"The Physical, Chemical and Technological Aspects of the Fundamental Transition in Energy Supply from Fossil to Renewable Sources – Key Aspect: Energy Storage"

791. WE-Heraeus-Seminar

18 – 22 June 2023

at the Physikzentrum Bad Honnef/Germany

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 791. WE-Heraeus-Seminar:

In this WE-Heraeus seminar the individual technological aspects for achieving the energy transition from fossil to renewable energy sources will be discussed in their physical coaction. These are: 1. power generation (by means of wind turbines, photovoltaics and biomass, etc.), 2. power transmission lines of many 10 GW capacity over many hundreds of km and 3. energy storage.

The addressees of this seminar are chemists, physicists and experts from industry in order to stimulate cooperation, especially in the field of renewable energy storage. The success of energy storage (short and long-term storage by means of ion batteries, power to gas, pumped-storage hydropower plant, etc.) is the key task to achieve an efficient energy transition. The technologies for hydrogen production (e.g. electrolysis, etc.) will be presented in several lectures. They require continuous 24-hour continuous operation, i.e. hydrogen technology also relies on gigantic short-term storage (at least for 24 hours) to bridge the nocturnal calm.

The invited speakers come from universities, Fraunhofer Institutes, industry and also from the political environment. As the chemical and physical storage options must be perfectly coordinated, a closely coordinated cooperation between engineers, physicists and chemists is absolutely necessary.

The goal of the seminar is to combine these broad skills in order to design a well-functioning energy transition. Since the energy transition is a central task for future generations, many young researchers should participate in this seminar. As the energy transition will take several decades, so it is essential to attract young scientists to it.

Scientific Organizers:

Prof. Dr. Horst Schmidt-Böcking, University of Frankfurt/Main
E-mail: hsb@atom.uni-frankfurt.de

Dr.-Ing. Dipl. Phys. Karl-Friedrich Ziegahn, Karlsruhe Institute of Technology KIT
E-mail: ziegahn@kit.edu

Prof. Dr. Kurt Wagemann, DECHEMA e.V., Frankfurt/Main
E-mail: kurt.wagemann@dechema.de

Introduction

Administrative Organization:

Dr. Stefan Jorda
Mojca Peklaj

Wilhelm und Else Heraeus-Stiftung
Kurt-Blaum-Platz 1
63450 Hanau, Germany

Phone +49 6181 92325-11
Fax +49 6181 92325-15
E-mail peklaj@we-heraeus-stiftung.de
Internet: www.we-heraeus-stiftung.de

Venue :

Physikzentrum
Hauptstraße 5
53604 Bad Honnef, Germany

Conference Phone +49 2224 9010-120

Phone +49 2224 9010-113 or -114 or -117
Fax +49 2224 9010-130
E-mail gomer@pbh.de
Internet: www.pbh.de

Taxi Phone +49 2224 2222

Registration:

Mojca Peklaj (WE Heraeus Foundation)
at the Physikzentrum, Reception Office
Sunday (16:00 h - 20:00 hrs) and Monday morning

Program

Program *(CEST)*

Sunday, 18 June 2023

16:00 – 20:00	ARRIVAL and REGISTRATION	
19:00	*BUFFET SUPPER*	

Start of the Scientific Program		
18:00 – 18:15	Dieter Meschede	**Welcome**
18:15 – 18:45	Karl Friedrich Ziegahn	**Introduction into the Technology Required for the Energy Revolution**
18:45 – 19:00	Stefan Jorda	**About the Wilhelm and Else Heraeus Foundation**

Monday, 19 June 2023

07:30	*BREAKFAST*	

Climate		
08:30 – 09:15	Marie-Luise Beck	**200 Years of Climate Science - from Physics to a Transdisciplinary Research Field**
09:15 – 10:00	Christian-D. Schönwiese	**Global Climate Change in Industrial Time - Observations and Forcing**
10:00 – 10:30	*COFFEE BREAK*	
10:30 – 11:15	Michaela Hegglin	**Climate Change Information - from Models to Observations**
11:15 – 12:00	Maximilian Fichtner	**The Transformation of Propulsion**
12:00 – 12:30	**Discussion**	
12:30– 12:45	**Conference Photo (outside at the main entrance)**	
12:45 – 14:00	*LUNCH BREAK*	

Program *(CEST)*

European Aspects of Energy Transition

14:00 – 14:45	Hans-Martin Henning	**Transformation of Germany's Energy System in the Context of the EU Green Deal Targets**
14:45 – 15:30	Laura García Laverde	**Bio Energy Resources**
15:30 – 16:15	Stefan Niessen	**Symbiotic Renewable Energy Supply for Europe**
16:15 – 16:45	*COFFEE BREAK*	

Electricity and Heat from Renewable Energy Sources

16:45 – 17:30	Rutger Schlatmann	**Status and Innovation Potential of Photovoltaics, Key Enabler for the Energy and Material Transition**
17:30 – 18:15	Stephan Barth	**Energy Supply by Wind Power – Current Status and Future Developments**
18:15 – 19:00	Eva Schill	**Geothermal Energy Supply**
19:00 – 20:00	*DINNER*	

20:00 – 22:00 **Poster Session 1 and Discussion**

Program *(CEST)*

Tuesday, 20 June 2023

07:30	*BREAKFAST*	
Energy Storage I (Power to Gas, Overview/Hydrogen)		
08:30 – 09:15	Roland Dittmeyer	**Overview to Power-to-Gas and Methanisation as Example**
09:15 – 10:00	Christian Gebauer	**PEM Electrolysis – Energy Storage via Hydrogen and the Role of Precious Metals**
10:00 – 10:30	*COFFEE BREAK*	
Energy Storage II (Conversion to Hydrocarbons and Chemical Batteries)		
10:30 – 11:15	Andrea Lübcke	**Ramp-Up of the Hydrogen Economy**
11:15 – 12:00	Laura Jung	**Hydrogen Integration in Industry**
12:00 – 12:30	**Discussion**	
12:30 – 14:00	*LUNCH BREAK*	
Energy Storage III (Conversion to Hydrocarbons and Chemical Batteries)		
14:00 – 14:45	Rüdiger Eichel	**SOEC and High Temperature CO-Electrolysis as a New Option**
14:45 – 15:30	Michael Felderhoff	**Heterogeneous Catalysis and Hydrogen Storage**
15:30 – 16:15	Franz W. Iven	**Die Rolle von Energiespeichern als eines der zentralen Elemente künftiger Energieversorgungssicherheit**
16:15 – 16:45	*COFFEE BREAK*	
16:45 – 17:30	Thorsten Seipp	**Redox-Flow-Batteries**
17:30 – 18:15	Wolfgang Bauer	**The Future of Batteries for Transportation**
18:15 – 19:00	**Discussion**	
19:00 – 20:00	*DINNER*	
20:00 – 22:00	**Poster Session 2 and Discussion**	

Program *(CEST)*

Wednesday, 21 June 2023

07:30	*BREAKFAST*	
Chemical Batteries		
08:30 – 09:15	Martin Greiner	**A Complex-system Modeller's View on the Decarbonization of the European Energy System**
09:15 – 10:00	Mirko Schäfer	**Net-zero Germany: Transition Paths to Climate Neutrality by 2045**
10:00 – 10:30	*COFFEE BREAK*	
Hydro Storage I		
10:30 – 11:15	Gerhard Luther	**The Role of Short-term Storage like Hydropower in Abandoned Opencast Mines in the Energy Transition**
11:15 – 12:00	David Gessel	**Profitability Analysis of the Different Storage Concepts**
12:00 – 12:30	**Discussion**	
12:30 – 14:00	*LUNCH BREAK*	
Hydro Storage II		
14:00 – 14:45	Matthias Feldmann	**Pumped Storage Hydropower in Former Surface Mining Pits**
14:45 – 15:30	Matthias Puchta	**Hydropower Storage - The STENSEA-Project**
15:30 – 16:00	**Discussion**	
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:15	Bernhard Ernst	**Electrochemical vs Pumped Hydro Systems for Bulk Energy Storage**
17:15 – 18:00	Ulrich Platt	**Renewable Energy in Europe - What is Necessary, What Is Possible?**
18:00 – 18:30	**Discussion**	
18:30	*HERAEUS DINNER at the Physikzentrum (cold & warm buffet, with complimentary drinks)*	

Program *(CET)*

Thursday, 22 June 2023

07:30	*BREAKFAST*	

Other Energy Storage Concepts

08:30 – 09:15	Annelies Vandersickel	**Thermal Storage and the Heating Sector – an Often Overlooked Potential**
09:15 – 10:00	Michael Düren	**From Desertec to the Present Stage of the Energy Transition**
10:00 – 10:30	*COFFEE BREAK*	

The Role of Politics

10:30 – 12:00	**Podiumsdiskussion zur Energiewende - aus Sicht von Politik und Wissenschaft** Frank-Detlef Drake (EON) Michael Düren (Physik) Kurt Wagemann (Chemie) Moderation: Karl Friedrich Ziegahn
12:00 – 12:30	**Closing and Poster Prizes**
12:30	*LUNCH*

End of Seminar / Departure

Posters

Posters

Johanna Adams	**Modelling Energy Storage Bidding Using Reinforcement Learning**
Tom Bender	**Shapes of Hydro Cavern Energy Storage Systems**
Carsten Büchner Sophie Schmeißner	**Verlustfreie Überbrückung von Kurzzeitschwankungen in Energieerzeugung und Verbrauch - Gigantisch große Hydrokavernenspeicher in Braunkohleabbaustätten**
Johannes Döhn	**Computational Screening of Oxide Perovskites as Insertion-Type Cathode Materials**
Carlos Frajuca	**Investigation of Geometries and Stability for Increasing the Energy Density in Electromechanical Battery Flywheels: New Geometry Proposal**
Lisanne Gossel	**Bridging Large Scale Gaps in a Metal-Fueled Energy Circular Economy**
Xaver Herrmann	**Characterization of the Cooling Power and Energy Efficiency on a Two Stage 4 K Pulse Tube Cooler Operated with Solenoid Valves**
Kay Jahnke	**Logistics of Hydrogen – A Challenge from Regulatory and Practical Considerations**
Michael Kahnt	**A Series of Lectures for Pupils on the Possible Yield of Renewable Energies in Germany**
Christoph Kiener	**Environmental Benign Process Intensification: Additive Manufacturing for Process Applications**

Posters

Philipp Jonathan Kompa/ Nais Monjuvent	**Transitioning the Schneebergerhof-farm to Climate Neutrality with the Use of Renewable Energies**
Anna Kornyushchenko	**Formation of Porous Metals with Nano- and Microsized Structural Elements Under Near-equilibrium Condensation Conditions**
Chen Li	**Optimal Power Flow in Highly Renewable Power System Based on Attention Neural Networks**
William Nash	**Experimental Development of an All-liquid Na-Zn Cell for Grid-scale Energy Storage**
Martin Pabst	**Probability Aspects of the Measures Towards the 1,5-Degree-Limit**
Matthias A. Popp	**A Semantic Knowledge Platform for the Energy Value Chain**
Philipp Rentschler	**Transient Operation of Power-to-X Plants Connected to Intermittent Renewable Power Sources in Isolated Networks**
Fritz Richarts	**Wind and Solar Power - Biomas - Hydrogen - CO2 - Methanol**
Joachim Schwister	**Projekt: Speicherstadt Kerpen**
BiancaBin Su	**How to Achieve the Balance of the Climate Friendly and Retaining Prosperity**

Abstracts of Lectures

(in alphabetical order)

Energy supply by wind power – current status and future developments

S. Barth[1]

[1]*ForWind – Center for Wind Energy Research, Oldenburg, Germany*

In the face of growing global challenges such as climate change, energy security and environmental degradation, accelerated deployment of wind energy has become imperative. This presentation highlights the urgent need for rapid expansion of wind energy infrastructure and increased investment in wind energy research. By examining the environmental, economic, and social benefits of wind energy, as well as the potential challenges associated with its deployment, this presentation underscores the critical role of wind energy in the transition to a sustainable and low-carbon future. It highlights the need for international collaborations and gives examples why it is an exciting field of research for physicists, engineers and social scientist.

The Future of Batteries for Transportation

W. Bauer[1]

[1] *Department of Physics and Astronomy*
Michigan State University
East Lansing, MI, 48824, USA

Currently, the overwhelming choices for batteries in electric vehicles are lithium-ion based. They take a long time to charge, degrade over time, and extremely expensive to replace. We propose a new way to power electric vehicles with swappable batteries, not unlike those that are used in cordless power tools. Consequences for the overall electric grid and individual vehicle owners are discussed.

200 Years of Climate Science -
from physics to a transdisciplinary research field

Marie-Luise Beck

Deutsches Klima-Konsortium (DKK e. V.), Berlin, Germany

Perhaps one the most amazing facts about the history of climate science is that the basic physical principles of global warming have been known since the late 19th century. Still there is an audible although diminishing doubt about the existence of human made climate change and the successes of climate policy fall far short of what would be required according to the precautionary principle.

As early as 1824 the French mathematician and physicist Jean-Baptiste Fourier identified the greenhouse effect. In 1896 the Swedish Nobel laureate Svante Arrhenius drew up the first radiation balance calculating by how many degrees the earth's surface would warm up if the CO_2 concentration doubled. It became the most important characterization of how sensitively the climate reacts to greenhouse gases such as CO_2. Generations of climate researchers have endeavored to define this measure more precisely. At that time the world seemed "infinite" and full of opportunities. Natural Philosophers, discoverers and scientists confidently set about solving "God's perfect clockwork" (Wilhelm Leibniz). That mankind could change geophysical phenomena such as the climate, was inconceivable.

In the 20th century, technological advances were rapid, allowing researchers to seek confirmation of their physical findings in the real world. In 1958, US climate researcher Charles Keeling established the systematic measurement of CO_2 in the atmosphere showing that the concentration of greenhouse gases only knows one direction: upwards. In 1979 German physicist Klaus Hasselmann, building on the work of US-researcher Syukuro Manabe, came up with a trick to be able to recognize the human contribution to the weather. Only in the 1990s Hasselmann was able to implement his argument. The growing evidence of human made climate change was so breath-taking and so abstract that it first was largely ignored. After all this fact would have questioned the prerequisite of modern prosperity: the combustion of coal, oil and gas.

The road to Paris and beyond was and is rocky and full of setbacks. Which show that knowledge is necessary to take action but not at all sufficient to fundamentally take the societal, economic and political steps that are required. This is mirrored by an accelerating increase of social sciences and humanities in the realm of climate research and more and more interdisciplinary and co-creative projects.

Marie-Luise Beck, Jochem Marotzke: Sehenden Auges ins Treibhaus geraten – ein Streifzug durch die erstaunliche Geschichte der Klimaforschung; in: Lohse, Martin (Hrsg.): Wenn der Funke überspringt, Passage-Verlag Leipzig 2022 (only in German)

From Desertec to the present stage of the energy transition

Michael Düren[1]

[1]II. Phys. Institute and Center for International Development and Environmental Research, Justus-Liebig-University Giessen, Gießen, Germany
michael.dueren@uni-giessen.de

In 2008, the DESERTEC foundation proposed large scale solar power and wind power generation in Middle East and North Africa (MENA), including solar thermal energy storage and high voltage DC lines to Europe for a base load import of renewable electrical power. In 2009, the Desertec Industrial Initiative (Dii) was formed as a consortium of industry from Europe and MENA, led by powerful German companies as Munich Re, Deutsche Bank, Siemens, RWE, E.ON and others.

The DESERTEC foundation proposed a win-win cooperation where Europe offered expertise on solar and wind power generation, including energy storage and HVDC lines. Western investments would have allowed MENA countries to export power for western currency, build up jobs and perspectives for the young generation, and to develop their own energy systems.

In 2014, most European countries left Dii and the company moved from Munich to Dubai. Today its main drivers are Saudi Arabia and China, with a growing number of partners and shareholders from 25 countries across MENA, Europe, Africa and Asia. The focus shifted from projecting the electrical power systems for Europe to building up capacities for renewable hydrogen export to the whole world, which is much more profitable from the producer's point of view because of the expected high prices of green hydrogen.

From the European point of view, today still the original idea of powerlines across the Mediterranean Sea would be more favorable, as cost projections show that the hydrogen option will be more than twice as expensive as the cable option, due to the immanent efficiency losses in hydrogen production and in the subsequent electricity generation.

In the cable scenario, solar heat storage is the most cost-efficient storage system on the producer side to cover the day-night variations, while on the consumer side a combination of battery storage and large pump storage is required to account for the volatility of local production and consumption.

Heterogeneous Catalysis and Hydrogen Storage

M. Felderhoff[1]

[1]*Max-Planck-Institut für Kohlenforschung*
45470 Mülheim an der Ruhr
Germany

Heterogeneous catalysis is an important part of the activation or utilization of hydrogen, since the hydrogen gas and the storage material are in different phases (gaseous - liquid or solid). Without a catalyst, the storage process is often impossible or very slow. The choice of catalyst for different storage processes depends on several requirements, such as the storage process in general, the temperature of hydrogen uptake and release, the stability of the material and the catalyst and also the required amount (price!) of the storage material used. Based on examples from the field of hydrogen storage, the application range of different catalyst systems will be presented and described. The focus is not only on hydrogen storage materials, but also on reversible reactions for heat storage using metal hydrides [1].

References

[1] : Adams, et al. Progress in Energy **4**, 032008 (2022)

Pumped storage hydropower in former surface mining pits

M. Feldmann

Tractebel Hydroprojekt GmbH, Munich, Germany

E-Mail: matthias.feldmann@tractebel.engie.com

One of the most promising technologies for storing electrical energy is the pumped storage technology given its various advantages over other technologies. In particular, the huge storage capacities, the capability of fast load changes and the high efficiencies make pump storage hydropower plants one of the most efficient electrical storage technologies. A further advantage of the technology is that it is well established – worldwide and since decades.

The aim of the study carried out by Tractebel in 2020 was to investigate possibilities for constructing pumped storage hydropower plants in former surface mining pits in North Rhine-Westphalia, which offer huge storage potential due to their large sizes and depths (Fig. 1). Huge storage potential again is very much needed for storing energy surplus generated by the increasing weather-dependent renewable energies.

The general idea was to install a closed cavern-type water storage complex at the bottom of the mining pit which would function as the lower reservoir of the pumped storage hydropower plant. The upper reservoir could be built either on the existing surface adjacent to the pit or on a nearby artificial elevation of an existing dump (Fig. 2). In fact, as the former mining pits will be filled with water, the water body of the mining pit itself could function as upper reservoir. Following up these design options, more detailed design work is now required to solve various technical challenges, e. g. in the area of geology and hydraulics.

Fig. 1: Surface mining pit in North Rhine-Westphalia (source: GTB Aachen, 2017)

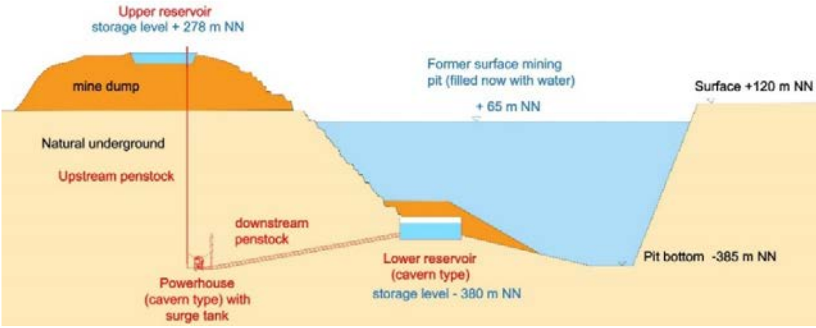


Fig. 2: Scheme of a pump storage system in a surface mining area

The transformation of propulsion

Maximilian Fichtner

Helmholtz-Institute Ulm, Ulm, Germany

The search for alternative drivetrains follows a rational approach, where questions related to greenhouse gas reduction potential, efficiency, safety, and cost play a critical role. The talk will address these issues and compare drivetrains based on combustion engines running on e-Fuels, hydrogen cars with fuel cells and full electric vehicles driven by batteries. The case of both passenger cars and trucks will be discussed.
The second part of the presentation will give an overview on the actual development of modern batteries for electric cars involving recent progress towards sustainable battery chemistries and new battery pack designs[1] which allow first middle-class cars on the road with 1000 km driving range and 700 km recharging within 10 minutes.

References

[1] M. Fichtner, Batteries&Supercaps (2022) e202100224

PEM Electrolysis – Energy storage via Hydrogen and the role of Precious Metals

Dr. Christian Gebauer
Heraeus Deutschland GmbH & Co. KG.
Heraeusstraße 12-14, 63450 Hanau/Germany

Abstract

For the path of de-fossilization, hydrogen becomes increasingly important. As stated in various national and supranational roadmaps, green H_2 generated via water electrolysis is the preferred route. H_2 is supposed to act as energy storage medium, as building block for the chemical industry, as substitute in thermal processes like steelmaking, as well as a fuel for the re-electrification via fuel cells.

This variety in application already shows the large amount of H_2 needed. For water electrolysis, there are several competing technologies: the so-called solid oxide electrolysis cell (SOEC), alkaline water electrolysis (AEL) and polymer electrolyte membrane electrolysis (PEM EL). Here, the latter shows significant benefits, as high current density operation (> 2 A cm^{-2}) and thus a smaller areal footprint, highly dynamic operation mode and high gas purity as well as release of pressurized hydrogen. However, PEM EL is based on precious metal catalysts for H_2 generation on the cathode (Pt-based) and O_2 evolution on the anode (Ir-based), where the second metal is a rather scarce one [1].

To keep up the supply of iridium with respect to the announced increase in electrolyzer capacities material innovation to reduce the use of this precious metal as well as recycling activities strategies must be implemented better sooner rather than later.

For material innovation on scientific and industrial level the path from the pure Ir material, called Ir black, via Ir-dioxide (IrO_2) to less iridium containing materials, e.g. a supported Iridium-oxide has been initiated to achieve a stepwise reduction of the Ir content. For the supported catalyst, developed at Heraeus and further investigated in the BMBF project Kopernikus P2X, at least 50% lower Iridium electrode loadings can be achieved (approx. 0.3 mg cm^{-2} / < 0.1 g kW^{-1}) compared to state-of-the-art materials, without any losses in activity or stability [2, 3].

References

[1] "Iridium Quaterly Market Report", SFA Oxford (2021) 31
[2] M. Bernt, A. Hartig-Weiß, M.F. Tovini, H.A. El-Sayed, C. Schramm, J. Schröter, C. Gebauer, H.A. Gasteiger, Chem. Ing. Tech. 92, 31 (2020)
[3] M. Möckl, M.F. Ernst, M. Kornherr, F. Allebrod, M. Bernt, J. Byrknes, C. Eickes, C. Gebauer, A. Moskovtseva, H.A. Gasteiger, J. Electrochem. Soc. 169, 064505 (2022)

Climate change information – from models to observations

M. I. Hegglin[1]

[1]*Institute of Energy and Climate Research, Stratosphere (IEK-7), Forschungszentrum Jülich, Jülich, Germany*

For many decades, climate change has largely been presented in terms of what the future will bring. This has placed an emphasis on projections from climate models. However, it is clear that climate change is now in our face, through increasingly intense extreme events — heatwaves, wildfires, flooding — that cost human lives and billions of economic damages. Earth observations can capture the impact of such events in single images in addition to revealing, documenting, and visualising the slow changes in the climate system, which has been their traditional purpose. In this presentation, I will argue that as climate scientists, we need to up our game in using the meaningful information we obtain from Earth observations [1] to help humanity mitigate and adapt to climate change over the coming years to decades.

References

[1] Hegglin, M. I., Bastos A., Bovensmann H., Buchwitz M., Fawcett D., Ghent D., Kulk G., Sathyendranath S., Shepherd T. G., Quegan S., Rthlisberger R., Briggs S., Buontempo C., Cazenave A., Chuvieco E., Ciais P., Crisp D., Engelen R., Fadnavis S., Herold M., Horwath M., Jonsson O., Kpaka G., Merchant C.J., Mielke C., Nagler T., Paul F., Popp T., Quaife T., Rayner N.A., Robert C., Schrder M., Sitch S., Venturini S., van der Schalie R., van der Vliet M., Wigneron J.-P. and Woolway R. I., Space-based Earth observation in support of the UNFCCC Paris Agreement. Front. Environ. Sci. 10:941490. doi: 10.3389/fenvs.2022.941490 (2022).

Transformation of Germany’s energy system in the context of the EU Green Deal targets

Hans-Martin Henning

[1]*Fraunhofer Institute for Solar Energy Systems ISE*
Heidenhofstr. 2, D-79100 Freiburg, Germany and
University Freiburg, Technical Faculty

The European Union plans to achieve climate neutrality in 2050 and has adopted several policy measures to achieve this goal. A central role plays the conversion of the European energy system to technologies without emission of greenhouse gases during their operation. The German energy transition fits into this objective. Germany is striving for an energy system that will achieve climate neutrality already in 2045, relying almost exclusively on the use of renewable energies.

In the lecture, different ways to achieve such an energy system will be presented, which result from the cost optimization of transformation pathways, and which differ by different societal behaviors. Thereby, the embedding in the European energy system is considered, which results particularly from the expansion of coupling points of the electricity transmission grid to neighboring countries, as well as the role of the import of climate-neutral produced chemical energy carriers; an exemplary composition of domestic and imported energy sources today (2020) and in 2045 is shown in the attached figure 1. In the presentation of the results, particular attention is paid to the role of different types of energy storage.

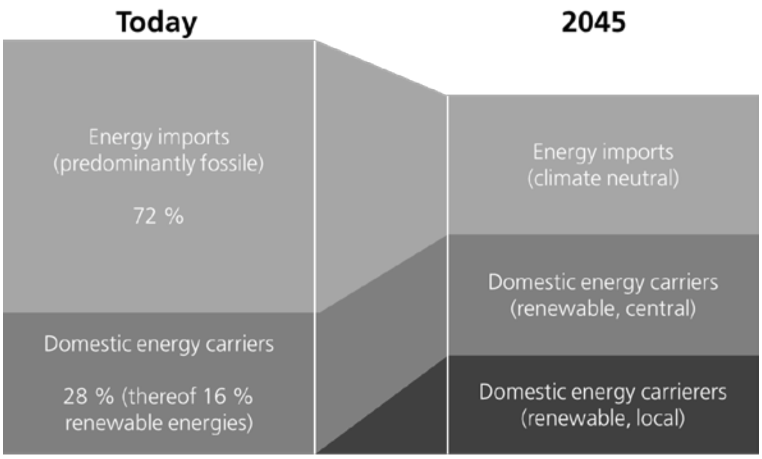


Figure 1: Example for the composition of primary energy today (2020) and tomorrow (2045), resulting from optimization of transformation pathways

Reference: Fraunhofer ISE, Wege zu einem Klimaneutralen Energiesystem – Die deutsche Energiewende im Kontext gesellschaftlicher Verhaltensweisen, Update November 2021: Klimaneutralität 2045.

Hydrogen Integration in the Industry

Laura Jung[1,2]

[1]Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Nobelstrasse 12, 70569 Stuttgart, Germany
[2]Institute for Energy Efficiency in Production EEP, University of Stuttgart, Nobelstrasse 12, 70569 Stuttgart, Germany

Hydrogen integration in the industry has emerged as a promising solution to address the challenges of decarbonization and sustainability. This presentation aims to provide a comprehensive overview of the utilization of hydrogen in various industrial applications, covering energy and heat supply, raw material utilization, and transportation.

The presentation begins by discussing the benefits and the role of hydrogen in the industry, emphasizing its potential to significantly reduce greenhouse gas emissions from energy-intensive sectors. Hydrogen offers a clean and efficient alternative for powering industrial processes and meeting the growing demand for sustainable energy solutions.

Furthermore, the presentation shows examples of the transformation of the industrial energy system through hydrogen integration. Ongoing research projects, such as "WaVeH2" focusing on the establishment of an industry research platform for the exploration of different hydrogen technologies, will be highlighted. This project aims to accelerate the deployment of innovative hydrogen solutions for diverse industrial sectors.

Additionally, the presentation explores the application of hydrogen in specific industrial processes, such as the use of hydrogen in a burner for a melting furnace in the die casting industry (project "HybridH2"). This approach shows how hydrogen and renewable electricity can be utilized to enhance process efficiency and reduce environmental impact.

Finally, this presentation aims to raise awareness about the potential of hydrogen integration in industry, inspire further research and development efforts, and pave the way for a more sustainable and low-carbon future.

Andrea Lübcke

Ramp-up of hydrogen economy

The project „H2-compass“ is elaborating paths towards a German hydrogen economy. It presents different options how hydrogen can contribute to a defossilized economy, and measures policymakers can take to shape the development of the German hydrogen economy. Special emphasis is placed on research and development demands.

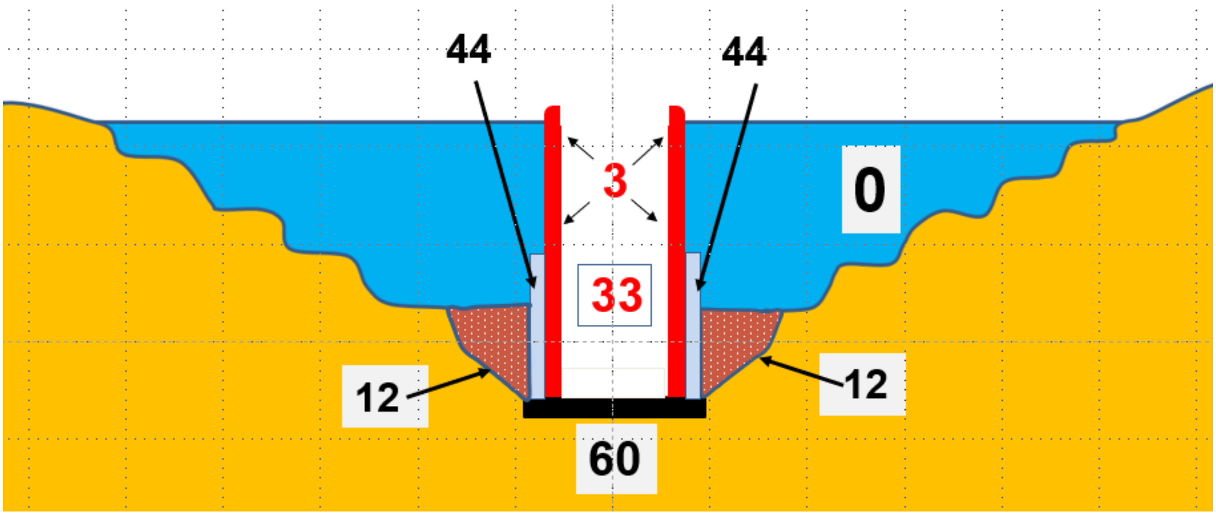
I will deliver new insights into our work and into the digital tool, which will be handed over to politics in September 2023.

The role of short-term storage like hydropower in abandoned opencast mines in the energy transition.

G. Luther[1] and H. Schmidt-Böcking[2]
[1] Universität des Saarlandes, Experimentalphysik, D-66123 **Saarbrücken, Germany**
[2] Universität Frankfurt, Institut für Kernphysik, D-60438 **Frankfurt/Main, Germany**

An energy transition that is largely based on wind and solar energy requires storage systems to safely bridge the times when the direct supply of renewable energy (RE) is not sufficient. However, the use of hydrogen or other green storage gases is very expensive, not least because of the high conversion losses; therefore, it will be necessary to largely buffer the use of these long-term/backup storage by short-term storage. Simple simulations of a full-time supply of RE on the basis of extrapolated and in favor for solar energy reweighted data of the current RE electricity generation in Germany show that the capacity of short-term storage should be increased at least tenfold.

In Germany, there is more than sufficient space for such new pumped storage power plants in the abandoned holes of the lignite opencast mines: On the still dry soil of the lake, the later upper basin and planned for recultivation anyway, a structural facility could be built as a lower basin. This structure could be designed as a closed lower basin on the bottom or as a ring-shaped closed arch dam raised to the surface of the lake, whose interior serves as the lower basin and whose outer space as the upper basin of a pumped storage power plant (figure).
It is shown which huge storage capacity could be gained by these constructions.



Pumped storage hydropower in an abandoned and recultivated opencast mine: From the recultivation lake, now serving as the upper storage basin **0** , a lower basin 33 is separated by a ring-shaped closed arch dam **3**. Further details see [1].

References

[1] G. Luther und H. Schmidt-Böcking: „Pumpspeicherkraftwerk mit einem von einer Ringstaumauer umschlossenen Speicherbecken“, **DE 10 2021 004 099**

Symbiotic Renewable Energy Supply for Europe

Prof. Dr.-Ing. Stefan Niessen MBA[1,2]

[1]Siemens AG, Erlangen, Germany
[2]TU Darmstadt, Darmstadt, Germany

The challenge

Laws like German Law on Climate Protection (Klimaschutzgesetz) and EU-Initiatives like RePowerEU define decarbonization targets. However, there are different possible routes to reach these targets and the media are full of good suggestions by interested parties on which technologies can do the trick. It is obvious though, that no one single technology alone will be able to decarbonize our society. Instead, we will need an evolution of today's energy system into a more and more decarbonized one that will be formed by an increasingly complex symbiosis of a wide range of different technologies bringing together all aspects of life like private and public buildings, transport, industry and agriculture. Unlike in nature however, this evolution will not happen all by itself.

The approach

Siemens AG, since the carve-out of Siemens Energy no longer has stakes in any power plant-, energy storage or conversion technology, and together with international partners Siemens AG has developed for many years a multimodal model of the European Union's Energy System that, based on a mathematical optimization method, allows to determine a cost-optimal path to decarbonization. It is the particularity of this method, that it is technology-agnostic. Every technology is modelled with its technical and economic properties as proven in real projects and the mathematical optimizer choses the combination of technologies that allows to reach the CO_2-target at lowest cost.

The decarbonization route

The presentation shows the resulting decarbonization route for the European Union along with the technology mix, minimum price levels for electricity and CO_2-emission rights. This overall concept sets the frame for concrete decarbonization roadmaps of individual cities, sites, factories and buildings.

Examples for the concrete implementation

Decarbonizing Europe requires a mix of measures on different granularity levels. Therefore, the presentation continues with some concrete examples for the decarbonization of the harbor of Bremerhaven, Germany's largest sea harbor, the Siemens factory in Amberg and a concept for a new electric vehicles factory.

Renewable Energy in Europe - What is Necessary, What Is Possible?

Ulrich Platt

Institute of Environmental Physics, University of Heidelberg

At present more than 1/3 of the global primary energy demand is due to electricity generation, and its share is likely to grow due to e.g. electrical vehicles, heat pumps, hydrogen generation, and a shift of industrial processes to electricity. For a 100% renewable and reliable electricity supply system storage is essential [1]. Based on a computer model using global weather data [2] the relationship of power plant mix and required energy storage capacity, a was investigated. The required energy storage capacity for an electricity supply entirely based on wind and photovoltaic (PV) was found to occur at a ratio of 30% wind and 70% PV capacity installed. The long term storage capacity would amount to about 4% of the annual electricity demand. However, the installation of additional excess wind and PV power plant capacity is found to efficiently reduce the required energy storage. For instance already 10% excess capacity lead to a reduction by 50% of the required storage capacity.
We describe the changes in energy sectors and the resulting required installation in wind and PV power. We briefly potential technologies to satisfy the storage demand. In summary, an electricity supply by wind and PV power is found to be completely feasible regarding the required energy storage capacity (which can be lower than 1% of the annual demand) together with the required land area for power plants, and with electricity generating costs of 0.09€ to 0.18€ per kWh depending on the power plant mix, excess capacity, and storage investment costs.

[1] Hansen K., Breyer C. und Lund H. (2019), “Status and perspectives on 100% renewable energy systems.” Energy 175: 471-480. doi, 10.1016/j.energy.2019.03.092.

[2] Tröndle T.W. (2014), Development of a global electricity supply model and investigation of electricity supply by renewable energies with a focus on energy storage requirements for Europe, Doctoral Thesis, Univ. Heidelberg, http://d-nb.info/1068377747/04

Net-zero Germany: Transition paths to climate neutrality by 2045

Mirko Schäfer[1] and Anke Weidlich[1]

[1]INATECH, University of Freiburg, Freiburg, Germany

In the 2021 Federal Climate Change Act, the German government set the goal of greenhouse gas neutrality by 2045. The Climate Protection Act already sets target paths for emission reductions in various sectors such as the energy sector, transport and industry. These ambitious target paths require great efforts in all dimensions of system transformation, such as the expansion of renewable energies, the ramp-up of hydrogen production and storage technologies or new processes in industry, but also the increase in energy efficiency and, more generally, the reduction of energy demand. Scenario studies on energy system transformation pathways can serve as inputs for scientific research and decision-making processes, providing guidance to policymakers and other stakeholders to shape this target path. Building on a recent study from the project "Energy Systems of the Future" initiated by the German Academies of Sciences [1,2], in this lecture an overview over different scenarios for transition paths will be given.

References

[1] acatech/Leopoldina/Akademienunion (Hrsg.): *Wie wird Deutschland klimaneutral? Handlungsoptionen für Technologieumbau, Verbrauchsreduktion und Kohlenstoffmanagement* (Schriftenreihe zur wissenschaftsbasierten Politikberatung), 2023. ISBN: 978-3-8047-4423-3

[2] Ragwitz M./ Weidlich, A. et al.: *Szenarien für ein klimaneutrales Deutschland. Technologieumbau, Verbrauchsreduktion und Kohlenstoffmanagement* (Schriftenreihe Energiesysteme der Zukunft), München 2023.

Status and innovation potential of photovoltaics, key enabler for the energy and material transition

Rutger Schlatmann

Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany

Photovoltaic technology (PV) is generally recognized as one of the key elements of the future renewable energy system and a no-regret option that merits massive investments in the coming decade [1], as has been increasingly recognized in the past years, where PV technology has seen the largest investment of all energy technologies, fossil included [2].

Still, massive innovation potential for PV technology is unexploited. Physically, the conversion efficiency from irradiated energy from the sun into electricity leaves ample space for further improvement, but should be achieved at acceptable cost, resource usage and, wherever possible, should be integrated into dual-benefit areas (building or agriculture integrated PV). In this presentation, we will mainly focus on the technological improvement potential, but will briefly touch on the second and third themes as well.

Silicon based PV has been the dominant technology for the past decades, but will reach the end of the physical limits to conversion efficiency. The advent of Peroskite materials, that combine a tunable bandgap in the 1.2-2.0 eV range with exceptionally good electronic quality and with ease of processing, has enabled the development of highly efficient combination of two semiconductor materials into a tandem junction solar cell.

Perovskite/Silicon tandem solar cells have experienced an impressive improvement in power conversion efficiency (PCE) to well above 33% in 2023 [3]. To bring this highly promising technology to market, we identify three crucial issues that have to be addressed: sufficient efficiency improvement over incumbent Silicon single junction technology, sufficient long-term stability for at least 30 years outdoor service life and finally industrial compatibility: homogeneous and high-speed large-area deposition , employing low-cost, low environmental impact materials.

References

[1] Haegel et al. Science 2023

[2] IEA World Energy Investment 2023, www.iea.org

[3] Best Research-Cell Efficiency Chart, NREL, https://www.nrel.gov/pv

Global climate change in industrial time - observations and forcing

C.-D. Schönwiese

Institute for Atmosphere and Environment, Frankfurt a.M., Germany

Climate varies on all scales of time and space. After an outstanding global warming of c. 4 °C roughly $10 \cdot 10^3$ years ago which can only be indirectly reconstructed by paleoclimatological methods, there were only moderate fluctuations in the centuries before c. 1800/1850 (IPCC, 2022; Schönwiese, 2020). But in industrial time, which is very well known by many direct observations a global warming occurred amounting to c. 1.2 °C on a global average since 1880. However there are considerable regional and seasonal peculiarities so that this warming covers a range of more than 4 °C in subpolar regions to a light cooling in a small North Atlantic region. The precipitation peculiarities are even much more pronounced and all this climate change includes more and more extreme events like heat waves, dryness or flooding, resp., and tropical storms/hurricanes. Due to ocean warming and melting processes of glaciers and polar ice shields the global mean sea level has risen since 1900 by c. 20-25 cm.

Although there is some natural forcing due to volcanism and atmosphere-ocean interactions (the solar activity influence is very small) etc. the predominant forcing is anthropogenic (IPCC, 2022; Schönwiese, 2020), mainly due to the atmospheric concentration increase of greenhouse gases (GHG) like CO_2, CH_4, N_2O etc. which warm the lower atmosphere and cool the stratosphere. In addition, aerosols cool somewhat the lower atmosphere. The related forcing (but not interactions) can be quantified by radiative forcing (IPCC, 2022): Since 1750 approximately 3.3 Wm^2 due to GHG (CO_2 57,0 %, CH_4 14,2 %, N_2O 5,5 %, CFCs 10,8 % etc.) and -1,6 Wm^2 due to aerosols (in addition land use effects e.g. due to deforestation). The detailed climate response, including regional-seasonal details, are simulated by means of coupled atmosphere-ocean models which also account for all important interactions and feedbacks. These models show that the global warming within industrial time can only be explained by anthropogenic forcing and that this may lead until 2100, without reduction of GHG from the atmosphere, to a further global warming of 2.1 - 5.7 °C, moreover change of precipitation patterns, further sea level rise and more extreme events. Therefore, it is urgently necessary to protect climate by avoiding these adverse change effects and their impact on mankind.

References

[1] IPCC (V. Masson-Delmotte et al., eds.), Climate Change 2021, The Physical Science Basis, AR6, WGI, 2409 pp., Internet; https://www.ipcc.ch (2021/22)

[2] C.D. Schönwiese, Klimatologie, Ulmer, 492 pp., 5. Aufl. (2020)

Thermal Storage and the heating sector – an often overlooked potential

A.Vandersickel[1,2]

[1]German Aerospace Center (DLR), Stuttgart, Germany
[2] Stuttgart University, Stuttgart, Germany

Around 50% of the global final energy demand is used for heating and hot water supply in buildings, districts and industrial processes. So far, these heat requirements are mostly supplied using coal, natural gas and oil, such that the heating sector is responsible for over 30% of the global CO2-emissions [1]. Yet, when it comes to reaching climate goals, we mostly talk about electricity, maybe mobility.

Decarbonizing the heating sector is a daunting task, with heat required at a very wide range of temperatures and a wide variety of forms e.g. as process steam, hot gases or heat transfer fluids. Thermal storage will be the key to mastering this challenge, and achieve a reliable and cost-effective heat supply from renewable energy in particular in the high temperature range. In combination with Power-to-Heat solutions, thermal storage can furthermore play an important role also in the electricity grid.

This keynote will discuss the above challenges and opportunities and provide an overview of the state of the art on thermal storage to tackle the above.

References

[1] Net Zero by 2050 - A Roadmap for the Global Energy Sector

Abstracts of Posters

(in alphabetical order)

Modelling Energy Storage Bidding Using Reinforcement Learning

J. Adams[1]

[1]*INATECH, University of Freiburg, Freiburg im Breisgau, Germany*

When talking about storages in the energy only market, there seem to be contradicting goals: First of all, transmission operators have to provide service security, while on the other hand there is the need to decrease carbon emission and therefore replace stable conventional generation by fluctuating renewable energy sources. Storages are meant to increase stability, but in the current energy only market storage operators only try to maximize their profit. Therefore, in this work the following question is addressed: Does the current energy-only market design provide enough incentives for storage operators to contribute to higher renewable share, especially during times of scarce renewable generation?

To model the storage operator a reinforced learning agent is implemented using only open accessible data for each time step. The results are then compared to a naive model with rule-based bidding as base-line and two optimization models, one for profit maximization and one for renewable share maximization, which assume the market clearing prices to be perfectly known for the total time horizon.

The results show, that profit and renewable share optimization are almost identical in their outcome over one year, which would suggest a correct market design to achieve high shares of renewable energy. But the reinforcement learning model only achieves about 30% of the possible profit under testing conditions and therefore also didn't reach the optimum renewable share. Also, no tendency to discharge during times of scarce renewable generation could be found (see marked areas in Figure 1). Consequentially, new rules or incentives have to be applied to exploit the potential of storages in the energy-only market according to this simplified example.

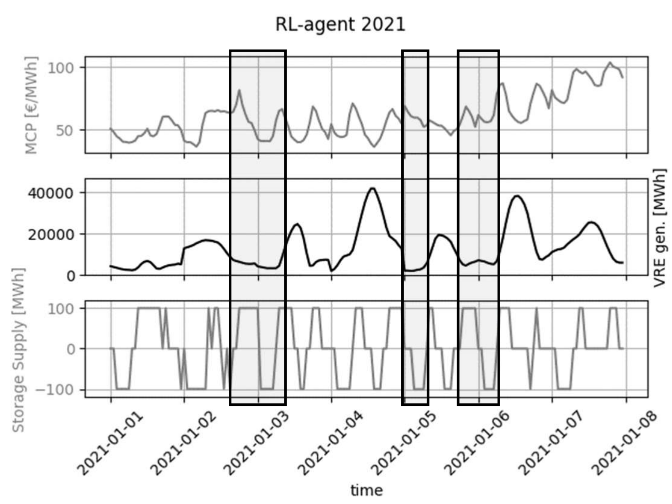


Figure 1: Time series for market clearing prices, renewable generation and storage supply when bidding using a reinforcement learning agent for the first week in 2021

Computational Screening of Oxide Perovskites as Insertion-Type Cathode Materials

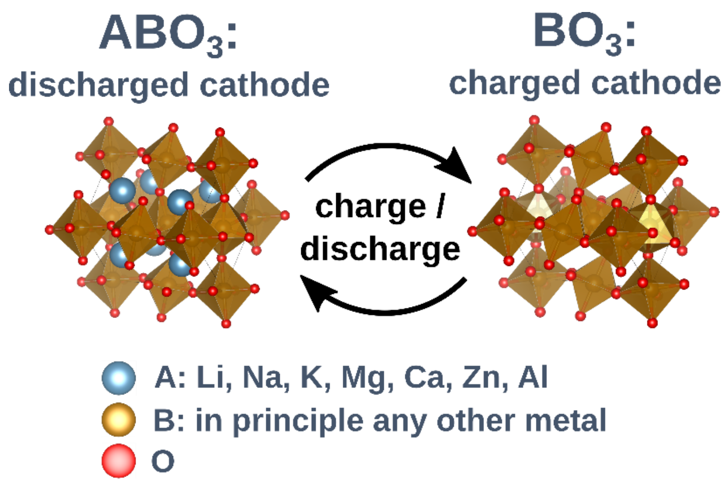
Johannes Döhn[1] **and Axel Groß**[1,2]

[1]Institute of Theoretical Chemistry, Ulm University, Germany
[2] Helmholtz Institute Ulm, Germany

The intermittency of wind and solar power – the solely sustainable energy sources which are considered to be abundantly available – leaves only one consequence: For the transition towards renewable energy systems, efficient and reliable storage technologies are needed. Batteries are one of the most widely used storage devices but current technology based on the transfer of Li-ions faces several challenges including their dependence on critical materials with respect to both, scarcity and toxicity.

In our contribution we will discuss atomic-scale investigations of potential future battery materials carried out using density functional theory (DFT). We employed a high-throughput approach in order to screen the well-known material class of oxide perovskites as insertion-type cathode materials and we derived several crucial battery properties including voltage, volume change during charge/discharge, theoretical energy density and chemical stability for in total 280 compounds. For those candidate materials with promising properties, we evaluated additional features such as voltage profile, the band gap, and diffusion barriers for ionic transport.

Such in-silico investigations significantly narrow down the potential materials space for experimental coworkers and thereby contribute to finding green, cheap and reliable devices for energy storage.



Investigation of Geometries and Stability for Increasing the Energy Density in Electromechanical Battery Flywheels: New Geometry Proposal

C. Frajuca[1], D. Coppede[2] , F.B. Bortoli[3] and M. A. de Souza[3]
[1]FURG, Rio Grande Federal University, Rio Grande, RS Brazil
[2]UFABC, Santo Andre, SP, Brazil
[3]Sao Paulo Federal Institute, IFSP, Sao Paulo, SP, Brazil

This work presents a study on possible geometries and materials in flywheels through finite element modeling (FEM). Flywheels compose a fundamental part of the electromechanical batteries. This study aims to analyze the behavior of flywheels rotating at the highest possible rotational speed to produce the best mass–energy ratio for a certain rotor geometry. For this, different flywheel models were created and simulated through successive changes in their geometry to increase the rotational speed and energy. The geometry obtained with the best performance in the form of a Gaussian solid of revolution and made entirely of the carbon fiber Hexcel UHM 12000 allows the development of a low cost and high performance flywheel in revolutions of up to ≈279.000 rpm and stored energy density of up to ≈ 430 Wh/kg. Then the next step was to also increase the total energy interconnecting the solids obtained to create a battery with the highest possible energy and energy-density. Adding the study of rotational stability, a problem is found then a new geometry is proposed and the results are presented.

Reference

[1] D Coppede, MA de Souza, F da Silva Bortoli, C Frajuca Investigation of Geometries and Stability for Increasing the Energy Density in Electromechanical Battery Flywheels. Proceedings of 1st International Conference on Mechanics of Solids 2022, (2023)

Bridging Large Scale Gaps in a Metal-Fueled Energy Circular Economy

L. Gossel[1], M. Fricke[1] and D. Bothe[1]

[1] *Institute for Mathematical Modeling and Analysis, Technical University of Darmstadt, Darmstadt, Germany*

In the field of chemical energy carriers, metals are gaining growing interest in research as a concept for convenient, recyclable, and low-emission renewable energy storage [1,2]. While having great potential as part of a fully renewable energy supply system, the idea is still not as present in the scientific and social discourse as other alternatives like hydrogen, ammonia and so on.
One key feature behind the idea of metal energy carriers is their recyclability. Renewable energy can be stored in metal oxide powder by reduction to the pure metal. The energy is released again by combustion of the metal powder, and the resulting metal oxide powder can be used for energy storage again. Hence, metals can be the fuel of a carbon-free energy cycle [2].
Metal (oxide) powders are transportable, so energy storage and release are independent from each other in terms of place and time.
Within the cluster project Clean Circles, iron as an energy carrier is investigated in a holistic approach covering single particle physics, laboratory and industry scale reactors, and the thermodynamic, economic, ecological and political assessment of a full energy circular economy. Therefore, large scale- and complexity gaps need to be overcome. For example, large parameter studies on the iron oxidation and reduction behavior in reactors are needed for enabling thermodynamic and economic optimization of the full system. Those are not feasible from experiment or detailed simulations, which are costly but provide understanding of the underlying processes on a deep level. One promising method to overcome this are chemical reactor networks (CRNs), which enable time-efficient simulations by strongly reducing the flow field complexity in chemical reactors [3]. However, several developments on different levels are needed for them to enable simulations of iron-fueled reactors in broad parameter ranges, so our research focuses on making CRNs the efficient scale bridge for Clean Circles.

References

[1] Bergthorson, J. M. *et al.*, *Applied Energy*, *160*, 368-382 (2015).
[2] Debiagi, P. *et al.*, *Renewable and Sustainable Energy Reviews*, *165*, 112579 (2022).
[3] Trespi, S. *et al.*, *Energy & Fuels*, *35*(9), 7121-7132 (2020).

Characterization of the cooling power and energy efficiency on a two stage 4 K pulse tube cooler operated with solenoid valves

X. Herrmann[1,2], **J.-A. Schmidt**[1,2], **B. Schmidt**[1,2], **J. Falter**[2] **and A. Schirmeisen**[1,2]

[1]Institute of Applied Physics, Justus-Liebig-University, Giessen, Germany
[2]TansMIT-Center for Adaptive Cryotechnology and Sensors, Giessen, Germany

Since the discovery of superconductivity there is a need for finite cooling power at superconducting temperatures[1]. With the development of high temperature superconducting materials and subsequent interest for the use of these materials in commercial products like superconducting generators/motors[2], research for methods of cooling to cryogenic temperatures intensified. A prominent method for cooling is the Pulse Tube Cryocooler (PTC)[3]. A PTC uses periodic compression and expansion of a working fluid, generally Helium, to generate cooling power at the cold end of the PTC. PTCs are environmentally friendly because they are long lasting, energy efficient and closed cycle systems. Since their invention a major method to operate GM-type PTCs is the rotary valve[4]. Rotary valves are robust but have the drawback of not being adjustable without remanufacturing part of the valve and being expensive. Furthermore they induce losses due to gas bypass. This work will look at an alternate approach to drive a two stage 4K PTC by using solenoid valves. They offer timing adjustability via simple change of software, are cheap and have no losses due to gas bypass. Furthermore the influence of timing parameters on cooling power is investigated.

References

[1] H. K. Onnes, Nobel lecture **4**, 306-336 (1913)

[2] J. R. Hull, Rep. Prog. Phys. **66**, 1865 (2003)

[3] D. Sun, M. Dietrich and G. Thummes, IEEE Trans. Ap. Superconductivity **22**, 4703704 (2012)

[4] D. Liu et al., Cryogenics **81**, 100-106 (2017)

Logistics of hydrogen – A challenge from regulatory and practical considerations

Dr. Kay D. Jahnke[1]
[1]*Independent Consultant, Dangerous Goods Officer, Küfergasse 1, 89073 Ulm*

Hydrogen can be stored and handled in gaseous or liquid form. Due to the special properties of hydrogen being a highly flammable gas it is classified as a dangerous good and special measures need to be taken in handling it. The logistics is therefore governed by the ADR regulations for road and IATA regulations for air transport.
The different modes of transport with their specific requirements are analyzed and scenarios are outlined on how hydrogen logistics can be handled in practice. A selection of the available solutions for the German market is presented.

Environmental benign process intensification: Additive Manufacturing for process applications

Christoph Kiener

Siemens AG, Technology, Munich/Berlin, Germany

Process equipment for decentralized next generation energy applications should allow most resource efficient processes and reactions. The equipment itself should best fulfill robust eco-design demands as e.g., environmentally benign manufacturing, recyclability, and be made of alloy components with minimum supply risk and eco-footprint. Industrialized Additive Manufacturing (AM) technologies (planar: metal laser powder bed fusion PBF-LB/M; multi-axis: directed energy deposition DED, wire arc WAAM) have the ability to meet these needs and to realize valuable functionality:

- Reaction technology: Optimized fluid guiding and mixing structures for minimum pressure drop; improved heat management (e.g., avoidance of undesired side reactions; increased selectivity).
- Thermal management: Fast heating and cooling.
- Exergy-oriented thermal design: Heat removal at highest possible temperature using optimized heat exchangers.
- Hierarchic functionality [1]:
  - Tool-free generation of sophisticated shapes without additional cost & effort.
  - Heat and corrosion resistant super-alloys with structures below 100 µm.
- Parameterized 3D CAD models offer a catalogue of generic modular solutions
  - Best performance for each individualized application by multi-physics simulation.
  - Combination of several functional solutions into an integrated monolithic model.
- Function from geometry, not from chemical composition: Low eco-footprint alloys.
- Multi-function with mono-material: Recycling gets easier.

Typical workflows and demonstrators explain the versatility of AM-made parts, e.g. for high pressure applications, in synthesis gas chemistry, for in-process product separation, in combustion technology and the use of hierarchic structured functionality [2]. Special emphasis is on first results from the BMWK-funded public project "3D-PROCESS" (FKZ 03EN2065B).

References

[1] Additive manufacturing of open porous functional structures: roadmap from manufacturing to the application. Otto R., Kiener C., Küsters Y., Sorby K., *Procedia CIRP* **2022**, *112*, 334 - 339.

[2] Hochdruck-geeignete AM-Konstruktionselemente mit hierarchisch-funktionalen Metallstrukturen. Kiener C., Boschert S., Küsters Y., Nicolai A., Otto R., *Chem. Ing. Tech.* **2022**, *94,* No. 7, 1040 - 1045.

Transitioning the Schneebergerhof-farm to climate neutrality with the use of renewable energies

V. Galinskii, C. Helmker, P. Kompa, N. Monjuvent, J. Thomas

Johannes Gutenberg - University Mainz, Saarstr. 21, 55099 Mainz, Germany

The Schneebergerhof #14 is a former farm located between Mainz and Kaiserslautern, which has been using the abundance of wind energy for several years for its own power supply. The operator now wants to take the next step: reviving the farm, increasing its energy source (100MW wind energy) by solar power (30-50MW) and finding new business models matching this abundance in energy supply while achieving 100% climate neutrality. Part of this transition is the formation of a new agricultural facility in combination with Germany's largest aquaponics project. The student group will make proposals of additional business lines to make best use of the energy supply.

One of the biggest challenges of this rearrangement will be the storage of the energy produced by the existing wind turbines and future photovoltaic, in order to ensure reliable and sufficient energy supply in summer as well as in winter. In addition to guaranteeing energy supply to the buildings, the energy requirements of agriculture, aquaponics and additional business lines also need to be taken into account.

In the course of a 12-month lasting seminar, an interdisciplinary group of five students from the Johannes Gutenberg-University of Mainz are working on the development and implementation of ideas to help the farm owner in the transition. These ideas will feed into the concept of the Schneebergerhof, making it an example showing how the creation of value can relate to sustainable future perspectives in rural areas with the use of renewable energy sources.

References

[1] Discussion with Irina Clemens and Matthias Willenbacher, 02.06.23

Formation of porous metals with nano- and microsized structural elements under near-equilibrium condensation conditions

A. Kornyushchenko[1,2], V. Perekrestov[2], Y. Kosminska[2], S. Shevchenko[2], V. Natalich[2], G. Wilde[1]

[1]*Institute of Materials Physics, University of Muenster, Wilhelm-Klemm Str. 10, 48149 Muenster, Germany*
[2]*Sumy State University, Rymskogo-Korsakova Str.2, 40007 Sumy, Ukraine*

It is known, that porous structures depending on morphology can possess unique physical properties which can determine areas of their application. In the proposed work a new technique for synthesizing metal porous micro- and nanostructures has been developed. This approach is based on the phase transition of sputtered substances into the condensed state under conditions close to thermodynamic equilibrium. The low dimensional metal systems (Cr, Zn, Cu, Ti, Ni, Al) have been obtained in the different morphological forms, such as network structures, nanowires, agglomerations of weakly-bound crystals, columnar structures consisting of prolonged crystals with approximately identical habitus, etc. The results confirm the important new opportunities for size, shape and physical property tuning of nanostructured materials that are given by deposition near thermodynamic equilibrium conditions. It has been established that the growth mechanism under conditions close to thermodynamic equilibrium possesses principally new peculiarities and possibilities in comparison with traditional methods of condensation from vapor state and consequently can contribute to a new zone in the structure zone model.

References

[1] A. Kornyushchenko, Y. Kosminska, S. Shevchenko, V. Natalich, V. Perekrestov. Journal of Nano- and Electronic Physics **13**, 02034 (2021).

[2] A. Kornyushchenko, Y. Kosminska, S. Shevchenko, G. Wilde, V. Perekrestov. Journal of Electronic Materials **50**, 2268 (2021).

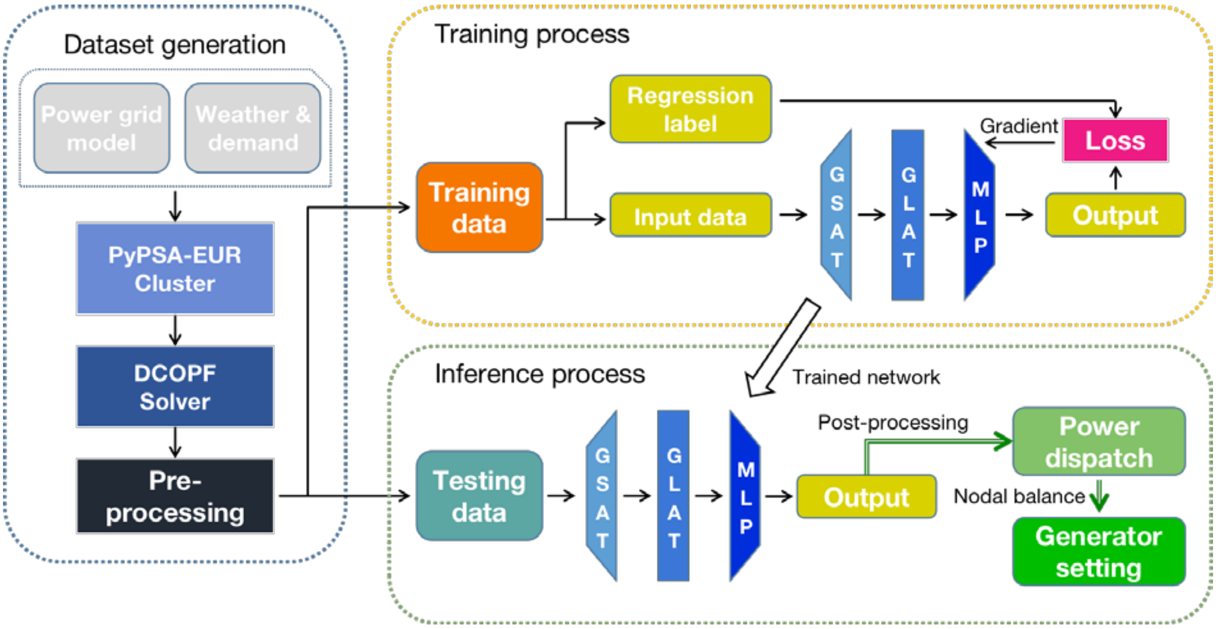
Optimal Power Flow in Highly Renewable Power System Based on Attention Neural Networks

Chen Li[1], **Alexander Kies**[1,2], **Kai Zhou**[1]

[1] *Frankfurt Institute for Advanced Studies, Goethe University Frankfurt, Ruth-Moufang-Str. 1, 60438 Frankfurt am Main, Germany*
[2] *Aarhus University, Nordre Ringgade 1, 8000 Aarhus C, Denmark*

Optimal Power Flow (OPF) problem is one of the most significant problem during power system operating. The setting point of generators i.e. the power productions are determined to meet the power demand while minimizing the total system cost of the grid, subject to physical and engineering constraints. The increasing share of renewable energy sources such as wind and solar brings instabilities into the power system, the ever-changing weather condition leads to totally different power setting points, forcing the grid operator solve the OPF problem very frequently. The problem is intractable using conventional numerical approaches, especially for a large-scale power system. In this work, a physics-informed machine learning approach is proposed, which is trained using historical weather data in Europe under the imitation learning framework. It directly maps the electricity demand as well as weather data to the power dispatch and generation. This data-driven approach is less time consuming compared to the conventional OPF solvers which require iterations, thus could be used in real time scenario. Experiments are done on clustered European power grids, and simulation results show that the proposed neural network achieves better performance compared to other data-driven approaches widely used in OPF problem.

Fig. The flowchart of proposed ML framework for OPF.



Experimental development of an all-liquid Na-Zn cell for grid-scale energy storage

William Nash[1,], Martins Sarma[1], Tom Weier[1], Norbert Weber[1], Carolina Duczek[1],

[1]Helmholtz-Zentrum Dresden Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany.

Large-scale energy storage is an essential pre-requisite for the proliferation of renewable energy generation. Viable storage media must be inexpensive however, if they are to compete with fossil fuels. One potential solution is offered by Liquid Metal Batteries (LMBs): electrochemical cells that comprise molten metallic electrodes separated by a fused salt electrolyte. Low costs are anticipated for these cells because they incorporate earth-abundant materials and because their construction need not involve sophisticated manufacturing processes. Furthermore, they are well suited to applications that require high power densities, since their high operating temperatures promote faster kinetics and reduced electrode polarization, and their molten salt electrolytes offer significantly higher conductivities than those in many alternative electrochemical cells [1].

An ALB employing Na and Zn electrodes and a $NaCl-CaCl_2-ZnCl_2$ electrolyte has received support from the SOLSTICE project (part of the EU's HORIZON 2020 programme). Power is generated by displacement of Zn^{2+} by Na^{+} in the electrolyte:

$$2\ Na + ZnCl_2 \rightarrow Zn + NaCl$$

The cell has an operating temperature of 600°C and exhibits a theoretical open-circuit voltage of 1.87 V [2]. Prototypes have been constructed that discharge close to this voltage [3,4], but they also demonstrate practical challenges such as self-discharge and corrosion of structural materials by the cell's electroactive components. Research is therefore focused on understanding and suppressing these phenomena. Self-discharge arises from dissolution of zero-valent Na in the electrolyte (which makes it slightly electrically conductive), and diffusion of Zn^{2+} ions to the Na electrode, where they can be reduced without contributing energy to the external circuit. Strategies for minimizing these processes are being explored, assisted by neutron-imaging of the cell's active materials during discharge. Results from these activities and their implications for optimum cell design will be presented.

References

[1] D. A. J., Swinkels, Advances in Molten Salt Chemistry (book chapter), (1971)

[2] W. J. Hamer, M. S. Malmberg, B. Rubin, J. Electrochem. Soc. **103**, 8 (1956)

[3] J. Xu, O. S. Kjos, K. S. Osen, A. M. Martinez, O. E. Kongstein, and G. M. Haarberg, Journal of Power Sources, **332**, 274–280 (2016)

[4] J. Xu, A. M. Martinez, K. S. Osen, O. S. Kjos, O. E. Kongstein, and G. M. Haarberg, J, Electrochem. Soc., **164,12**, A2335–A2340 (2017)

Probability aspects of the measures towards the 1,5-Degree-Limit

M. Pabst

Özel Alman Lisesi, Şahkulu, Şah Kulu Bostan Sk. No. 10, 34420 Beyoğlu/İstanbul, Turkey

In October 2020, the Wuppertal Institute, Germany (Wuppertal Institut für Klima, Umwelt, Energie) published the so-called "Fridays-for-Future Study" [1]. In this meta-study, the authors calculate the remaining CO_2 budget for Germany, based on IPCC data. They conclude that the CO_2 neutrality must be reached in Germany already in the year 2035 to limit the global temperature rise to 1,5K, with a probability of 50%.

In the next step, they took a closer look on four scenarios described in three studies, where the CO_2 neutrality will be reached in 2050. They changed the timelines and measures proposed with the goal to reach the CO_2 neutrality already in 2035. The authors estimate the possibility to realize this as "extremely difficult but basically possible."

We took a critical look at nine concrete measures from the study that must be successful implemented under this time constraint. Based on this, we assumed a hypothetical probability for each. Applying simple stochastics path rule we find a total probability of far below 1%.

2,5 years later and even if the 1,5-Degree-Limit now probably will probably exceeded, this study can serve as an example of how information from scientists should be presented to non-scientist decision maker.

References

[1] G. Kobiela et al. „CO2 -neutral bis 2035:Eckpunkte eines deutschen Beitrags zur Einhaltung der 1,5-°C-Grenze“ https://wupperinst.org/a/wi/a/s/ad/5169 (2020)

A Semantic Knowledge Platform for the Energy Value Chain

Matthias A. Popp[1] and Simon Stier[1]

[1]*Fraunhofer ISC, Würzburg, Germany*

Many discussions of non-experts about energy systems end like “One should just calculate the cost of this system or the efficiency of that”. However, these quantitative measures can be difficult to overview since data is scattered over a multitude of information sources. Further, costs and key performance indicators such as efficiency of solar cells, battery or hydrogen energy storage change over time with the evolution of technologies.

Additionally, advantageous quantitative descriptors cannot guarantee the spreading and implementation of technologies, as exemplified by wind turbines and photovoltaics. Social, psychological or political implications play a role during scale-up, showcasing that the energy value chain is as a complex system with dependencies and challenges on a multitude of levels.

This is why we at the group of Digital Transformation at Fraunhofer ISC develop a system called OpenSemanticWorld[1,2]. It is a holistic knowledge web platform that semantically describes complex connections between pieces of information in terms of knowledge graphs that can be connected to ontologies. A variety of visualization tools provides access not only to experts but also to the public.

The structured, yet flexible modelling and description of knowledge is not only valuable for humans but also prepares the use of knowledge-based machine learning methods. These will be important when extrapolation beyond known data sets meet extreme cost for further experimental data, as it is the case for the energy value chain on a national/international level.

Here, I will present an attempt to use our latest version of OpenSemanticWorld to model connections, implications and quantitative assessments within the energy value chain. I will present an interactive knowledge-graph with the possibility for other seminar members to add their expertise and further contribute to its completion, and therefore a holistic picture of the presence and future of the energy value chain.

References

[1] S. Stier *et.al.,* github, https://github.com/OpenSemanticLab

[2] S. Stier *et.al.,* OpenSemanticLab demo platform, https://demo.open-semantic-lab.org/wiki/Main_Page

Transient Operation of Power-to-X Plants Connected to Intermittent Renewable Power Sources in Isolated Networks

P. Rentschler[1], C. Klahn[1] and R. Dittmeyer[1]

[1]*Karlsruhe Institute of Technology (KIT), Institute for Micro Process Engineering (IMVT), Karlsruhe, Germany*

A key factor for the success of the energy transition in Germany is the provision of large amounts of renewable electricity with a high availability and low prices.

In this respect, offshore wind turbines, which have now reached a considerable capacity of 15 MW per turbine, offer the potential to be able to produce Power-to-X (PtX) products at low cost, such as hydrogen, liquefied methane, methanol, liquid hydrocarbons and ammonia. They are particularly suitable if they are not connected to the power grid but are directly coupled with an electrolysis process as well as the subsequent conversion into more easily transportable PtX products - beyond hydrogen. For this purpose, the individual process steps must be directly coupled to offshore wind turbines and operated under offshore conditions, as well as being able to follow the dynamics of the generation of renewable electrical energy.

Against this background, tools for simulating the transient operation of PtX process chains in isolated networks are developed and validated on the basis of experimental data. The focus is on the three process chains Power-to-Liquid, Power-to-Methanol, and Power-to-Ammonia. The tools are to be used for questions of system design and for optimizing the operation of isolated PtX networks including on-site provision of the reactants, such as CO_2 by extraction from the ambient air, as well as energy and product storages. The focus is not on a detailed spatially resolved, non-stationary modeling of the processes, but rather on a time-resolved description of the dynamics of the PtX process chains relevant for the isolated energy system. For the modeling of this characteristic behavior, current approaches in the field of artificial intelligence and machine learning will be used.

A Balance of Efficient and Renewable Energy

Dr.rer.nat. B.Su

bin.su@alumni.tu-berlin.de

We meet now the fundamental transition of energy supply from efficient to renewable sources. From ecological and economic points of view we must discuss the efficiency of the existed energy sources meanwhile their disadvantage in climate atmosphere climate versus co2-emmission generally. The climate change, which arise on the earth not in short time, has beyond energy sources several reasons, for example the raised temperature, overflowed plastics in sea, in ocean and in soil etc, which do not have much to do directly with the energy sources.

The efficiency of the renewable energy sources is weaker than those ever used either fossil or atomic energy. The renewable energy suffers fluctuations in produce in terms of power and quantity. This instability imposes restrictions on energy applications. The renewable energy needs therefore storage as energy supply, which may be very large if demand is greater. There are extra suitable technical equipments to be established in order to satisfy the demand of modern industry. Consequently, the price of the energy sources is going to rise if there are no other measures to take. Because of the impotence of quality of energy sources in the modern competitive industrialization, this fundamental transition from efficient to renewable sources influences so that unavoidably the prosperity of the countries, which go along a way in such a direction neglecting international economic environment and without complete intervenes against climate pollution. A consideration, how to balance energy sources and to satisfy both factors in ecology and economy under retaining the prosperity, is necessary under the guidance of scientific and technical research works and results.

References

[1] www.schroedel.de,page 266 (2006)
[2] L. Erhard, Wirtschaftsfrage der Freien Welt, page 100-200 (1957)
[3] D. Goergaler,L.Scholz, Energie fuer Morgen – Plannung von Heute