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(Abstract)

A multi-energy company's approach to sustainability

Dr. Shaffiq Jaffer

The world population is projected to reach 11 Billion in 2100. The Human Development Index shows that to achieve a fairly good quality of life, each person should have access to 100GJ of energy. This equates to ~ doubling our energy production today from 600 EJ/yr to 1100EJ/yr. As we look to achieve sustainability from a climate viewpoint there are many challenges and headwinds. Let's start with the challenge to deliver renewable energy at an affordable price as a low carbon emitting solution when ~85% of the population living on < $32/day remains daunting. For the next decade: a key objective of the world must be to phase out coal as a primary energy source even if this is potentially with natural gas. Steel and cement are critical to emerging economies growth. However, emissions from steel and cement account for ~ 15% of CO2 emissions today and the carbon free manufacturing of these materials remain extremely challenging. As the economic wealth increases globally, the consumption of meat is rising rapidly where 5X more meat is being eaten today vs 1960 (even though population increased 2.5X) resulting in 7GT/yr of CO2 emissions. From just these few examples, it is clear there are broad issues at play that must be addressed to make the necessary changes to sustainability. A large part of this will be the behavioral changes of wealthy economies and the investment needed in emerging economies to make low carbon primary energy affordable. This presentation will highlight these global challenges to achieve energy and climate sustainability.

Modular technologies for decentralised Power-to-X Application

Dr. Roland Dittmeyer

In order to limit global climate change, greenhouse gas emissions need to be avoided in the first place, reduced if avoiding is impossible, and compensated by taking out CO_2 from the air where both of the aforementioned don't work. Climate scientists have established that global anthropogenic greenhouse gas emissions must be decreased to net zero by about 2050 and thereafter CO_2 must be removed from the atmosphere at a scale of gigatons per year to keep the surface temperature increase within limits that may be dealt with without catastrophic consequences. Given that the world today is predominantly powered by fossil energy, this needs a massive change of technologies and infrastructures for energy supply and industrial production as well as mobility and housing in addition to behavioral changes. In that context "electrification" clearly is one of the megatrends because at point of use, electrical energy is often the most efficient among all forms of end energy. In addition, renewable power generation, most importantly from photovoltaics and wind turbines, has experienced strong cost reductions in the past, and its worldwide deployment is on a steep rise. Yet, on one hand, photovoltaics and wind energy are highly variable, and electrical energy can neither by stored in batteries in large quantities nor be transported via transmission lines over long distances to bridge a temporal mismatch of demand and supply. On the other hand, some applications such as long-distance air transport, shipping, heavy-duty road traffic, etc. call for high energy density which rules out the use of batteries there in the foreseeable future. This is where "Power-to-X" (PtX) comes into play, as a means for seasonal energy storage, long-distance energy transport, providing sustainable fuels and chemical feedstocks, and optimization of the energy system via sector coupling. From this reasoning, one can derive two types of PtX applications: One is connected to locations with high potential for renewable power generation at low cost, low population density, little local demand, and poor local infrastructure. In such a setting large dedicated plants running 24/7 at high capacity utilization due to intermediate storage are conceivable which convert renewable energy, water, and eventually CO_2 or N_2 into easily transportable chemical energy carriers, mostly for export. The other is connected to distributed power generation from renewables in regions with high population density, high local demand, and good local infrastructure. Here, smaller and more agile PtX plants are needed which are grid-connected and operated with transient load to balance local supply and demand by harvesting local excess energy.

With the aim of enabling load-flexible PtX plants, modular microstructured reactors were developed at the Institute for Micro Process Engineering over the past 5 years both for Fischer-Tropsch synthesis and methanation from lab-scale devices to prototypes for demonstration. They are based on stacked metal plates where the repeating unit accommodates a 2D micro-packed bed of a powder catalyst sandwiched between cooling plates having a patented fluid distribution channel design which enables an efficient 2D evaporation cooling pattern. The prototypes were successfully tested in PtX container plants established at KIT's Energy Lab 2.0. In addition, since a few years metal 3D printing is being evaluated for the industrial fabrication of compact reactors for Fischer-Tropsch synthesis, ammonia synthesis, and methanol synthesis as well as for compact distillation units. Two different routes are followed here: thin-walled 3D-printed structured parts as inserts for conventional pressure vessels and entirely 3D-printed devices which include a pressure-resistant shell. The presentation highlights the design principles for microstructured and 3D-printed reactors for selected applications and summarizes their status.

The presentation will further highlight the status of a new modular Power-to-Methanol process developed at the Institute for Micro Process Engineering which is based on the absorption of CO_2 from higher concentrated gas mixtures in the methanol-water product mixture resulting from CO_2-based methanol synthesis. This process can be used to upgrade biogas to e-Methanol and biomethane with favorable economics and integrates well in wastewater treatment plants.

The future direction of the chemical industry

David Purvis

The critical need to reduce carbon emissions and the disruptive shift from traditional linear towards circular value chains emphasize the importance of sustainability and resource efficiency. The impact of these changes upon a complex and well-established chemical industry is discussed and exemplified by considering the decarbonization of three major chemical intermediate technologies – Ammonia, Methanol, and Ethylene. All three technologies need low-cost clean electrical power for effective decarbonization or alternatively, in the case of ethylene, the deployment of conventional steam methane reforming for high-volume hydrogen production and carbon dioxide sequestration to circumvent the considerable electrical power demand of the ethylene units' pyrolysis furnaces. Electrical power challenges and the development of efficient CO_2 routing mechanisms are explored while considering the grid limitations and the necessity for infrastructure upgrades to support decentralized power generation. Moreover, the discourse underscores the pivotal role of economics in shaping industry practices, driving innovation, and fostering the adoption of sustainable solutions. Long-term strategies, including the development of various catalysts, advancements in electrochemistry, and the exploration of quantum sieving, to achieve a more resilient and eco-friendly chemical industry landscape. The industry's ongoing journey towards greater efficiency, innovation, and environmental stewardship allows us to attain a sustainable future.

Photo-electrolysis of water: a path for solar hydrogen

Dr. Zetian Mi

The quest for solar hydrogen production through photo-electrolysis of water emerges as a promising avenue towards realizing green hydrogen, essential for achieving clean energy goals. Solar water splitting, driven by semiconductor photocatalysts like gallium nitride (GaN), stands at the forefront, with its scalable, cost-effective manufacturing and tunable properties opening new horizons. This talk describes the recent advances of GaN-based solar water splitting, including the underlying physics, chemistry, and engineering challenges for achieving high efficiency and long-term stability. We further show that through meticulous research and innovation, the pathway toward solar hydrogen production unveils a promising trajectory toward a sustainable energy future.

Colloidal Metamaterials

Dr. Edgar Costa

The exploration of colloidal metamaterials for solar refinery applications addresses critical challenges in solar-to-hydrogen (STH) conversion, shedding light on the economic viability and practicality of various configurations of photoelectrochemical (PEC) cells. Delving into the complexities of different cell types, ranging from economically attractive yet impractical configurations to those with higher production costs, the pivotal role of real solar-to-hydrogen efficiency as an economic driver is outlined. Challenges such as limited band gaps and poor light absorption are dissected, alongside proposed solutions like multilayer metacolloids and surfactant-guided metamaterial assembly. The discussion extends to scalable bottom-up synthesis methods and experimental synthesis techniques, offering insights into the fabrication and enhancement of colloidal metamaterials. Future studies aim to explore polymeric metamaterials, self-assembled metamaterials, and process design considerations, paving the way for a comprehensive evaluation of metamaterials in PECs and their potential integration into solar refinery concepts for sustainable energy production