Petroleum and Coal

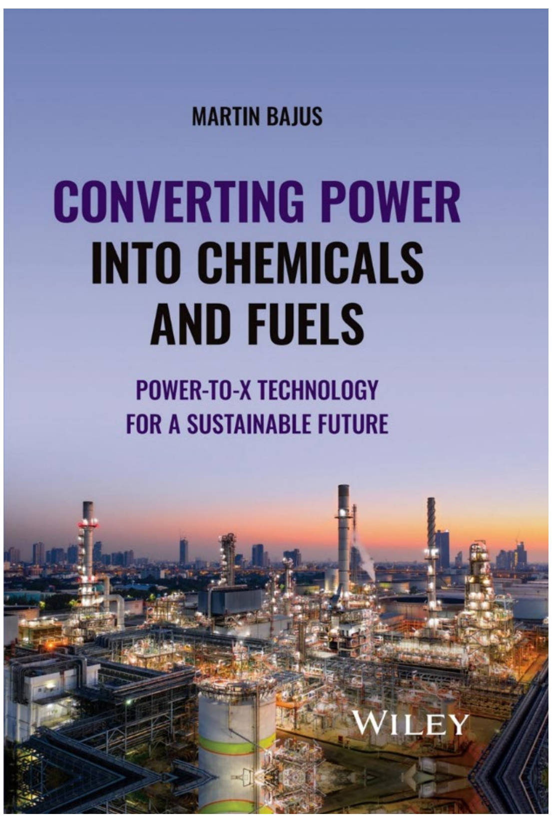
Book review

Converting Power into Chemicals and Fuels: Power-to-X Technology for a Sustainable Future

Martin Bajus

ISBN: 978-1-394-18429-3 Wiley July 2023 512 Pages

The book *Converting Power into Chemicals and Fuels: Power-to-X Technology for a Sustainable Future* concept covers the activities involved in taking surplus renewable electricity from wind, solar, water or nuclear energy and converting it into other energy carriers (the "X") to be able to store the energy for later use and absorb energy fluctuations.



This book starts with a preface containing a list of "General Literature," "Nomenclature," and "Acronyms and Abbreviations." Together with the index at the end of the book, these give a comprehensive guide to anything one is likely to encounter. The author is to be commended for his efforts in this; unfortunately, few other authors follow his example. There are numerous illustrations in black and white and other colours.

Chapter 1 covers Power-to-Chemical Technology. They are following an introduction that shows the growing importance of petrochemical engineering processes in hydrocarbon technology. This part presents the fundamentals of chemical mechanisms as the basis of those processes. The disciplines are carbon dioxide thermodynamics, water electrolysis thermodynamics, methane pyrolysis reaction thermodynamic consideration, reaction kinetics and mechanism, catalysts and reactors. The author gradually reveals potential steps towards sustainable hydrocarbon technology: vision and trends for the oil refinery—the transition from fuels to chemicals. The Technology Readiness Levels (TRL) are appropriate for estimating technological maturity. Digital transformation offers new tools that enable downstream producers to improve the yield of valuable products while reducing energy consumption and increasing throughput. The main objectives of RAM analysis are to increase system productivity, increase the overall profit and reduce the total life cycle cost, which includes lost production cost, maintenance cost, and operating cost.

The Green Shift in Power-to-Chemical Technology and Power-to-Chemical Engineering: A Framework for a Sustainable Future is explored in Chapter 2. Hydrogen is the core of Power-to-X. Heterogeneous catalysts will play essential roles in the different steps of solar refinery. Among the many valuable chemicals that can be synthesised directly from carbon dioxide, methane, methanol, higher alkanes, lower alkenes, formic acid, and formaldehyde have a strategic use in the chemical industry, either as platform chemicals and/or for the production/storage of energy. Alternatively, carbon dioxide can be directly reduced into valuable products via electrochemical reduction and renewable energy. The political and economic considerations critical to successfully transitioning to a circular economy are explored.

Where Chapter 2 explores Power-to-Chemical technology and Power-to-Chemical Engineering: a framework for a sustainable future, Chapter 3 explores storing renewable Power-to-Chemicals. Power-to-X is the next industrial revolution. Power-to-X will be a critical component of future power systems and a crucial part of the energy transition and decarbonisation. Implementing Power-to-X technology and products will allow renewable energy integration into other energy-consuming sectors. Power-to-X can be crucial in accelerating the energy transition by shifting the demand and dependency away from fossil fuels in transportation, manufacturing, chemicals, and agriculture.

Chapter 4 explores the adaptation of carbon capture, utilisation, and storage technologies. Turning renewable electrical power into something else, the X is known as Power-to-X. As energy is only generated when needed, increasing solar, wind and nuclear power will result in us generating more electricity than we use. This scenario will raise the need for energy storage, allowing Power-to-X to convert the excess energy into something else, such as gas, synthetic fuel, or ammonia, and assist in decoupling energy generation from consumption. Chapter 4 examines the linkages between carbon dioxide sources (e.g. industrial and power plants, ambient air), carbon dioxide capture processes (e.g. amine scrubbing, adsorption), and carbon dioxide utilisation (as in the processes mentioned above, thus providing a temporary carbon dioxide sink) or carbon dioxide sequestration underground (providing a permanent sink).

Chapter 5 covers integrated refinery petrochemical complexes, including Power-to-X Technologies. The focus of the closer integration between refining and petrochemical industries is to promote and seize the synergies existing opportunities between both downstream sectors to generate value for the whole crude oil production chain. The synergy between refining and petrochemical processes raises the availability of raw materials to petrochemical plants and makes the supply of energy to these processes more reliable. At the same time, it ensures better refining margins for refiners due to the high added value of petrochemical intermediates when compared with transportation fuels. The development of crude-to-chemical technologies reinforces the necessity of closer integration of refining and petrochemical assets by the brownfield refineries aiming to face the new market that tends to be focused on petrochemicals against transportation fuels. It is important to note the competitive advantage of the refiners from the Middle East, who have easy access to light crude oils, which can be easily applied in crude to chemical refineries.

Unlike other fuels, hydrogen requires more integration of fossil, nuclear, and renewable energy systems. To realise its full potential and benefits, it will take an integrated approach from all energy sectors. A vital aspect of the strategy is to enable hydrogen production from a diverse array of low-carbon domestic energy resources, including renewables, nuclear energy, and fossil fuels with CCS.

Chapter 6 focuses on Power-to-Hydrogen Technology. Hydrogen plays a crucial role in many industrial applications and is currently seen as one of the most promising energy vectors. Many efforts are being made to produce hydrogen with zero carbon dioxide footprint via water electrolysis powered by renewable energies.

Chapter 7 demonstrates how hydrogen can be used for transportation in fuel cell vehicles (FCV) but can also react with carbon dioxide to form other fuels→ Power-to-Fuels. The author presents a technical, environmental, and economic comparison of direct hydrogen use in fuel cells and the production of methane →Power-to-Methane methanol→Power-to-Methanol; and dimethyl ether→Power-to-DME for use in internal combustion engines for light-duty vehicle applications. Concerning their suitability as diesel fuels for the transport sector, the Power-to-Fuels products: dimethyl ether → Power-to-DME; oxymethylene dimethyl ether → Power-to-OME_{3-5}; and n-alkanes → Power-to-FT diesel.

Chapter 8 investigates the role of the production of light alkenes. Conversion of carbon dioxide to value-added chemicals has been a long-standing objective. Direct hydrogenation of carbon dioxide to lower olefins is highly desirable but still challenging. In this regard, copper-based catalysts and several newly reported metal-based and metal oxide-based catalysts have shown good performance in methanol synthesis from carbon dioxide hydrogenation.

Thus, the low-carbon production of aromatics is the subject of Chapter 9. In this context, the direct conversion of carbon dioxide to aromatics is particularly attractive, which reduces the demand for fossil resources in aromatics production. Although lots of progress has been made in the production of basic chemicals, like methanol, through carbon dioxide hydrogenation, the direct conversion of carbon dioxide to value-added aromatics, especially p-xylene, is still under great challenge due to the inert nature of carbon dioxide and high barrier for C-C coupling. The process of carbon dioxide hydrogenation to aromatics can be divided into two types according to different intermediates.

Chapter 10 examines the Power-to-C_1 chemicals. Using carbon dioxide does not necessarily involve developing new processes and specific processes, such as methanol synthesis and methane steam reforming. Methanol and dimethyl ether synthesis are carbon dioxide's most important heterogeneous hydrogenation reactions. Homogenous and heterogeneous hydrogenation, oxidative dehydrogenation, oxidative coupling of methane, and dry reforming of methane are reactions that are focused on in this book. Potentials and challenges are addressed, examples of our research findings are provided, and recent technological developments are discussed.

Some products obtained because of carbon dioxide reduction include methanol, formic acid, carbon monoxide, methane, ethylene, and gasoline. This chapter gives an overview of inalienably associated methodologies and outlines ongoing advancements in the improvement, design, and comprehension of carbon dioxide reduction using photochemical, biochemical, and electrochemical methods.

While previous chapters focus primarily on technological developments required of specific chemistries, these are only one crucial piece to the puzzle. In Chapter 11, Power-to-Green Chemicals, the critical role in the transition to a sustainable future is explored. Bioethylene production is based on bioethanol. Biopropylene production is a further step following bioethylene production. The production of BTX from biomass can follow several routes. As the most developed route, gasification of biomass, methanol synthesis, and methanol-to-aromatics are used.

Glycerol is a significant product derived from the oleochemistry industry. A significant excess volume of glycerol is produced through the processing of biodiesel. The supply of glycerol will increase in the coming years owing to a tremendous rise in biodiesel production globally. As the current market for glycerol is small, it cannot absorb the surplus of glycerol produced by the development of biodiesel.

Glycerol condensation with cyclic ketals and acetals is among the most promising applications of glycerol for chemical/fuel intermediates. A promising synthesis route for the tailored production of various bioderived fuel candidates, including the higher alcohol n-octanol and n-octane, as well as the higher ethers including di-n-octyl ether, ethyl octyl ether and 2-butyl tetrahydrofuran are depicted in Chapter 11.

Chapter 12 explores the industrial and small reactors that will be key to the successful transition to a circular economy. This chapter assumes a technologically neutral approach that is exible to new innovations and future challenges as they arise. Several routes a nuclear reactor may take for hydrogen production in the chemical industry depend on available reactor outlet temperature. As stated in the chapters of this book, hydrogen may be produced in many ways. The focus of this chapter is on renewable hydrogen production from water that requires only excess heat and electricity that can be produced from the thermal energy of a nuclear reactor.

Chapter 13 aims to cover the recent highlights in waste plastics pyrolysis including critical observations from the past to provide precise understanding. Consequently, the reactivities and product distributions for plastic feeds, pyrolysis reactors, roles of catalysts, and effects of operating parameters on reactivity and selectivity have been covered. Furthermore, an overview of plastic pyrolysis's kinetics and mechanistic aspects is presented, and relevant analytical techniques are discussed. The applications of pyrolysis oil as a fuel or fuel additive are in a separate section. Lastly, comparisons of existing chemical recycling technologies, summaries of commercial operations, and future projections are provided.

The author's talent, pedagogical mastery and technological experience were again demonstrated. The emphasis is on concepts rather than on facts. Hopefully, this approach will stimulate chemical engineering and those who play a significant role in the field, such as graduates and technologists who work in or are interested in chemical technology. The next generation should invent and develop novel operations and processes.

ABOUT THE AUTHOR

Martin Bajus, PhD is Professor of Chemical Technology at the Institute of Organic Chemistry, Catalysis, and Petrochemistry, Slovak University of Technology, Bratislava, Slovak Republic. He founded the Bratislava School of Pyrolysis at the Slovak University of Technology, and has published extensively on energy and petrochemical subjects.

Prof. Ing. Viktor MILATA, DrSc., Fellow IUPAC and ChemPubSoc Europe Honorary President of the Slovak Chemical Society (www.schems.sk) President of the Board of Slovak Scientific Societies of SAS (http://www.rsvs.sav.sk/) head of the Institut of Organic Chemistry, Catalysis and Petrochemistry, Faculty of Chemical and Food Technology, Slovak University of Technology Radlinskeho street 9, SK-812 37 Bratislava, SLOVAK REPUBLIC