2-2. Light Energy Conversion

Overview

Photochemistry can be defined as the chemistry of light energy conversion, since energy is converted through all physical and chemical processes, such as radiation (fluorescence and phosphorescence), non-radiative deactivation, energy transfer, electron transfer, bond formation and cleavage, after a substance absorbs light. However, here we will focus on solar energy conversion as a renewable energy source. As summarized in the 9 items in this section, light energy conversion is classified into 1) direct conversion to electrical energy (solar cells, etc.), 2) direct conversion to chemical energy (artificial photosynthesis), and 3) conversion to chemical energy coupled with electrical one, where the renewable energy factor (REF) is an important concept for the evaluation.

Current Status and Frontiers

Light energy conversion can be classified into 1) direct conversion to electrical energy (such as solar cells), 2) direct conversion to chemical energy (artificial photosynthesis), and 3) conversion to chemical energy couples with electrical energy, where an important concept for the evaluation is the renewable energy factor (REF) (Equation 1).

$$\mathrm{REF} = \frac{\text{Energy output (EO)}}{\text{Eneergy input (EI)}} = \frac{\eta * J}{\left[\frac{CF}{\tau} + M + T\right] + \frac{CR}{\tau'}} > 1 \qquad (1)$$

, where each parameter is defined as η (energy conversion efficiency), J (solar radiation energy), CF (energy costs for facility installation), τ (operating period), M (energy costs for maintenance), T (costs for extracting energy/transportation, etc.), CR (costs for catalysts, etc.), τ' (lifetime of catalysts, etc.).

For a light energy conversion system intended for energy storage, the energy output (EO) must be larger than or equal to the energy input (EI), leading to that REF must exceed 1. The conditions for REF > 1 (Eq. 1) are illustrated in Fig. 1.

The energy output (EO) on the vertical axis reaches its maximum value at the amount of solar radiant energy (J) (conversion efficiency of 100%). As a light energy conversion device, it must exist in the shaded area above the line REF = 1 (EO = EI). Generally, reports of high energy conversion efficiency (η) tend to attract attention, but the amount of EI must also be considered. For example, at point (**1**) in the figure, η is high, but EI is also large, so it is still in the region of REF << 1 and is regrettably meaningless as a light energy conversion system. On the other hand, at point (**2**), η is rather low, but EI is also small enough that REF > 1, indicating that it is valid as a light energy conversion system. In contrast to the above considerations of one-step light energy conversion such as 1) solar cells and 2) artificial photosynthesis, 3) in systems combining the both, for example, in two-step light energy conversion systems where light energy is converted into electrical energy using solar cells and then converted into chemical energy such as hydrogen evolution or carbon dioxide reduction using co-catalysts or molecular catalysts developed in artificial photosynthesis systems, the required condition becomes even severer, with REF >> 1 (Eq. 2).

$$\mathrm{REF}\ (\text{two-step device}) = \frac{\mathrm{EO}(2)}{\mathrm{EI}(1)+\mathrm{EI}(2)} = \frac{\eta'\mathrm{EO}(1)}{\mathrm{EI}(1)\left[1+\frac{\mathrm{EI}(2)}{\mathrm{EI}(1)}\right]} > 1. \quad \frac{\mathrm{EO}(1)}{\mathrm{EI}(1)} > \frac{1+\frac{\mathrm{EI}(2)}{\mathrm{EI}(1)}}{\eta'} \gg 1 \qquad (2)$$

, where EI(1), EI(2), EO(1), EO(2), and η' denote EI and EO of the first-stage (solar cell) and the second-stage (chemical conversion), and (chemical conversion efficiency of the second-stage (< 1). As shown in Fig. 1, the essential conditions for a two-step light energy conversion system are limited to a narrower range. In multi-step light energy conversion, where hydrogen and CO obtained in the second-stage chemical conversion undergo further chemical conversion into methanol, ammonia, etc., from the perspective of storage and utilization, the REF conditions become even severer. Even at the basic research stage, it is desirable to not only improve energy conversion efficiency but also to fully consider the REF requirements.

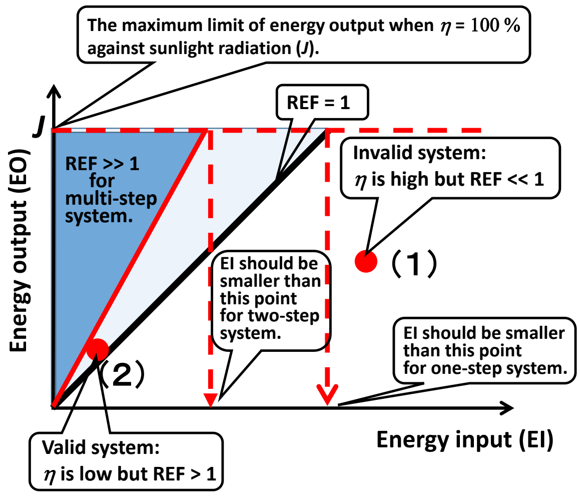

Figure 1. Renewable energy factor (REF) and feasibility assessment

Reference

1. F. Kuttassery, S. Mathew, S. N. Remello, A. Thomas, K. Sano, Y. Ohsaki, Y. Nabetani, H. Tachibana, H. Inoue, *Coordination Chem. Rev.*, **377**, 64–72 (2018).

Future Perspectives and Directions

Challenges to be resolved and realized within the next 10 years: In addition to further improving the efficiency of light energy conversion as a unit reaction process, realizing a comprehensive light energy conversion system with a renewable energy factor exceeding 1, enabling social implementation, is required.

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