

Prof. Dr. rer. nat. Kaspar Andreas Friedrich



Born on December 13th, 1962 in Broken Hill / Zambia
German nationality, married

Professional addresses:

University of Stuttgart
Institute of Energy Storage
Pfaffenwaldring 31
D-70550 Stuttgart

Deutsches Zentrum für Luft- und
Raumfahrt e.V. (DLR)
German Aerospace Center
Institute of Engineering Thermodynamics,
Electrochemical Energy Technology
Pfaffenwaldring 38-40
D-70569 Stuttgart

Tel.: +49-(0)711-6862278

Mobile: + 49-(0)1738917006

Fax: +49-(0)711-68621278

Email: andreas.friedrich@dlr.de or andreas.friedrich@itw.uni-stuttgart.de

Curriculum Vitae

Professional Positions

- 08/2004-present: Head of section Electrochemical Energy Technology at the German Aerospace Center (DLR), Institute of Engineering Thermodynamics. Professorship (C3) at the University of Stuttgart, Faculty of Energy-, Process- and Bio-Engineering.
- 01/2002-06/2004: Project Leader and Senior Scientists at the Centre for Solar Energy and Hydrogen Research (ZSW) Section 3, Electrochemical Energy Conversion and Storage, Ulm.
- 01/1998-12/2001: Senior Scientist and Research Associate at Department of Physics, E19, Technical University of Munich. Chair of Interfaces and Energy Conversion, Prof. Dr. U. Stimming. Deputy function and head of group of low temperature fuel cells.
- 02/1993-12/1997: Research Scientist at Institute of Energy Process Engineering, Forschungszentrum Jülich GmbH (Director Prof. U. Stimming).
- 12/1990-12/1992: Postdoctoral Research Associate at University of Oregon, Eugene, Oregon/USA, group of Prof. G. L. Richmond.

Education and Training

- 11/1990: Doctor (Ph.D) of Natural Sciences: Disputation (Defense of the Dissertation) on November 5th, 1990 "summa cum laude" at Free University of Berlin.
Thesis: Investigation of Single-Crystal Gold Electrodes by Second Harmonic Generation.
- 10/1987-11/1990: Fritz-Haber Institute of the Max-Planck-Society: Doctoral study at the Department for Physical Chemistry.
Head of institute and supervisor: Prof. Dr. Gerhard Ertl (Nobel prize laureate, 2007)
- May 1987: Diploma of Physics, Examination: "summa cum laude".
- 1982-1987: University of Frankfurt, undergraduate studies of Physics.

Awards

2nd prize of F-Cell Award 2016 – Research & Development

Ertl prize at the 3rd Ertl Symposium 2014, personal

Clean Tech Media Award 2012 (Aviation), for the DLR group

Hellmuth Fischer Medal 2009 (DECHEMA), personal

f-cell Award in Silver (DLR with Airbus): International Expert Forum "f-cell" in Stuttgart on September 29th, 2008 for the DLR group

Kekulé stipend for doctoral students of the Volkswagenwerk Foundation, 1987 personal

Main Research Topics:

- **Fuel cell technology, in particular polymer electrolyte fuel cells (PEFC) and solid oxide fuel cells (SOFC), and lithium batteries**

The primary goals for the fuel cell research comprise enhanced power density, long lifetime, reduction of materials and manufacturing costs, identification of degradation mechanisms in stacks and their prevention, advanced stack design, highly integrated system components and optimized integration of fuel cells into energy supply systems. Priorities in component research are optimization and understanding of membrane electrode assemblies (MEAs), gas diffusion electrodes, gas diffusion media and membranes. Further activities are the development of hydrogen and reformat-fuelled systems as well as in the past of direct methanol fuel cells. The development of metal-supported SOFC with integration into light-weight stacks is a major topic for high-temperature fuel cells. Investigation of degradation mechanisms is performed within international and national cooperation. System analysis and system modelling is performed for transport, stationary as well as portable applications. Special application of fuel cell systems for aircraft application has been a system priority. For the aircraft application the team at DLR has obtained the **f-cell Award Silver** at the expert forum "f-cell" in Stuttgart, September 29th, 2008 together with Airbus Germany. In addition, the group has been awarded the **Clean Tech Media Award 2012** in der category aviation for the world first demonstration of emission-free e-taxiing of a commercial aircraft (A320). Since 2009 also advanced battery technology for electro-mobility has been added as a research priority. A large variety of analytical and diagnostic methods are used (segmented cells, EIS, CV, Raman, FTIR, XRD, SEM, XPS).

- **Electrolysis technology, in particular polymer membrane electrolysis (PEMEL) and solid oxide electrolysis (SOEC)**

The electrolysis activities have been intensified in 2011 with the available funding through the national storage initiative for PEMEL and SOEC. A research priority is cost reduction of components and systems. In particular the polymer membrane electrolysis promises a compact design, high efficiencies and a highly dynamic operation. This technology is especially suited for on-site hydrogen generation but presently is still significantly more expensive than alkaline electrolysis. Novel supported electro-catalyst – mainly for the anode with electro-ceramic supports - are being researched and developed to reduce the noble metal content. The fundamental investigation of electro-catalytic properties of nano-structured surfaces is a complementary research activity. In addition, corrosion stable coatings for inexpensive bipolar plates are being developed (e.g. modified titanium coatings on stainless steel). The innovative components are integrated in stacks and systems of industrial partners and evaluated with regards to performance, durability and economical relevance. The experimental activity is supplemented by system modelling activities to describe and understand the dynamic behavior of electrolysis systems and degradation effects under intermittent operation. These activities are integrated into a large scale industrial project with the aim to provide advice for the operation of a MW-scale polymer electrolysis plant in order to ensure high efficiency and superior durability.

The highest electrical efficiencies can be reached with high-temperature solid oxide steam electrolysis in the temperature range of 700 to 900 °C. Efficiencies of 90% and even higher can be achieved if high temperature heat from industrial or solar thermal processes can be integrated into the electrolysis reactor. Furthermore, an interesting option is the co-reduction of CO₂ to CO if a concentrated carbon dioxide source is available. In this way the SOEC process can yield synthesis gas for the production of synthetic fuels (e.g. alcohols). The development of novel cells with superior functionality and durability is the focus of current research. Short stacks and stacks are assembled and tested regarding performance, endurance, high steam content, and co-electrolysis. For the cell and electrode development the groups at Forschungszentrum Jülich are the main partners.

- **Electrocatalytic properties of nanoscale surfaces and interfaces**

The understanding and elucidation of electro-catalytic properties of electrode surfaces on the nanoscale has been a priority topic starting in 1992. The properties of nano-sized particles on surfaces and supported nano-particles (1 - 10 nm) have been a fundamental research topic. To investigate the surfaces, scanning probe techniques in combination with in-situ and ex-situ spectroscopies have been applied. Methods included STM/AFM, DEMS (differential electrochemical mass spectrometry), IR-Absorption, SHG/SFG (second harmonic generation/ sum-

frequency generation), and classical electrochemical methods (CV, EIS, Pulses etc.).

Publications:

• Journals (peer reviewed):

172. P. Lettenmeier, S. Kolb, N. Sata, A. Fallisch, L. Zielke, S. Thiele, A. S. Gago, K.A. Friedrich "Comprehensive investigation of novel pore-graded gas diffusion layers for high-performance and cost effective proton exchange membrane electrolyzers" *Energy & Environmental Science* xxx (2017),
171. D. Garcia Sanchez, T. Ruiu, I. Biswas, M. Schulze, S. Helmly, K.A. Friedrich "Local impact of humidification on degradation in polymer electrolyte fuel cells", *J. Power Sources* **352** (2017) 42-55.
170. P. Mottaghizadeh, S. Santhanam, M. P. Heddrich, K. A. Friedrich, F. Rinaldi "Process modeling of a reversible solid oxide cell (r-SOC) energy storage system utilizing commercially available SOC reactor" *Energy Convers. Manag.* **142** (2017) 477-493
169. J. Shan, P. Gazdzicki, R. Lin, M. Schulze, K. A. Friedrich "Local resolved investigation of hydrogen crossover in polymer electrolyte fuel cell" *Energy* **128** (2017) 357-365
168. P.A. García-Salaberri, D. Garcia Sanchez, P. Boillat, M. Vera, K.A. Friedrich, "Hydration and dehydration cycles in polymer electrolyte fuel cells operated with wet anode and dry cathode feed: A neutron imaging and modeling study" *J. Power Sources* **359** (2017) 634-655
167. L. Wang, V. A. Saveleva, S. Zafeiratos, E. R. Savinova, P. Lettenmeier, P. Gazdzicki, A. S. Gago, K. A. Friedrich "Highly active anode electrocatalysts derived from electrochemical leaching of Ru from metallic Ir_{0.7}Ru_{0.3} for proton exchange membrane electrolyzers" *Nano Energy* **34** (2017) 385–391
166. P. Lettenmeier, L. Wang, R. Abouatallah, B. Saruhan, O. Freitag, P. Gazdzicki, T. Morawietz, R. Hiesgen, A. Gago, K.A. Friedrich "Low-Cost and Durable Bipolar Plates for Proton Exchange Membrane Electrolyzers", *Sci. Rep.* **7** (2017) 44035
165. M. Steinhauer, S. Risse, N. Wagner, K. A. Friedrich "Investigation of the Solid Electrolyte Interphase Formation at Graphite Anodes in Lithium-Ion Batteries with Electrochemical Impedance Spectroscopy" *Electrochim. Acta* **228** (2017), 652-658
164. M. Steinhauer, T. Diemant, C. Heim, R. J. Behm, N. Wagner, K. A. Friedrich „Insights into solid electrolyte interphase formation on alternative anode materials in lithium-ion batteries" *J. Appl. Electrochem.* **47** (2017) 249–259
163. L. Wang, F. Song, G. Ozouf, D. Geiger, T. Morawietz, M. Handl, P. Gazdzicki, C. Beauger, U. Kaiser, R. Hiesgen, A. S. Gago, K. A. Friedrich "Improving the Activity and Stability of Ir Catalysts for PEM Electrolyzer Anodes by SnO₂:Sb

- Aerogel Supports: Does V Addition play an Active Role in Electrocatalysis?", *J. Mat. Chem. A* **5** (2017), 3172-3178
162. N. A. Cañas, P. Einsiedel, O. T. Freitag, C. Heim, M. Steinhauer, D.-W. Park, K. A. Friedrich "Operando X-Ray Diffraction during Battery Cycling at Elevated Temperatures: A quantitative analysis of lithium-graphite intercalation compounds" *Carbon* **116** (2017), 255 - 263
161. S. Helmly, M. J. Eslamibidgoli, K. A. Friedrich, M. H. Eikerling "Local Impact of Pt Nanodeposits on Ionomer Decomposition in Polymer Electrolyte Membranes", *Electrocatalysis* (2017) xxx.
160. M. Riegraf, V. Yurkiv, R. Costa, G. Schiller, K. A. Friedrich "Evaluation of the effect of sulfur on the performance of Ni/CGO based solid oxide fuel cell (SOFC) anodes" *ChemSusChem* **10** (2017), 587 – 599
159. P. Lettenmeier, R. Wang, R. Abouatallah, F. Burggraf, A. S. Gago, K. A. Friedrich, "Proton Exchange Membrane Electrolyzer Systems Operating Dynamically at High Current Densities" *ECS Transactions*, **72** (23) (2016) 11-21
158. P. Lettenmeier, J. Majchel, L. Wang, A. S. Gago, K. A. Friedrich, "Electrochemical Analysis of Synthesized Iridium Nanoparticles for Oxygen Evolution Reaction in Acid Medium" *ECS Transactions*, **72** (23) (2016) 1-9
157. P. Stahl, P. Biesdorf, P. Boillat, K. Kraft, K.A. Friedrich "An Investigation of PEFC Sub-Zero Startup: Evidence of Local Freezing Effects", *J. Electrochem. Soc.* **163** (14) (2016) F1535-F1542
156. T. Morawietz, M. Handl, C. Oldani, K.A. Friedrich, and R. Hiesgen "Quantitative in Situ Analysis of Ionomer Structure in Fuel Cell Catalytic Layers", *ACS Appl. Mater. Interfaces* **8** (2016) 27044–27054
155. V.A. Saveleva, L. Wang, W. Luo, S. Zafeiratos, C. Ulhaq-Bouille, A.S. Gago, K.A. Friedrich, E.R. Savinova "Uncovering the Stabilization Mechanism in Bimetallic Ruthenium-Iridium Anodes for Proton Exchange Membrane Electrolyzers", *J. Phys. Chem. Lett.* **7** (16) (2016) 3240-3245
154. P. Gazdzicki, J. Mitzel, D. G. Sanchez, M. Schulze, K.A. Friedrich "Evaluation of reversible and irreversible degradation rates of polymer electrolyte membrane fuel cells tested in automotive conditions" *J. Power Sources* **327** (2016) 86-95
153. P. Lettenmeier, R. Wang, R. Abouatallah, F. Burggraf, A.S. Gago, K.A. Friedrich "Coated Stainless Steel Bipolar Plates for Proton Exchange Membrane (PEM) Electrolyzers", *J. Electrochem. Soc.* **163** (11) (2016) F1-F6
152. D.-W. Park, N.A. Cañas, N. Wagner, K.A. Friedrich "Novel solvent-free direct coating process for battery electrodes and their electrochemical performance", *J. Power Sources* **306** (2016) 758–763

151. D.-W. Park, N.A. Cañas, M.S. Hosseini, B. Milow, L. Ratke, K.A. Friedrich "A dual mesopore C-aerogel electrode for a high energy density supercapacitor", *Curr. Appl. Phys.* **16** (2016) 658-664
150. P. Lettenmeier, R. Wang, R. Abouatallah, S. Helmly, T. Morawietz, R. Hiesgen, S. Kolb, F. Burggraf, J. Kallo, A.S. Gago, K.A. Friedrich "Durable Membrane Electrode Assemblies for Proton Exchange Membrane Electrolyzer Systems Operating at High Current Densities", *Electrochim. Acta* **210** (2016) 502–511
149. P. Lettenmeier, S. Kolb, F. Burggraf, A.S. Gago, K.A. Friedrich "Towards developing a backing layer for proton exchange membrane electrolyzers", *J. Power Sources* **311** (2016) 153–158
148. M. Henke, S. Hillius, M. Riedel, J. Kallo, K. A. Friedrich "Gas Recirculation at the Hydrogen Electrode of Solid Oxide Fuel Cell and Solid Oxide Electrolysis Cell Systems", *Fuel Cells* **16**, (2016), 5, 584–590.
147. S. Risse, N. A. Cañas, N. Wagner, E. Härk, M. Ballauff, K. A. Friedrich "Correlation of Capacity Fading Processes and Electrochemical Impedance Spectra in Lithium/Sulfur Cells" *J. Power Sources* **323** (2016) 107-114
146. D. G. Sanchez, T. Ruiu, K.A. Friedrich, J. Sanchez-Monreal, M. Vera "Analysis of the Influence of Temperature and Gas Humidity on the Performance Stability of Polymer Electrolyte Membrane Fuel Cells", *J. Electrochem. Soc.* **163** (3) (2016) F150-F159
145. A.S. Gago, S.A. Ansar, B. Saruhan, U. Schulz, P. Lettenmeier, N.A. Cañas, P. Gazdzicki, T. Morawietz, R. Hiesgen, J. Arnold, K.A. Friedrich "Protective coatings on stainless steel bipolar plates for proton exchange membrane (PEM) electrolyzers", *J. Power Sources* **307** (2016) 815–825
144. P. Lettenmeier, L. Wang, U. Golla-Schindler, P. Gazdzicki, N.A. Cañas, M. Handl, R. Hiesgen, S.S. Hosseiny, A.S. Gago, K.A. Friedrich "Nanosized IrOx-Ir Catalyst with Relevant Activity for Anodes of Proton Exchange Membrane Electrolysis Produced by a Cost-Effective Procedure", *Angew. Chem. Int. Ed.* **55** (2016) 742 –746
143. L. Wang, P. Lettenmeier, U. Golla-Schindler, P. Gazdzicki, N.A. Cañas, T. Morawietz, R. Hiesgen, S.S. Hosseiny, A.S. Gago, K.A. Friedrich "Nanostructured Ir-supported on Ti₄O₇ as a cost effective anode for proton exchange membrane (PEM) electrolyzers", *Phys. Chem. Chem. Phys.* **18** (2016) 4487-4495
142. D. Wittmaier, N.A. Cañas, I. Biswas, K.A. Friedrich "Highly Stable Carbon-Free Ag/Co₃O₄-Cathodes for Lithium-Air Batteries: Electrochemical and Structural Investigations", *Adv. Energy Mater.* **5** (19) (2015) 1500763

141. P. Stahl, P. Biesdorf, P. Boillat, K. Kraft, K.A. Friedrich "Water Distribution Analysis in the Outer Perimeter Region of Technical PEFC Based on Neutron Radiography", *J. Electrochem. Soc.* **162** (7) (2015) F677-F685
140. M. Linder, T. Hocker, L. Holzer, O. Pecho, K.A. Friedrich, T. Morawietz, R. Hiesgen, R. Kontic, B. Iwanschitz, A. Mai, J.A. Schuler "Ohmic resistance of nickel infiltrated chromium oxide scales in solid oxide fuel cell metallic interconnects", *Solid State Ionics* **283** (2015) 38-51
139. M. Linder, T. Hocker, C. Meier, L. Holzer, K.A. Friedrich, B. Iwanschitz, A. Mai, J.A. Schuler "A model-based approach for current voltage analyses to quantify degradation and fuel distribution in solid oxide fuel cell stacks", *J. Power Sources* **288** (2015) 409-418
138. B. Martinez-Vazquez, D.G. Sanchez, J.L. Castillo, K.A. Friedrich, P.L. Garcia-Ybarra "Scaling-up and characterization of ultralow-loading MEAs made-up by electrospray", *Int. J. Hydrogen Energ.* **40** (2015) 5384-5389
137. M. Riegraf, G. Schiller, R. Costa, K.A. Friedrich, A. Latz, V. Yurkiv "Elementary kinetic numerical simulation of Ni/YSZ SOFC anode performance considering sulfur poisoning", *J. Electrochem. Soc.* **162** (1) (2015) F65-F75
136. S. Wahl, A.G. Segarra, P. Horstmann, M. Carré, W.G. Bessler, F. Lapique, K.A. Friedrich "Modeling of a thermally integrated 10 kWe planar solid oxide fuel cell system with anode off-gas recycling and internal reforming by discretization in flow direction", *J. Power Sources* **279** (2015) 656-666
135. N. A. Cañas, A. L.P. Baltazar, M. A.P. Morais, T.O. Freitag, N. Wagner, K.A. Friedrich "Fabrication of sulfur cathodes by wet-powder spraying and the understanding of degradation", *Electrochimica Acta* **157** (2015) 351-358
134. M. Riegraf, G. Schiller, R. Costa, K.A. Friedrich, A. Latz, and V. Yurkiv "Elementary Kinetic Numerical Simulation of Ni/YSZ SOFC Anode Performance Considering Sulfur Poisoning", *J. Electrochem. Soc.* **162** (1) (2015) F65-F75
133. R. Hiesgen, T. Morawietz, M. Handl, M. Corasaniti, and K. A. Friedrich "Atomic Force Microscopy on Cross Sections of Fuel Cell Membranes, Electrodes, and Membrane Electrode Assemblies", *Electrochimica Acta*, **162** (2015) 86–99
132. H. M.A. Amin, H. Baltruschat, D. Wittmaier, K.A. Friedrich "A Highly Efficient Bifunctional Catalyst for Alkaline Air-Electrodes Based on a Ag and Co₃O₄ Hybrid: RRDE and Online DEMS Insights", *Electrochim. Acta* **151** (2015) 332–339
131. C. Willich, A. Tomaszewski, M. Henke, K.A. Friedrich, and J. Kallo, "Temperature Effect due to Internal Reforming in Pressurized SOFC", *J. Electrochem. Soc.*, **161** (5) (2014) F674-F678
130. D. G. Sanchez, T. Ruiu, I. Biswas, K. A. Friedrich, J. Sanchez-Monreal, M.

- Vera, Effect of the Inlet Gas Humidification on PEMFC Behavior and Current Density Distribution, *ECS Trans.*, **64** (3) 603-617
129. S. Gago, A. S. Ansar, P. Gazdzicki, N. Wagner, J. Arnold, K. A. Friedrich, Low Cost Bipolar Plates for Large Scale PEM Electrolyzers, *ECS Trans.* **64** (3) 1039-1048
128. D. Wittmaier, N. Wagner, K.A. Friedrich, H. Amin, H. Baltruschat, "Modified carbon-free silver electrodes for the use as cathodes in lithium-air batteries with an aqueous alkaline electrolyte", *J. Power Sources*, **265** (2014) 299-308
127. N. Cañas N.; D. Fronczek; N. Wagner; A. Latz.; and K.A. Friedrich, "Experimental and Theoretical Analysis of Products and Reaction Intermediates of Lithium-Sulfur Batteries", *J. Phys. Chem. C*, **118** (2014) 12106–12114
126. R. Hiesgen, T. Morawietz, M. Handl, M. Corasaniti, and K.A. Friedrich, "Insight into the Structure and Nanoscale Conductivity of Fluorinated Ionomer Membranes", *J. Electrochem. Soc.*, **161** (12) (2014) F1214-F1223
125. M. Henke, C. Willich, J. Kallo, and K. A. Friedrich, "Theoretical study on pressurized operation of solid oxide electrolysis cells", *Int. J. Hydrogen Energy* **39** (2014) 12434-12439
124. M. Linder, T. Hocker, L. Holzer, K. A. Friedrich, B. Iwanschitz, A. Mai, and J. A. Schuler, "Model-based prediction of the ohmic resistance of metallic interconnects from oxide scale growth based on scanning electron microscopy", *J. Power Sources*, **272** (2014) 595- 605
123. D. Wittmaier, Dennis; T. Danner, N. Wagner, and K. A. Friedrich, "Screening and further investigations on promising bi-functional catalysts for metal-air batteries with an aqueous alkaline electrolyte", *J. Appl. Electrochem.* **44** (1) (2014) 73-85
122. D. G. Sanchez, A. Ortiz, and K. A. Friedrich, "Oscillation of PEFC under Low Cathode Humidification: Effect of Gravitation and Bipolar Plate Design", *J. Electrochem. Soc.*, **160** (6) F636-F644 (2013)
121. D. G. Sanchez, A. Ortiz, and K. A. Friedrich, "Oscillation of PEFC under Low Cathode Humidification: Effect of Gravitation and Bipolar Plate Design", *ECS Trans.*, **58** (1) (2013) 209-221
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119. R. Hiesgen, T. Morawietz, S. Helmly, I. Galm, and K. A. Friedrich, "Atomic Force Microscopy Studies of Conductive Nanostructures in Solid Polymer Electrolytes", *ECS Trans.*, **58** (1) (2013) 595-605
118. S. Helmly, B. Ohnmacht, R. Hiesgen, E. Gülzow, and K. A. Friedrich, "Influence

- of Platinum Precipitation on Properties and Degradation of Nafion® Membranes”, *ECS Trans.*, **58** (1) (2013) 969-990
117. T. Morawietz, R. Hiesgen, S. Helmly, I. Galm, and K. A. Friedrich, “Atomic Force Microscopy Detection of Electronic Short-Circuits in Solid Polymer Electrolytes Fuel Cell Membranes after Accelerated Degradation”, *ECS Trans.*, **58** (1) (2013) 1085-1096
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98. G. Renouard-Vallet, M. Saballus, P. Schumann, J. Kallo, K.A. Friedrich, H. Müller-Steinhagen, “Fuel cells for civil aircraft application: on-board production of power, water and inert gas”, *ChERD* **90** (2012) 3-10
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