EDITORIAL

Solar energy and the circular economy: An introduction

MRS Energy & Sustainability links materials research with technological forecast, policy, and social change. Inspired by a large European initiative on carbon dioxide (CO₂) reduction and synthetic fuel production powered by solar energy (SUNRISE [1]), we invited papers for a special issue on circular economy. By circular economy, we simply understand the return of used material back into production, also known as “recycling”. The hierarchy of waste and waste management (compare [2]) has led to the 3R (Reduce, Reuse, and Recycle) and eventually 4R principle (Recover), which includes resource management.

In the worst case, spent material ends up in the pure environment as illegally deposited waste. Legal ways of waste disposal include adding to landfills or burning in incinerators, the latter of which will bring about heat, which can be used for district heating, and ash, which may contain valuable materials including noble metals. More sophisticated ways of waste disposal encompasses recycling methods, which, depending on the material and industry, can represent an industry of its own.

The ancient Greeks and Romans collected metal and glass, and remelted them, showing that recycling is nothing new. Likewise, circular economy is not new, as Sikdar points out [3]. The SUNRISE initiative aims to expand the technology of the circular economy toward CO₂ assimilation. This is the type of circular economy which has been demonstrated in the natural world for billions of years. This is known as carbon cycle [4] and includes one of the most fundamental processes of primary production by photosynthesis. Practically, this is the conversion of atmospheric CO₂ (and CO₂ from industrial point sources) along with water to hydrocarbon fuels (which Melvin Calvin projected as petroleum plantations [5]) and base chemicals. It also includes the production of nitrogen compounds such as ammonia [6, 7], which has its own biogeochemical cycle. The necessary energy for powering these cycles shall come from renewable sources, primarily from solar energy. Worldwide research activity on renewable energy can easily be interpreted as *circular economy* research efforts.

The contributions to this special issue serve as a snapshot of technical efforts and policy worldwide toward use of renewable energy, some of it well established and some quite novel. We hope that readers will find inspiration to further their own work or encourage the work of others to further these goals toward a circular economy fueled by solar energy.

Fermeglia et al. warn of a “storm” of food and water shortage, increased energy prices, and detrimental effects on the

environment [8], to be expected in the not too distant future unless mankind turns to renewable energy technology, which was inspired over 100 years ago by Ciamician [9]. The paper by Erat showcases one such example in the Turkish national program for the energy transition from fossil to renewable [10].

Decentralization of production facilities is part of the SUNRISE concept and addressed in the paper by Krasnolovets [11]. Lorge points out that the world economy is predominantly a thermal economy, which should be replaced by an electroprotonic economy (call it hydrogen economy) as soon as possible [12]. Aguey-Zinsou et al. clarify in their review on renewable hydrogen for the chemical industry [13] as how hydrogen, the prospective fuel of the future, has for a long time been used already in many industries. Hence, hydrogen is nothing new for many established industries.

Successful capturing of CO₂ from the air, other than by production of biomass by agriculture and forestry and ocean plankton, can help meet the goals of the Paris Agreement. Pettinari and Tombesi present two papers on the use of molecular frameworks for carbon dioxide storage [14] and carbon dioxide conversion [15]. Hernandez and Sheehan [16] present a carbon dioxide reduction technology, which can outperform the natural CO₂ assimilation of trees. The molecular mechanisms of photosynthesis, and artificial photosynthesis, as projected by Ciamician, are very difficult to expose. The principles of electrochemical conversion of hydrogen, CO₂, and nitrogen toward fuels and chemicals and their subsequent decomposition can be easily sketched in chemical reaction equations. But the exploration of the mechanistic details of the reactions taking place in reactor materials is not trivial and requires sophisticated analytical methods. Naldoni et al. provide a review of the novel *operando* and in situ analytical methods for the study of photoelectrochemical systems in this respect [17].

Plastic, a valuable industrial solid lightweight hydrocarbon with countless applications and a genuine material of the twentieth century, has come under scrutiny as not being environmentally benign. While its degradation produces mostly water and carbon dioxide—principal ingredients for the global biogeochemical cycle, degradation times can be very long in the environment. Bora reviews the biotechnological degradation of waste plastics [18].

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