of clean energy technologies.



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## The ÚJV Řež namely is technical-engineering and design capacities, applied research, and technological equipment for safe and reliable energy, industry or nuclear medicine.

**One of the key tasks of ÚJV Řež is to support the safety and reliability of nuclear power plants in the Czech Republic and worldwide. Current clients from all over the world include power plant operators, regulatory bodies, industrial technology investors, radioactive waste producers and nuclear medicine facilities.**

### ÚJV Řež and services

They are primarily focused on the safe and efficient operation of energy sources, in particular nuclear sources, fuel cycle chemistry, and complex services in the management of radioactive and other waste products. In the field of design and engineering offer a comprehensive set of services to support their activities, from feasibility assessments to the realization of investment projects. In nuclear medicine, we are involved in the development, production, and distribution of radiopharmaceuticals and the construction and operation of positron emission tomography (PET) centers.

### ÚJV Řež and research projects

Research and development projects of the company are devoted, for example, to 4<sup>th</sup> generation nuclear reactors, small modular reactors, material research or use of nanotechnologies for energy and industry.

### ÚJV Řež and Hydrogen Technologies

The onset of hydrogen technologies in the Czech Republic is closely connected to the Řež project of hydrogen bus – TriHyBus, a system of storing surplus energy from solar panels in hydrogen or the Power-Box 180 W portable power source prototype with a hydrogen element.

### ÚJV Řež and International Cooperation

Active participation in several international organisations and cooperation on major multilateral projects enables NRI Řež / ÚJV Řež to remain at the top of European services in energy and industry.



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NUCLEAR  
RESEARCH  
INSTITUTE

## Czech Technical University in Prague (CTU)

**The Czech Technical University in Prague is one of the biggest and oldest technical universities in Europe. It was founded on the initiative of Josef Christian Willenberg on the basis of a decree issued on January 18<sup>th</sup>, 1707 by Emperor Josef I.**



CTU currently has eight faculties (Civil Engineering, Mechanical Engineering, Electrical Engineering, Nuclear Science and Physical Engineering, Architecture, Transportation Sciences, Biomedical Engineering, Information Technology) and about 21,000 students.

The aim of the faculty is a top pedagogical and scientific Czech workplace recognized at home and abroad. The Faculty actively participates in the harmonization of the European Education and Research Area in order to be compatible with the European system, attractive for the listeners and to meet the needs of the society.

The departments of the Faculty of Mechanical Engineering are located in Prague-Dejvice, in a historic building on Charles Square, Horská Street and Julisce. Since the academic year 2003/04, a newly-deployed workplace was established in Sezimovo Ústí. The faculty also has several training centers. Currently, there are 32 professors, 78 associate professors, 175 lecturers and assistants at the faculty at 14 institutes and two research centers, who also make significant contributions to research and development projects. The Faculty also participates in the activities of other research centers, cooperates with the Academy of Sciences of the Czech Republic, the Academy of Engineering of the Czech Republic, the Association of Research Organizations, the Union of Industry and Transport, the Association of Manufacturers of Engineering Technology, a number of large, medium and small industrial companies such as Siemens, Porsche, Škoda Auto, The Hydrosystem Olomouc and many others.

International cooperation in education takes place in several ways. In addition to the mobility of students and academics under contracts, this is mainly about scientific, research and pedagogical activities connected with participation in scientific and professional seminars and conferences, especially in the EU countries. International R&D cooperation is implemented through direct links to individual EU programs or other international programs. At the Faculty of Mechanics, it is also possible to study in English. This teaching is designed for our and foreign students and is greatly supported by regular purchases of foreign study literature.

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## PRAŽSKÁ PLYNÁRENSKÁ (Prague's Gas Supplier)

The company Pražská plynárenská (Prague's Gas Supplier), has been for a long time one of the most important domestic suppliers of energy. Reliably supplies almost 420 thousand supply points. Although the history of Pražská plynárenská is inseparably linked with Prague and the roots of the gas industry can be traced back to 1847, today the company is a reliable supplier of energy and related customers services throughout the Czech Republic. It deals with natural gas and electricity.

To the company's main priorities belong comfortable customer service, energy security and a wide range of exclusive services, often unique in the Czech Republic. Pražská plynárenská supports environmental friendly energy use by ecological and efficient technologies, especially the use of natural gas and electricity in transport.

Pražská plynárenská is working on a long-term and systematic strategy to enable the use of alternative drive systems, which reduce greenhouse gas emissions, noise and operating costs and thus contribute to improving the lives of citizens.



### PRAŽSKÁ PLYNÁRENSKÁ

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## DEVINN s. r. o.

### Who we are:

**We are a Czech development company. We work in the heart of the Czech automotive industry, in Mladá Boleslav. We mainly focus on smart innovative solutions, which we implement starting from the initial phase of the preliminary development up to the production and prototype testing. We are developers in the area of alternative-fuel passenger cars. We execute lighting tests, tests of cable harnesses, tests of control units and tests of other automotive electronics.**

### We engage in development of:

- alternative fuel / electric mobility
- energy storage systems
- lights and lighting for cars
- electrical systems and electronics of cars
- race cars
- custom-made production of flood lights

### Hydrogen technologies at DEVINN:

We are engaged in the development and the application of efficient hydrogen systems for use in energetics and in the future automotive industry.



### DEVINN s. r. o.

#### Domicile:

DEVINN s. r. o.

Skřivánčí 4769/38, 466 01 Jablonec n. N.

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#### Development center:

DEVINN s. r. o.

Koněvova 134, 293 01 Mladá Boleslav

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# DEVINN

## Energy financial group a. s.

**The investment corporation Energy Financial Group focuses on projects aimed at energy production from renewable sources. We develop projects of ecological energy production, contributing to research and development of new technologies and cooperation with leading universities. Our vision is to promote the responsible waste management of in the Czech Republic and contribute to the development of the energy segment, which will be environmentally friendly.**

### Our motto:

We do not inherit the earth from our ancestors, we borrow it from our children.

Antoine de Saint-Exupéry

### We are dealing with:

- BDW energetic use
- Developing ideal biogas practices
  - By membrane separation of biomethane from biogas
  - Biological methanization of carbon dioxide from biogas
- Cooperating with universities in further research and development
- Purchase, collection and sorting of the energetically usable of biodegradable waste (BDW)

### We operate:

- Biogas station energetically utilizing BDW: EFG Rapotín BPS
- Company producing biomethane from biogas: EFG Rapotín upgrading
- Company building biogas stations: EFG Engineering
- The central BDW depot and sorting facility: EFG Kralice na Hané
- Collecting company equipped with technology for the BDW collection: EFG Waste logistic

### EFG and hydrogen technology

In hydrogen technology, we are particularly interested in P2G technology, mainly in connection with the project of the biogas station of the EFG Rapotín BPS.

P2G technology is perceived as a suitable addition to this project where the produced biogas is further processed by membrane separation. The result is separation of biomethane from carbon dioxide and other substances. Our next aim is to utilize the waste carbon dioxide in the new project of carbon dioxide methanization.

We are actively interested in its methanisation by biological means.



### Energy financial group a. s.

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**ENERGY FINANCIAL  
GROUP**

## ENVISAN-GEM, a. s.

is a specialized company with a focus on providing services in waste management, remediation of environmental damage, environmental protection and special applied microbiology. The company has gained a lot of experience in these fields and has a wide range of technical and technological backgrounds.

The company provides comprehensive services for business/industrial waste management in the South Bohemian region.

Since 2016, the company has started research and development in electricity storage and hydrogen technologies, specifically with the focus on alkaline systems.

### ENVISAN-GEM, a. s. services

- Ecological Consulting
- Waste collection and disposal
- Optimization of waste management
- Soil and water analysis
- Remediation of environmental damage
- Applied microbiology

### ENVISAN-GEM, a. s. and hydrogen

In our innovation center, we focus on environmental research and technology transfer. Our company joined a consortium to develop electrolyzer powered by renewable energy in 2016. Follow-up projects are directed towards the conversion of hydrogen back into electricity and hydrogen storage.



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## We make your projects delivered on time!

**CHEMINVEST was founded in 1995 in Litvínov, Czech Republic, as a subsidiary of Chemopetrol Group a. s., but its foundations were laid in 70's. Due to this fact our history is strongly connected with chemical industry.**

**Our originally designing and engineering company has become a strong EPC contractor with an ability to satisfy the most demanding customers. Our sales were 264 mil. CZK in 2017 and we had ca. 50 employees at that time.**

### Our Services

- Designing and Engineering Activities
- CAPEX Project Management
- EPC Projects
- Client Representation

### Areas of Expertise

- Chemical Industry
- Traffic Constructions
- Long Distance Pipeline Constructions
- Power Engineering
- Water Constructions

### CHEMINVEST and Hydrogen

We consider hydrogen as one of the most promising clean energy sources of the future. We want to be involved in general use of the hydrogen and focus on designing and constructing the hydrogen operating units including the infrastructure for FC engines.



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## Energy Research Center

**The Energy Research Center (ERC) at Technical university of Ostrava is a specialized workplace dealing with research and development (R&D) activities primarily in the field of energy. Since 2002 ERC has become an independent HE university institute. One of the principles of ERC's functioning is the systematic building of partnerships with enterprises and the conduct of research activities for the needs of industrial practice.**

**Part of ERC is an accredited, authorised and notified testing laboratory for measuring heat'n' technical quantities and emission of pollutants in waste gases (including continuous measurement of mercury concentration), and testing of energy devices.**

### Improvement of technical level of energy devices

- Investigation of a characteristics of energy processes and technologies
- Increase of energy transformation and equipment efficiency
- Reduction of negative impacts of fuel combustion on the living environment

### Use of alternative fuels, RES and waste energy

- Characterization and use of solid alternative fuels (SAF)
- R&D equipments for use of SAF
- Use of biomass for cogeneration, photovoltaic production of electric energy
- Production of liquid 2<sup>nd</sup>-generation biofuels by the Fischer-Tropsch synthesis

### Hydrogen energy

- The issues of fuel cells
- Operational characteristics of hydrogen production due to RES
- Storage and reuse of hydrogen
- Comprehensive hydrogen infrastructure for homes and transport
- Hydrogen storage and its utilization for network management

### Safety in power engineering and industry

- Identification of risks related to the use of alternative fuels
- Modeling tools for explosions of fuel-air mixtures
- Analysis and experimental verification of limits of flammability and explosiveness, determination of explosion parameters
- Problematics of nanoparticles

### Cooperation with industrial partners is oriented on

- Elaboration of energy studies (ES), energy audits (EA), energy assessment (EA) and building energy use intensity certificates (EUI)
- Energy monitoring and optimization (Energoguard), energy management
- Monitoring of renewable resources (SunnyGuard)
- Complete projection and design engineering in energy
- Accredited emissions measurement, authorised testing of boilers
- Consulting and implementation of EN ISO 50 001



### VSB – Technical University of Ostrava

Energy Research Center

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# HYTEP

CZECH HYDROGEN  
TECHNOLOGY PLATFORM

— SINCE 2007 —



[www.hytep.cz](http://www.hytep.cz)

## HYTEP is a grouping

of commercial, scientific, research and educational entities active in the field of advanced hydrogen and related technologies. HYTEP was created on the initiative of the Ministry of Industry and Trade of the Czech Republic in 2007.

## HYTEP defines, represents, defends

and promotes the legitimate common interests of its members in order to create a suitable environment for the application of modern technologies in sustainable energy development.

## HYTEP supports effective communication

between different entities, effective cooperation in dealing with projects of research, development and innovation, as well as activities within the framework of the implementation of hydrogen technologies into current power engineering and other industries.

## HYTEP organizes international conferences

on hydrogen technologies in Central Europe. HYTEP organized the World Hydrogen Technology Convention WHTC 2017 and brought, for the first time, a big hydrogen event to the Czech Republic and Central Europe. HYTEP also organizes every year in spring the international conference Hydrogen Days.

## HYTEP enables effective involvement

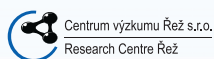
of its members entities in state and European energy and research policies with the aim to increase national competitiveness in the field of power engineering technologies.

## HYTEP is an association open to other businesses

and entities that are actively engaged or wish to engage in the issues of innovative power engineering technologies; for those, who want to participate in the Czech Republic's -involvement in research, development, and application of hydrogen technologies and other supporting activities in the area of clean energy technologies.

## Czech Hydrogen Technology Platform

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**SAVE THE DATE**



**HydrogenDays** 2020

**11<sup>th</sup>**

# **HYDROGEN DAYS 2020**

**JOIN US  
IN MARCH 25–27, 2020  
IN PRAGUE**

[www.hytep.cz](http://www.hytep.cz)  
[www.hydrogendays.cz](http://www.hydrogendays.cz)



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