Robert Schlögl*

Editorial

DOI 10.1515/green-2015-0023

The quest for renewable energy systems in future has multiple sources. There is the stream of arguments for protecting us from the consequences of global warming and other climate changes arising from burning fossil fuels and from excessive land use (also for apparently "green" energy farming). There is another stream of arguments coming from the environmental protection of fragile ecosystems on land and under the sea where we increasingly invade with substantial damage for harvesting fossil resources. There is the political stream of arguments known under the term "energy security" postulating the uninterrupted supply of energy for economic and societal activities in the developed economies. And finally, there are arguments about energy participation, meaning that multiple poor countries without a developed energy infrastructure lack almost all chances for societal development and should not try to resolve this issue by using local inefficient fossil generation infrastructures.

All these streams of arguments lead to the insight that at least one dominating element of the solution is the massive application of renewable primary electricity generation mainly with wind and PV power systems. Its distribution may be centralized or decentralized or co-exist in hierarchical systems. This is a global trend now and cannot be reverted any more meaning that any design of future energy systems has to take this infrastructure into account. Its weak points are neither physical or economic efficiency any more nor excessive material consumption but their inabilities even in large network structures to compensate the volatility of solar radiation due to local weather and to seasonal changes.

This can be compensated by the integration of renewable with fossil and nuclear (both fission and fusion) options. Such integration will have to occur any way, as the transition pathways from present infrastructures to renewable electricity generation will require decades of time purely from economic reasons. One central element of this integration is the effective, time-variable and large-scale inter-conversion of chemical energy carriers into free electrons and vice versa. The schematic drawing indicates the challenge.

From this diagram it is clear that in future energy systems all end energy uses will be used as flexibilization options making up for the volatility of solar energy. The significant complexity behind the seemingly easy structure shown in the diagram concerns not only the technological options but also the organizational and societal challenges that will not be treated here.

When we prioritize the efforts for closing the deficits in our portfolio of technological options we quickly find that converting free electrons into chemical bonds for generating "solar fuels" and sustainable materials is the core challenge. From considering the aspect of integration of primary electricity in the whole energy system it becomes clear that the conversion of free electrons to chemical bonds rather than of photons is the critically needed function. The science behind these processes (electrochemistry, catalysis) benefits in addition the direct conversion of photons to fuels that require these technologies as additions to the charge carrier generation.

This issue of GREEN presents a collection of efforts tackling all chemical energy conversion (CEC). Two contributions deal in detail with aspects of the systemic challenges and with emerging solutions. Ingenious synthetic work, nanotechnology and increasingly deeper insight into the function of heterogeneous reactions are the essential scientific ingredients. When reading these articles it transpires quickly that we stand in front not only of technological but also of deeply fundamental challenges concerning design and function of hetero-interfaces as the common scientific basis of all technologies needed for CEC. In this light it is premature to try to sort today the many approaches documented here and in the literature for their effectiveness or usability. We should not select certain ways and discard others before we have not collected sufficient secure knowledge about their potential under world-scale application conditions. Neither arguments of lacking time nor of excessive resource requirements should be brought against a rigorous evaluation of technology options, as the scale of later application is larger than of any technology that we have been using so far. Considering this, the present

***Corresponding author: Robert Schlögl,** Department of Inorganic Chemistry, Fritz-Haber-Institut der, Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany; Max Planck Institute for Chemical Energy Conversion, Stiftstr. 34-36, Mülheim an der Ruhr, Germany, E-mail: acsek@fhi-berlin.mpg.de

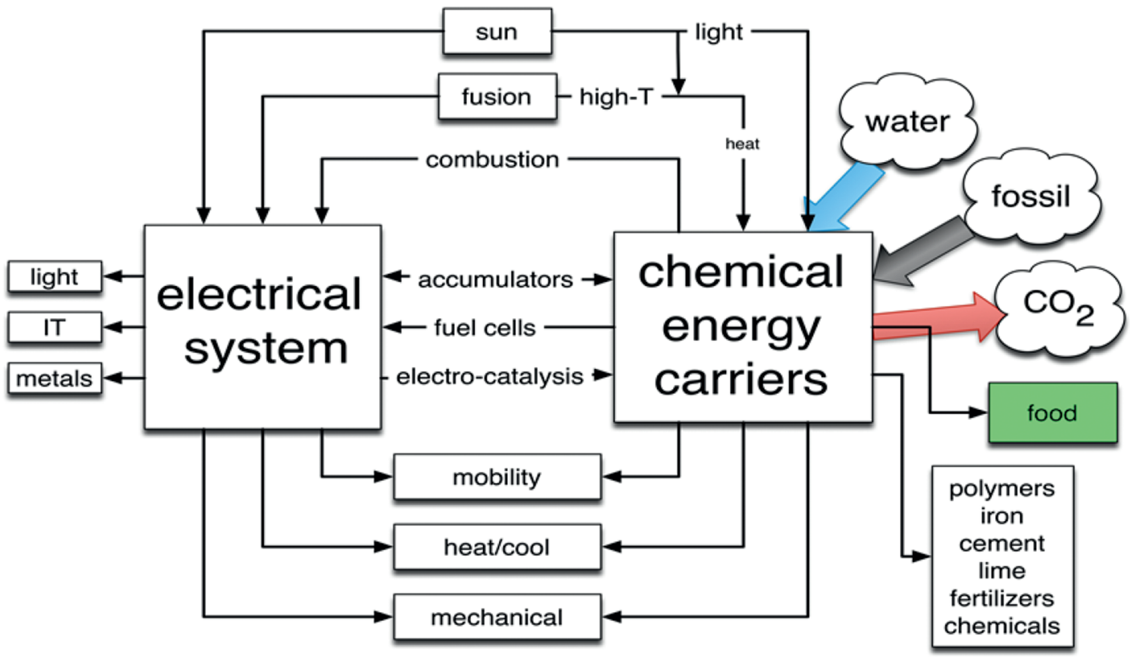

Figure 1: Schematic diagram presenting the technological dimension of an energy system. When the fossil contribution is minimized, excess CO_2 should vanish and sustainability in a technological sense should be reached. Note the extreme complexity behind this simple diagram serving merely as an ordering scheme for challenges rather than as descriptor for the system. Note also that economic political and societal sub-systems are intertwined with this technological part of the energy system.

expenditure of efforts is way too small when referring to the historic experience of developing other core technologies of our modern world.

Addressing the scientific challenges and the transfer of their solutions into technologies is truly a trans-disciplinary effort and cannot be handled either by one individual or a disciplinary team. It clearly requires a multi-disciplinary approach. The example of MAXNET energy shows how the Max Planck Society with its strictly fundamental scientific orientation contributes to the energy challenge. In this work electrochemical activities are the focal point of efforts. Described are also organizational strategies of how to bring trans-disciplinarity into practical operation. Another contribution puts its focus on our understanding of photochemical reactions focusing on one particular material class. This class was selected not only from aspects of excellent analytical possibilities for studying its function but rather from the insight that the natural CEC system called photosynthesis uses a molecular catalyst for water oxidation with also this element as the metallic active component.

This collection of publications exemplifies the wide range of efforts how science responds to the energy challenge even in the limited area of CEC. As useful solution-oriented phenomenological work is to trigger functional understanding and to pave pathways to technologies, as

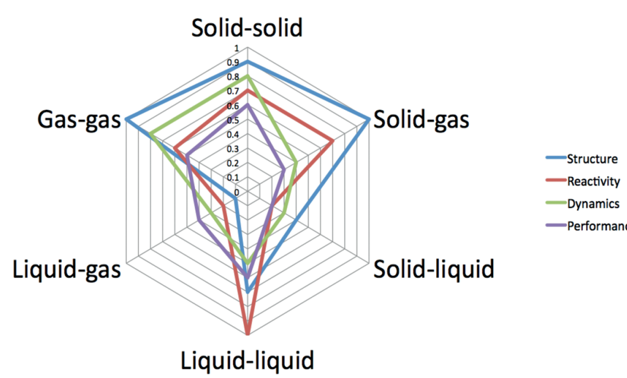

Figure 2: The common fundamental science basis for energy conversion is interface science. The scheme illustrates that this multi-disciplinary field is quite heterogeneous in its evolution along the descriptors of structure, reactivity, dynamics and application performance. The personal judgment behind this graph tries to consider the whole breadth of interface phenomena without emphasizing too much punctual enormous successes (such as in semiconductors or aerodynamics for example).

much it becomes clear that the common underlying theme of interface science is only punctually developed to a state that it could serve as a firm basis for knowledge-based design approaches to particular problems.

The devices used for generating renewable electricity are excellent examples of punctual successes of interface science. They on the other hand illustrate how far we are behind in chemical energy conversion systems such as batteries, fuel cells (e. g. for solid fuels like carbon) or solar fuel generators. Even in the underlying large-scale hydrocarbon transformations following downstream from CO_2 hydrogenation to synthesis gas or to methanol we are far from being able to control reactivity and selectivity to a level that effective world-scale application would be possible. Also the here widely treated example of water splitting is a good example of a triple phase interfacial problem where gas-liquid, gas-solid and solid-liquid interfacial properties together determine the kinetic conditions of this process being basic for all sustainable energy system designs.

Would the present issue of GREEN contribute to the dissemination of the insight that multiple collective and fundamentally grounded efforts are still required to generate the solutions required for CEC as a limited part of the overall energy challenge, then the great efforts of all authors would have additional value over the excellent representation of their individual scientific work. The editor wishes to thank the editorial staff of GREEN and D. Damm for the continuous and skillful support in bringing together this issue.

Berlin, autumn 2015

Bionote

Robert Schlögl
Department of Inorganic Chemistry, Fritz-Haber-Institut der, Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany; Max Planck Institute for Chemical Energy Conversion, Stiftstr. 34-36, Mülheim an der Ruhr, Germany,
acsek@fhi-berlin.mpg.de

Prof. Dr. Robert Schlögl, Editor-in-Chief *GREEN*, is Director of the Department of Inorganic Chemistry at the Fritz Haber Institute of the Max Planck Society. He is also Founding Director at the Max Planck Institute for Chemical Energy Conversion.