Introduction—Solar to Chemical Energy Conversion

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First, let me start this introduction by briefly describing the history of the invention of the piston steam engine during the Industrial Revolution in Great Britain.

The Industrial Revolution [1] was a transition to new manufacturing processes from about 1760 to sometime between 1820 and 1840. This transition included going from hand production methods to machines and new chemical manufacturing and iron production processes. It improved the efficiency of water power, and promoted the increasing use of steam power and the development of machine tools. For the readers of this book—***Solar to Chemical Energy Conversion***, the most important aspect of the Industrial Revolution is without doubt the transition **from** "***wood and other bio-fuels***" **to** "***coal***".

The first successful piston steam engine was introduced by **Thomas Newcomen** before 1712. His steam engines were extremely inefficient by modern standards, but helped expand coal mining by allowing mines to go deeper. Despite their disadvantages, Newcomen engines were reliable and easy to maintain, and continued to be used in coalfields until the early decades of the 19th century.

A fundamental change in working principles was brought about by Scotsman **James Watt.** In close collaboration with Englishman **Matthew Boulton**, by 1778, he had succeeded in perfecting his steam engine, which incorporated a series of radical improvements (for further details, please refer to Refs. [1, 2]).

In relation to the long-term and difficult themes which this book deals with, i.e. ***Solar to Chemical Energy Conversion***, I would like to emphasize that although the first invention by Newcomen triggered the start of the transition, it was the Watt and Boulton engines that truly contributed to the Industrial Revolution. Through this example, I would like to stress that younger generations have a better chance than their predecessors to make breakthroughs to reach such a long-term achievement as solar-to-chemical energy conversion. The fact that we use Watt as the physical unit of ***power*** today surely supports this view.

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M. Sugiyama et al. (eds.), *Solar to Chemical Energy Conversion*,
Lecture Notes in Energy 32, DOI 10.1007/978-3-319-25400-5_1

Secondly, I would like to introduce the world view, ***Spaceship Earth***. This term [3] usually expresses concern over the use of limited resources available on earth and encourages humankind to act as a harmonious crew working toward the greater good. The earliest known use is mentioned in a passage in Henry George's best known work, *Progress and Poverty* (1879). After it was rephrased several times by others, the phrase was popularized by Buckminster Fuller in his book in 1968 called *Operating Manual for Spaceship Earth* [4]. This quote, referring to fossil fuels, reflects his approach:

> …we can make all of humanity successful through science's world-engulfing industrial evolution provided that we are not so foolish as to continue to exhaust in a split second of astronomical history the orderly energy savings of billions of years' energy conservation aboard our Spaceship Earth. These energy savings have been put into our Spaceship's life-regeneration-guaranteeing bank account for use only in self-starter functions.

I hope, within the next half a century or the next century at the longest, we will succeed in producing artificial fuels at reasonably low costs, by the development of the research fields discussed in this book. Examples of artificial fuels include H_2 produced from water and CH_4 and CH_3OH from CO_2 and water by utilizing solar energy at their extremely high power conversion efficiencies without the expense of fossil fuels. During the Industrial Revolution described in the beginning of this introduction, Newcomen as well as Watt and Boulton used coal mainly as the energy source of their piston steam engine. In the coming century, we will probably not be allowed to use fossil fuels anymore, regardless of whether we agree with the view proposed by Buckminster Fuller in 1968.

Thirdly, I would like to point out that a century is not long enough to make breakthroughs for such long-term research themes. To clarify the grounds for speculating the time necessary for the achievement of such long-term research goals, I would like to introduce an international conference deeply related to these long-term research themes. We called the conference "***the International Conference on Photochemical Conversion and Storage of Solar Energy (IPS)***". The conference has been held every 2 years since the first one (IPS-0) in Boston in September 1974. Fortunately, I was involved in this international conference as a member of the international organization committee from IPS-10 in 1994 to IPS-12 in 1998.

When the conference started in 1974, I was 30 years old and had just come back to the University of Tokyo from Ohio State University after a 2 year post-doctoral experience in the USA [5]. I thus had little background knowledge of why the conference was organized. Probably or hopefully the conference was motivated by: (1) oil crisis which started in 1973, (2) Nature's publication of water photolysis on TiO_2 reported by Honda and Fujishima in 1972 [6], and (3) the Spaceship Earth view written in 1968 described above.

On the occasion of the 10th International Conference (IPS-10) in 1994, the Chairman of IPS-1, Bolton, was asked to write a historical perspective [7]. In 2014, IPS-20 was held in Berlin. All the past host cities of the conference are listed on the conference website [8]. From the comparison between Bolton's historical perspective and the IPS-20 program, we can clearly see the progress made from IPS-10 in 1994 to IPS-20 in 2014. I hope someone in the present international organization committee will one day describe another historical perspective of these two decades (IPS-11–IPS-20). Only by witnessing the long-term progress made in a particular field can we envision the future prospects of that field correctly.

Finally, I would like to mention that Japan is still suffering from the 9.0 magnitude Great East Japan Earthquake which hit the Tohoku area at 14:46 on Friday March 11, 2011. A year after the disaster, a new conference "International Workshop on Solar-Chemical Energy Storage" was held in Sendai, the capital city of the Tohoku area, gathering world leading researchers of solar to chemical energy conversion. After the conference, some of the participants of the Sendai Conference saw the devastation of the earthquake during their visit to the coastal area by bus. The conference motivated the organizers to compile this book in the hope to succeed in some of the long-term difficult themes faced, through concentrated efforts to overcome the hardships caused by this serious disaster, especially energy related problems. To end, I would like to express my gratitude to the organizers of the Sendai Conference, Masakazu Sugiyama, Katsushi Fujii, and Shinichiro Nakamura for their efforts in realizing such a wonderful meeting and completing this significant book, Solar to Chemical Energy Conversion.

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