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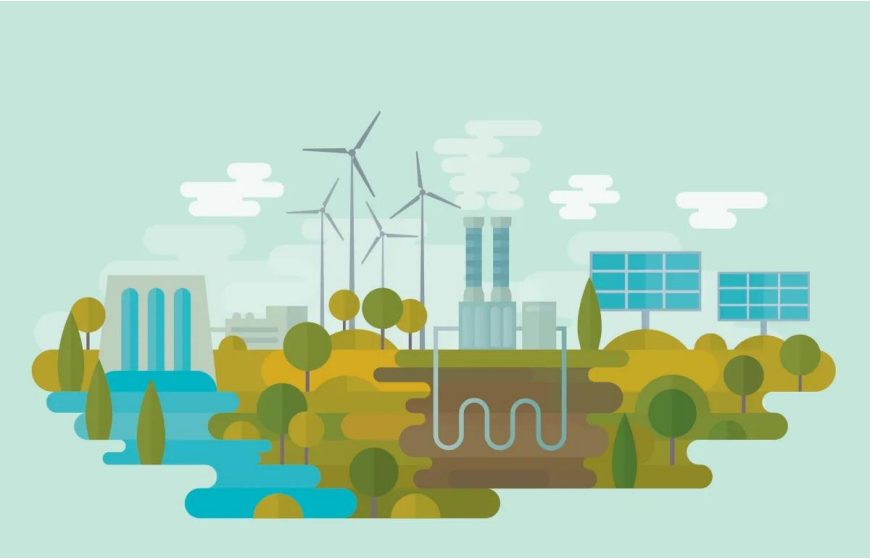
Annotated bibliography on

Clean Fuel Technologies



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Introduction:

Clean fuel technologies are becoming increasingly important as the world grapples with the urgent need to reduce greenhouse gas emissions and mitigate the impacts of climate change. These technologies are not only environmentally friendly but can also offer several other benefits. For example, renewable energy sources such as solar and wind power can be deployed in remote areas that are not connected to the grid, providing electricity to millions of people who currently lack access to reliable power (United Nations Development Programme [UNDP], 2019). Biofuels can also offer an alternative to traditional fossil fuels in the transportation sector, reducing the carbon footprint of cars, trucks, and other vehicles (International Renewable Energy Agency [IRENA], 2019). Clean fuel technologies can help to stimulate economic growth and development. For example, the development of the solar power industry has led to the creation of thousands of jobs in manufacturing, installation, and maintenance (UNDP, 2019). Similarly, the development of biofuels has the potential to create new opportunities for farmers and other rural communities, who can grow crops specifically for fuel production (IRENA, 2019).

In addition to their environmental and economic benefits, clean fuel technologies can also enhance energy security by diversifying the energy mix and reducing dependence on imported fossil fuels. For countries that are heavily reliant on imported oil and gas, investing in clean fuel technologies can help to reduce vulnerability to price shocks and supply disruptions (IEA, 2020). Clean fuel technologies are critical to achieving a sustainable, low-carbon future. By providing environmentally friendly and socially responsible solutions to our energy needs, these technologies can help to address some of the most pressing challenges of our time while creating new opportunities for economic growth and development.

The annotated bibliography aims to assist the Petroleum Research Center, and especially the Optimization of Petroleum Refinery Processes (OPRP) program by providing a list of most recent articles that cover the topic: Clean Fuel Technologies

This annotated bibliography contains articles' abstracts from 2022 – 2023.
E-resources used: Scopus – OnePetro – ACS Publications.

Contact NSTIC to request full-text articles

Articles' Abstracts

1. Al-Yaseri, A., Abu-Mahfouz, I. S., Yekeen, N., & Wolff-Boenisch, D. (2023). Organic-rich source rock/H2/brine interactions: Implications for underground hydrogen storage and methane production. *Journal of Energy Storage, 63*

Abstract: There is increasing global interest in the attainment of a carbon dioxide-free global economy by replacement of carbon-based fossil fuels with clean hydrogen. But huge volume of hydrogen needs to be stored to address the imbalance between energy demand and supply due to low volumetric energy content of H2. Underground Hydrogen Storage (UHS) is an integral part of the hydrogen economy value chain and an appealing technology for the attainment of global decarbonization. The Jordan oil shale (Upper Cretaceous, organic-rich source rock sequence) has been proposed as a promising geological storage medium for hydrogen due to its exceptionally high organic content because methane can be produced from the reaction of trapped hydrogen with the kerogen. However, the extraction of methane from kerogen during hydrogen storage in organic-rich shale has not yet been reported. In this study, pressurized hydrogen was injected into high TOC shale samples for 80 days at 1500 psi and 75 °C to assess the extent of hydrogen-rock reaction and possible methane production. We also measured H2/brine and CH4/brine interfacial tensions (IFT), as well as the contact angles of H2/brine/shale and CH4/brine/shale systems at 75 °C and varying pressure (500–1500 psi) to understand the shale-fluid interaction at subsurface conditions. Results indicate some reaction of H2 with the shale after 80 days. No hydrogen sulfide was detected from gas chromatography analysis at the end of the experiment, but traces of methane (0.018 %) were detected. The reaction between hydrogen and organic matter of the shale yielded only a little methane under the conditions investigated in this research, possibly because the experimental temperature and reaction time was insufficient for copious methane generation. Furthermore, contact angle values of CH4/brine were found to be higher than of H2/brine. This means that under geo-storage conditions, the surface becomes fully CH4-wet condition (131o-149o) but remains only intermediate-wet in the presence of the H2/brine system (94o -106o) with increasing pressure, confirming that the interaction of methane with the shale surface is higher than hydrogen-shale surface interaction at similar conditions. The opposite trend was observed for IFT values. The hydrogen/brine IFT was 69.4 mN/m at 500 psi but decreased to 67.9 mN/m at 1500 psi. Likewise, the methane/brine IFT decreased from 69.7 mN/m to 58.3 mN/m with

increasing pressure from 500 to 1500 psi. The findings of this study contribute to a better understanding of the adsorption trapping potential of organic-rich source rocks. © 2023 Elsevier Ltd

2. Appiah, E. S., Gupta, A., Nashiru, M. N., Ampong, D. N., Agyemang, F. O., & Mensah-Darkwa, K. (2023). Biowaste-based porous carbon for supercapacitors: Synthesis, fabrication and electrochemical performances: A review. *Current Materials Science, 16*(2), 121-142.

Abstract: The development of low-cost, high-efficiency electrode materials for supercapacitors is motivated by the growing need for green and affordable clean energy (SDG goal 7). Developing new energy conversion and storage technologies, such as supercapacitors, batteries, and fuel cells, is a viable option for meeting energy demands while addressing environmental concerns. Recent advances in carbonaceous materials derived from biowaste for supercapacitor applications have piqued the interest of academics and industry alike. Because of their large surface area and porous structure, activated carbon-based electrode materials can be used in various applications, including supercapacitors, fuel cells, and batteries. Carbonaceous materials such as carbon nano-tubes, graphene, and activated carbon, exhibit EDLC-like behavior mainly due to ion adsorption at the electrode interface. In recent years, several potential strategies for the synthesis and structural architecture of biowaste-derived porous carbons have been tested with varying degrees of success. Thus, it is critical to evaluate the prospects for biowaste-derived porous carbon materials used as supercapacitor electrodes. In this review, we highlight how different biowaste-derived porous carbons affect the surface properties of carbon nanostructures and how this phenomenon affects their electrochemical per-formance. Additionally, the extent to which various biowastes have been utilized as porous carbon for supercapacitor electrodes is addressed. The different synthesis techniques, such as hydrothermal carbonization, physical activation, chemical activation, and microwave-assisted activa-tion, are briefly described in this review. Finally, we highlight fabrication techniques as well as electrochemical performance measurements such as CV, GCD, EIS, energy density, and power density. © 2023 Bentham Science Publishers.

3. Cui, P., Zhao, L., Long, Y., Dai, L., & Hu, C. (2023). Carbon-based electrocatalysts for acidic oxygen reduction reaction. *Angewandte Chemie - International Edition*, *62*(14).

Abstract: Oxygen reduction reaction (ORR) is vital for clean and renewable energy technologies, which require no fossil fuel but catalysts. Platinum (Pt) is the best-known catalyst for ORR. However, its high cost and scarcity have severely hindered renewable energy devices (e.g., fuel cells) for large-scale applications. Recent breakthroughs in carbon-based metal-free electrochemical catalysts (C-MFECs) show great potential for earth-abundant carbon materials as low-cost metal-free electrocatalysts towards ORR in acidic media. This article provides a focused, but critical review on C-MFECs for ORR in acidic media with an emphasis on advances in the structure design and synthesis, fundamental understanding of the structure-property relationship and electrocatalytic mechanisms, and their applications in proton exchange membrane fuel cells. Current challenges and future perspectives in this emerging field are also discussed. © 2023 Wiley-VCH GmbH.

4. Eyitayo, S. I., Watson, M. C., Kolawole, O., Xu, P., Bruant, R., & Henthorne, L. (2023). Produced water treatment: Review of technological advancement in hydrocarbon recovery processes, well stimulation, and permanent disposal wells. *SPE Production & Operations*, *38*(01), 51-62.

Abstract: Produced water (PW) is the most significant waste product in oil and gas exploitation, and numerous challenges are associated with its treatment. For over half a century, PW treatment and handling have evolved from a waste product to a reusable stream for the petroleum industry. PW is reused and recycled for hydrocarbon recovery processes, well completion, stimulation, drilling, etc. Despite this usage, enormous volumes are still required to be disposed of in the subsurface aquifers or surface water bodies after treatment. Challenges to PW treatment are related mainly to widely varying PW characteristics, nonuniformity of water treatment systems for different fields, and difficulty in designing novel technology due to changing production rates and other design parameters. This paper focuses on purpose-specific water treatment units used in various activities within the oil and gas industries and technological advancement. A detailed account of the historical development of current water treatment practices, disposal, available

technology, and challenges in implementation are presented. Forward-looking recommendations are given on how emerging technologies can be integrated into everyday oil and gas activities to achieve the purpose-specific treatment goal.

5. Gao, R., Zhang, L., Wang, L., Zhang, C., Jun, K. -., Ki Kim, S., . . . Guan, G. (2023). Conceptual design of full carbon upcycling of CO2 into clean DME fuel: Techno-economic assessment and process optimization. *Fuel, 344*

Abstract: To achieve efficient utilization of CO2 and produce clean alternative fuel, nowadays, CO2-to-DME (CTD) technology is regarded as a feasible and promising solution. Considering that there is no consensus on the techno-economic performances of the different CTD processes, it is necessary to conduct a comprehensive and systematic comparison of the existing and emerging CTD technologies and to deeply explore the influence of the process integration on technical feasibility and economic profitability. In this study, we proposed four CTD processes via different routes, namely purified methanol-mediated (Case 1), water-containing methanol-mediated (Case 2), CO-mediated (Case 3) and direct CO2 hydrogenation routes (Case 4). The rigorous system modelling and comprehensive comparison of the process performances of four cases were implemented. From the technical perspective, Case 4 has the highest energy efficiency (77.42%), exergy efficiency (88.46%), and net CO2 mitigation rate (67.71%). From the economic perspective, Case 2 has the lowest total product cost (1327.14 $/tonne DME), whereas Case 4 has the lowest net CO2 mitigation cost (589.34 $/tonne CO2). Moreover, to further enhance the system performance of Case 4, we also proposed effective improvement measures for process optimization, which shows that the net CO2 mitigation rate is enhanced by 1.94%, while the net CO2 mitigation cost is reduced by 19.79 $/tonne CO2. © 2023 Elsevier Ltd

6. Gautam, R., Nayak, J. K., Ress, N. V., Steinberger-Wilckens, R., & Ghosh, U. K. (2023). Bio-hydrogen production through microbial electrolysis cell: Structural components and influencing factors. *Chemical Engineering Journal, 455* .

Abstract: Microbial electrolysis cell (MEC) is a significantly sustainable bio-electrochemical system for biological hydrogen production. MEC is also regarded as an environmentally friendly

method for producing clean biohydrogen from a variety of waste organic matters and for its low greenhouse gas emissions. This technology involves the oxidation of organic matter at the anode and the reduction of proton at the cathode under the nominal external voltage supply. However, bio-hydrogen production efficiency and operating costs of MEC still need further optimization to implement in large-scale applications. For optimization, a detailed explanation of MEC components and major operational parameters should be available. This review discusses the principle, main components, and major operational parameters of MEC for significant performance. It also provides a brief overview of types of MECs, reactor configuration, and their advantages. Thermodynamically important aspects of the MEC for efficient performance are also discussed. It also conferred the critical structural components which are essential for the functioning MECs. Furthermore the performance evaluating parameters and indices for the biohydrogen yield and MEC performance are also addressed. Additionally, crucial influencing factors that affect the MEC performance such as microorganism, methanogens and their inhibition, various electrode materials, membranes and different substrates are also discussed. Afterwards needs and challenges for future development of the MEC technology are highlighted and suggested. The review aims to put forward the fundamental understandings of MEC technology to the research fraternity for further advancement for the large-scale applications.

7. Ghodke, P. K., Sharma, A. K., Jayaseelan, A., & Gopinath, K. P. (2023). Hydrogen-rich syngas production from the lignocellulosic biomass by catalytic gasification: A state of art review on advance technologies, economic challenges, and future prospectus. *Fuel, 342*.

Abstract: Global population growth, modernization, and industrialization have all significantly increased energy consumption, which has worsened the climate and led to greenhouse gas emissions, forcing researchers to look into eco-friendly, renewable, and sustainable energy sources. Hydrogen (H2) is emerging as one of the cleanest and most carbon-free future energy carriers generated from diverse domestic resources, organic wastes, lignocellulosic biomass, natural gas, and fossil fuels by biochemical and thermochemical routes. Applying thermochemical routes, lignocellulosic biomass for sustainable H2 production have shown great potential for industrial implementation. As a result, the current study emphasizes the state-of-the-art review of

developments in gasification technologies, operating circumstances, and catalysts employed for producing H2-rich syngas. Emerging catalytic technologies to improve H2-rich syngas production were discussed in detail. New technologies including, solar gasification, microwave gasification, plasma gasification, and integrated pyrolysis-gasification were also highlighted. Finally, the prospects and challenges of the process are also pointed out in brief to assist future researchers and stakeholders working for its commercialization. © 2023

8. Ghosh, K., Iffelsberger, C., Konečný, M., Vyskočil, J., Michalička, J., & Pumera, M. (2023). Nanoarchitectonics of triboelectric nanogenerator for conversion of abundant mechanical energy to green hydrogen. *Advanced Energy Materials, 13*(11)

Abstract: In the present world, the high energy demand rapidly depletes existing fossil fuel reserves, urging the necessity to harvest energy from clean and renewable resources. In this study, the use of a triboelectric nanogenerator (TENG) is shown beyond the conventional practice of use in self-powered electronics, to the production of green hydrogen from renewable mechanical energy. For the first time the use of a magnetic covalent organic framework composite as positive triboelectric material for a contact-separation mode TENG (CS-TENG) in which MXene incorporated polydimethylsiloxane (PDMS) film serves as negative triboelectric material, is demonstrated. A facile way of incorporating micropatterns on the surface of PDMS/MXene film is shown utilizing the advantages of 3D printing technology. The CS-TENG harvests energy from simple mechanical actions such as human handclapping and toe-tapping. The energy from such low-scale mechanical actions is applied for water electrolysis. Scanning electrochemical microscopy is employed to confirm the evolution of hydrogen and oxygen by the harvested electrical energy from mechanical actions. This research is expected to pave the way for producing green hydrogen anywhere, by utilizing the mechanical energy from nature such as raindrops, wind, and the movement of vehicles. © 2023 The Authors. Advanced Energy Materials published by Wiley-VCH GmbH.

9. Khan, H., Tanveer, M., Park, C. W., & Kim, G. M. (2023). Producing micro-power with microfluidic enzymatic biofuel cells: A comprehensive review. *International Journal of Precision Engineering and Manufacturing - Green Technology, 10*(2), 587-609.

Abstract: Enzymatic biofuel cells (EBFCs) use enzymes as biocatalysts to produce clean energy. They have attracted much attention owing to several interesting features, such as the use of cheap and renewable biocatalysts, utilization of abundantly available high-energy–density biofuels, and their capability to operate under mild temperature and pH conditions. The integration of EBFCs into microfluidic architecture enables their application as small-scale power sources for portable, implantable, and wearable microelectronics. However, despite extensive research over the last two decades, this technology is still in the early stages of development owing to critical challenges, such as inefficient fuel oxidation, short lifetimes, and limited power density. This review paper broadly discusses various attributes of microfluidic EBFCs, focusing on the different microfabrication techniques employed to date because miniaturization is considered a promising approach for developing this technology. A short history and evolution of EBFCs are presented, after which fundamentals of the chemistry of EBFCs are briefly discussed to clarify the basic terms. In addition, various microfabrication techniques for manufacturing microfluidic EBFCs, which have been practiced over the last two decades, are reviewed thoroughly and compared according to resolution quality, fabrication convenience, and cost-effectiveness. Furthermore, potential applications of EBFCs and various obstacles to the realization of these applications are reviewed. Finally, the key challenges in producing practical and commercialized EBFCs and different approaches to overcome these challenges are discussed. This review article provides insight into the past, present, and future of this rapidly emerging microscale EBFC-based green technology.

10. Khawaja, A. S., Zaheer, M. A., Ahmad, A., Mirani, A. A., & Ali, Z. (2023). Advances in limitations and opportunities of clean biofuel production to promote decarbonization. *Fuel, 342*.

Abstract: Factors such as higher fuel prices, limited and geologically posited fossil fuel resources along with the impact of fossil fuels on global warming are highly unsustainable for growing economies around the globe. For this reason, an unconventional sustainable energy root is desired. In recent years, biodiesel has gained much consideration because of its similar combustion properties like fossil fuels and its synthesis from edible and non-edible oils via a catalytic process. Various catalysts (homogeneous and heterogeneous in nature) have been investigated for sustainable and green production of biodiesel. The heterogeneous catalyst calcium oxide is an abundant, cheap and has a high activity for transesterification reaction. The review provides that there is strong need to focus on exploring the continuous heterogeneous nanoscale calcium oxide catalyst to improve the efficiency and cost-effectiveness biodiesel production technology. Calcium oxide catalytic activity can be improved by nanotechnology approach. This approach helps in the production of suitable catalyst at a low cost, minimizes the waste, and results in higher activity and selectivity for desired reaction. This study provides an overview on the literature existing on the preparation of nanosized-Calcium oxide (CaO), utilization for conversion of ester into biodiesel along, advantages over other heterogeneous catalysts and importance as a future catalyst for the production of biodiesel.

11. Larimi, A., Parlett, C. M. A., & Jiang, Z. (2023). Editorial—special issue “catalysis for sustainable hydrogen production”. *Materials Today Chemistry, 29*

Abstract: Given the finite nature of fossil fuel resources and the negative environmental impact of their combustion during energy production, a global transition to sustainable and renewable energy carriers which encompass a circular economy model is one of today's most pressing issues. Hydrogen represents a promising option, with industrial and academic attention shifting to sustainable H2 production, particularly via the catalytic conversion of inexpensive renewable feedstocks such as biomass, waste materials, and water. While this current stimulus has increased understanding, some key challenges still exist. If hydrogen production technologies are to become commercialized, their economics and efficiencies require improvements. In this regard, catalysts play a critical role at the heart of these processes, and therefore, developing inexpensive catalysts with high stability, selectivity, and activity are of extreme importance. Understanding the synthesis and behavior of these catalysts, coupled with elucidating structure–activity correlations, at the

atomic and molecular scale, is crucial to further developments and is the focus of ongoing research. This Special Issue provides a collection of high-quality full articles and comprehensive reviews on a diverse range of topics, which include photo (electro) catalytic water splitting, reforming and decomposition of oxygenated hydrocarbons and pyrolysis of plastics for sustainable hydrogen production. Authors from Australia, Belgium, Brazil, China, Cyprus, France, Germany, India, Iran, Italy, Japan, Kuwait, Portugal, Singapore, South Korea, and the United Kingdom contributed to the publications within this Special Issue, for which the Editors are grateful for their valuable contributions.

12. Li, H., Zhang, H., Liu, W., Huang, J., Lu, K., Shi, J., . . . Liu, M. (2023). Experimental demonstration of photocatalytic hydrogen production in series with a hydrogen fuel cell. *Journal of Chemical Education*, *100*(3), 1404-1409.

Abstract: In recent years, solar-powered photocatalytic water splitting for hydrogen production has drawn great attention as a method to supply clean energy and reduce environmental pollution. This approach, driven by solar energy to synthesize hydrogen gas, is completely renewable and can be used to power hydrogen fuel cells to effectively solve the global energy problem, while only releasing environmentally benign water. Accordingly, popularizing this subject and educating students with the knowledge of this powerful technology are urgently needed. In this paper, Pt-loaded commercial titanium dioxide (P25) is used as the photocatalyst to explore the process of photocatalytic hydrogen evolution. A simple experimental demonstration is presented, integrating photocatalytic hydrogen production with a hydrogen fuel cell system in chemistry class. This experiment is suitable for use with undergraduate students as a systematic and basic laboratory experience or as a demonstration for primary/middle/high school students to stimulate their research interests in field of renewable energy. The principles and reaction mechanisms involved in both photocatalytic water splitting and hydrogen fuel cell operation, as well as the experimental design to link photocatalysis with fuel cells, are systematically discussed.; In recent years, solar-powered photocatalytic water splitting for hydrogen production has drawn great attention as a method to supply clean energy and reduce environmental pollution. This approach, driven by solar energy to synthesize hydrogen gas, is completely renewable and can be used to power hydrogen fuel cells to effectively solve the global energy problem, while only releasing environmentally

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13. Li, S., Zhang, Z., Li, G., & Bai, S. (2023). Influence of off gas recirculation on the intermediate temperature SOFC with partial oxidation reformer. *Journal of Electrochemical Energy Conversion and Storage, 20*(3)

Abstract: Solid oxide fuel cell (SOFC) is a clean and efficient energy utilization technology. Partial oxidation reforming (POX) can be used to simplify the SOFC system structure, but its lower hydrogen production rate deteriorates the system performance. A wise method may be combining anode off gas recirculation (AOGR) and cathode off gas recirculation (COGR) with POX. Thus, their influence on the coupled system of intermediate temperature SOFC and POX is researched in detail in this paper. Results show that the reforming process gradually changes from exothermic to endothermic as AOGR rate increases. Meanwhile, its oxygen demand declines sharply and the process can even be self-sustained without external air input at the AOGR rate of 0.5 and 0.6. The application of AOGR can improve electrical efficiency by up to 51%, but at the expense of thermal efficiency. Excessive AOGR rates will result in decreased cell voltage and insufficient energy supply to the after-burner, so it should be restricted within a reasonable range and the best recommended value is 0.5. The application of COGR has little effect on fuel line parameters, so it causes little deterioration in electrical efficiency while improving thermal efficiency. Besides, the cell voltage is also insensitive to it. The combination of AOGR and COGR can obtain better fuel economy and larger cogeneration scale simultaneously at the cost of a tiny electrical output power,

while an optimal balance between three efficiencies is also achieved.

14. Tetteh, D. A., & Salehi, S. (2023). The blue hydrogen economy: A promising option for the nearto- mid-term energy transition. *Journal of Energy Resources Technology, Transactions of the ASME, 145*(4).

Abstract: Hydrogen is recently being promoted immensely as the primary energy carrier to replace fossil fuels for the envisioned environmentally friendly and sustainable future energy system, given its peculiar properties and advantages over conventional fuels and other alternative energy sources. Hydrogen is classified into various color categories based on the type of feedstock, technology, and CO2 emissions in its production pathway. This paper focuses on blue hydrogen, discussing its potential as the most promising hydrogen production pathway for the near-to-mid-term transition into a hydrogen economy. First, a comprehensive overview of the hydrogen economy is given with a detailed description of hydrogen's color-code categorization. Blue hydrogen production methods are explained, and blue and green hydrogen are compared on the subject of the grand energy transition. Furthermore, the arguments favoring blue hydrogen as the most promising alternative for the near-to-mid-term energy transition are explained. Finally, a comparative life cycle analysis (LCA) of environmental emissions and resource usage in blue hydrogen and other selected commonly used fuel production pathways is conducted using the greenhouse gases, regulated emissions, and energy use in technologies (GREET) model to analyze the potentials of the blue hydrogen production pathway. The LCA results showed that more efforts need to be committed to reducing nitrous and sulfur oxides in the blue hydrogen production pathway and improving energy and CO2 capturing efficiencies in carbon capture and storage (CCS) plants. © 2022 by ASME.

15. Wang, D., Chen, C., Sun, J., Ao, H., Xiao, W., Ju, H., & Wu, J. (2022). Refillable fuel-loading microshell motors for persistent motion in a fuel-free environment. *ACS Applied Materials & Interfaces, 14*(23), 27074-27082.

Abstract: Artificial micro-/nanomotors that harvest environmental energy to move require energy surroundings; thus, their motion generally occurs in fuel solutions or under the real-time stimuli of external energy sources. Herein, inspired by vehicles, a refillable fuel-loading micromotor is proposed based on a 2 μm hemispherical multimetallic shell using catalase or platinum on its concave surface as the engine and the bowl structure as the fuel tank. H2O2 fuel is drawn into the microbowl by capillary action and restricted inside the bowl space through a self-generated O2 bubble cap on the microshell mouth. The periodic growth and burst of the O2 cap cause the enhanced diffusion motion of micromotors. This motion behavior can last for at least 30 min in a fuel-free environment with one H2O2 fueling. Additionally, the micromotor can be refilled repeatedly to achieve permanent motion. This demonstration of a refillable fuel-loading micromotor provides a model design of an energy built-in micromotor.; Artificial micro-/nanomotors that harvest environmental energy to move require energy surroundings; thus, their motion generally occurs in fuel solutions or under the real-time stimuli of external energy sources. Herein, inspired by vehicles, a refillable fuel-loading micromotor is proposed based on a 2 μm hemispherical multimetallic shell using catalase or platinum on its concave surface as the engine and the bowl structure as the fuel tank. H2O2 fuel is drawn into the microbowl by capillary action and restricted inside the bowl space through a self-generated O2 bubble cap on the microshell mouth. The periodic growth and burst of the O2 cap cause the enhanced diffusion motion of micromotors. This motion behavior can last for at least 30 min in a fuel-free environment with one H2O2 fueling. Additionally, the micromotor can be refilled repeatedly to achieve permanent motion. This demonstration of a refillable fuel-loading micromotor provides a model design of an energy built-in micromotor.

16. Zhang, F., Wang, S., Duan, Y., Chen, W., Li, Z., & Li, Y. (2023). Thermodynamic assessment of hydrothermal combustion assisted fossil fuel in-situ gasification in the context of sustainable development. *Fuel, 335*

Abstract: Developing countries cannot get rid of the fate of relying on fossil energy development in the short term, so the low-carbon transformation must be carried out in the development process to achieve the goal of net zero emissions. This work proposed a novel hydrothermal combustion assisted fossil fuel in-situ gasification (HC-ISG) system combining renewable energy,

supercritical hydrothermal combustion technology and supercritical water gasification technology. The system has the advantages of high thermal efficiency, high hydrogen yield, carbon dioxide utilization and storage, and landfill of hazardous waste. Firstly, based on the concept of energy grade, the effects of renewable energy and auxiliary fuel on the characteristics of energy grade change in HC-ISG system is studied. Then, the Gibbs free energy minimization method is conducted to discuss the effects of fossil fuels, oxidants, sub- and supercritical water on the key parameters of the system. The results indicated that for HC-ISG system, the energy grade and input amount of renewable energy have the optimal values. Compared with coke and methane, the system with methanol as an auxiliary fuel for hydrothermal combustion owned better the matching between energy quantity and energy grade. Moreover, increasing the reaction temperature could reduce the exergy destruction of the system and increase the energy grade change of the input energy. When the combustion coefficient was 0.2–0.3, the molar fraction of H2 reached the maximum value. When fossil fuel with high carbon content was used, the maximum H2 yield could reach 89.4 mol/kg, and the carbon emission was 3.9 kg CO2/kg H2, so the HC-ISG system could produce clean hydrogen. The system proposed in this study may provide a promising method for efficient and low-carbon in-situ conversion of fossil energy to hydrogen production. © 2022 Elsevier Ltd

17. Zhi, K., Li, Z., Wang, B., Klemeš, J. J., & Guo, L. (2023). A review of CO2 utilization and emissions reduction: From the perspective of the chemical engineering. *Process Safety and Environmental Protection, 172*, 681-699.

Abstract: CO2 utilization can not only control greenhouse gas emissions but also provide renewable clean energy. CO2 utilization technology is an important technology to control carbon emissions. This work provides a review of CO2 utilization and emissions reduction technology which can provide important theory and a key technology for various applications enhancing cleaner production and carbon emissions reduction. This paper reviews the different areas of CO2 utilization and emissions reduction technology to show the developing timeline and trend of some technology, application scenarios, and development status. The review focuses on photocatalytic technology, synthetic liquid fuel technology, synthetic gas fuel technology, and amine synthesis technology for reducing carbon emissions from the perspective of chemical engineering. Some

classic diagrams of key technologies are illustrated, and their characteristics are analyzed. The future direction and potential of chemical engineering include the consideration of feasibility and security in the CO2 emission reduction in a longer period and conclusions made. The efficient use of sustainable energy and the assessment of security risks to human beings are also important areas to be tackled. © 2023 The Institution of Chemical Engineers

18. Song, C. H. (2023). Examining the patent landscape of E-fuel technology. *Energies, 16*(5).

Abstract: Although the end of combustion engine vehicles seems inevitable under a new climate target for 2030, a complete ban on the combustion engine would be counterproductive. E-fuels, which are produced using renewable electricity from hydrogen and carbon dioxide, could act as a possible large-scale solution for achieving climate-neutral mobility, as they allow us to reduce greenhouse gas emissions while leveraging the existing energy infrastructure. Against such a background, it is critical to examine how the related technological landscape is constructed and might affect the subsequent knowledge generation. By adopting a social-network perspective, the aim of this study is to investigate the degree of technological knowledge relatedness of e-fuel technology using patent data. This is accomplished by analyzing the influence of individual knowledge areas and categorizing them into a matrix model, with each quadrant playing a unique role. The main findings show that the patent landscape is dominated by applications from the private sector, and the main knowledge base is centered around chemical engineering and production techniques for liquid hydrocarbon mixture. Furthermore, the analyzed knowledge flows are dominated by intra-technology knowledge flows, thereby being less prone to convergent technology evolution. In particular, the knowledge areas C10L 01 and C10J 03 demonstrated a high influencer role. The findings can also support R&D advisors and decision makers in policy development in reducing their efforts required for conducting technical intelligence activities and determining adequate policies for R&D portfolio management. © 2023 by the author.

19. Li, X., Raorane, C. J., Xia, C., Wu, Y., Tran, T. K. N., & Khademi, T. (2023). Latest approaches on green hydrogen as a potential source of renewable energy towards sustainable energy: Spotlighting of recent innovations, challenges, and future insights. *Fuel, 334*

Abstract: Today, the generation of carbon-neutral hydrogen from renewable energy can be considered a significant achievement toward a circular bioeconomy in this industry. In contrast, carbon production is rising globally, with energy-related carbon emissions accounting for two-thirds of global emissions. Now, an energy factor is required to mitigate the correlation between economic growth and rising carbon emissions. This is where green hydrogen generation can enter the renewable energy equation. Hydrogen can contribute to reducing gas emissions in the coming decades, not only as a potential technology for the future but also as a successful technology already being implemented globally. This review aims to contribute to reducing greenhouse gas emissions, including carbon, by examining the possible pathways to a hydrogen-capable clean energy future. To this end, this article has challenged a deeper perspective on the relationship between hydrogen as a green fuel and renewable energy, as well as the economics of hydrogen supply considering the steadily declining costs of renewables and the role of hydrogen in energy transport as well as provides strategic considerations and applications. © 2022 Elsevier Ltd

20. Pocha, C. K. R., Chia, W. Y., Silvanir, Kurniawan, T. A., Khoo, K. S., & Chew, K. W. (2023). Thermochemical conversion of different biomass feedstocks into hydrogen for power plant electricity generation. *Fuel, 340*

Abstract: Most hydrogen production technologies are dependent on non-renewable resources, which are not sustainable in the long run. However, H2 can be produced in the future from renewable sources, becoming one of the cleanest energy carriers. Compared to other biomass treatment methods, the thermochemical pathways from biomass for sustainable H2 generation offers a considerable promise for its industrial use. The most studied routes are biomass gasification and reformation of the bio-oil generated by biomass pyrolysis, while some works on supercritical water gasification and bio-oil gasification are extensively developed to improve hydorgen production efficiency. This review discusses the most current developments in research

on the methods of pyrolysis, gasification, steam reformation, and microwave-induced plasma for producing hydrogen from various types of biomasses, including lignocellulosic and woody biomasses. By utilizing the hydrogen produced from biomass, possibilities of creating a sustainable city were analyzed. There are many upgraded technologies to generate electricity using hydrogen produced from biomass such as gas turbines, combined cycle power plants, and fuel cells. The environmental feasibility of hydrogen usage was also evaluated, along with the status quo of hydrogen power plants in several countries. This review contributes to the large-scale implementation of hydrogen energy with in-depth discussion on the latest development. © 2023 Elsevier Ltd

21. Sarfraz, B., Bashir, I., & Rauf, A. (2023). CuS/NiFe-LDH/NF as a bifunctional electrocatalyst for hydrogen evolution (HER) and oxygen evolution reactions (OER). *Fuel, 337*

Abstract: Increasing energy demands have motivated scientists to work out affordable, clean, and renewable energy technologies to replace conventional fossil fuels. Among different energy resources, hydrogen energy produced by electrochemical water splitting is gaining more attention. One electrocatalyst for both oxygen evolution reaction (OER) and hydrogen evolution reaction (HER) is the greatest challenge in the field of electrochemical water splitting. NiFe-LDH has been widely investigated for OER but shows poor performance for HER and overall water splitting (OWS). We have explored the enhanced electrochemical activities by depositing CuS particles on NiFe-LDH. The prepared CuS/NiFe-LDH/NF electrocatalyst requires an overpotential of only 55 mV to achieve the current density of 10 mA cm−2 in case of hydrogen evolution reaction (HER) which is close to the ideal noble metal catalyst (Pt/C 33 mV for 10 mA cm−2). While in the case of OER, CuS/NiFe-LDH shows an overpotential of 170 mV to deliver a current density of 10 mA cm−2. More importantly, CuS/NiFe-LDH/NF composite can act as an excellent bifunctional electrocatalyst for HER and OER. To achieve the current density of 10 mA cm−2 in the overall water splitting process, CuS/NiFe-LDH/NF cell voltage is 1.517 V. The prepared electrocatalyst also showed good stability for 72 h' time. The composite formation of CuS with NiFe-LDH opens a new way of boosting the electrochemical activity of water splitting. © 2022 Elsevier Ltd

22. Fan, X., Li, D., Cui, L., Chang, C., Yan, L., & Yang, B. (2022). Study on the preparation of clean liquid fuel by wide fraction high-temperature coal tar deep hydro-upgrading on a pilot plant trickle bed reactor. *ACS Omega*, *7*(51), 48163-48172.

Abstract: High-temperature coal tar contains a high content of heavy components, and the mechanism of its hydrogenation to fuel oil has not been completely revealed at present. In this work, clean environmental friendly fuel oil was obtained from wide fraction high-temperature coal tar (WHTCT) hydrotreated in a three-stage continuous pilot-scale trickle bed reactor filled with commercial catalysts. The effect of reaction temperature (345–405 °C), reaction pressure (10–18 MPa), and LHSV (0.2–0.4 h–1) on the product properties was investigated while the hydrogen/oil ratio remained constant (2000:1). Simultaneously, four lumped kinetic models were established to study the effects of reaction conditions on each component and interconversion between them. The results showed that the increase in temperature and pressure and the decrease in LHSV can effectively improve the quality of products. Under the reaction conditions of a temperature of 390 °C, a pressure of 16 MPa, an LHSV of 0.25 h–1, and a hydrogen/oil ratio of 2000:1, the S and N in the feedstocks can be reduced from 4600 and 6800 μg/g to 24.06 and 14.32 μg/g in the products, respectively. So WHTCT can be used as a suitable feed to obtain gasoline and low-freezing point diesel blending components through hydrogenation. Tail oil (TO) can easily be converted into diesel fraction (DF) and gasoline fraction (GF) with high selectivity. DF can be converted into GF only at higher temperatures, and GF hardly undergoes cracking to gas. The established kinetic model can accurately predict the content of TO, DF, GF, and gas of the products. Therefore, the results can provide a certain valuable reference for further development of industrial applications.; High-temperature coal tar contains a high content of heavy components, and the mechanism of its hydrogenation to fuel oil has not been completely revealed at present. In this work, clean environmental friendly fuel oil was obtained from wide fraction high-temperature coal tar (WHTCT) hydrotreated in a three-stage continuous pilot-scale trickle bed reactor filled with commercial catalysts. The effect of reaction temperature (345–405 °C), reaction pressure (10–18 MPa), and LHSV (0.2–0.4 h–1) on the product properties was investigated while the hydrogen/oil ratio remained constant (2000:1). Simultaneously, four lumped kinetic models were established to study the effects of reaction conditions on each component and interconversion between them. The results showed that the increase in temperature and pressure and the decrease in LHSV can effectively improve the quality of products. Under the reaction conditions of a temperature of 390

°C, a pressure of 16 MPa, an LHSV of 0.25 h–1, and a hydrogen/oil ratio of 2000:1, the S and N in the feedstocks can be reduced from 4600 and 6800 μg/g to 24.06 and 14.32 μg/g in the products, respectively. So WHTCT can be used as a suitable feed to obtain gasoline and low-freezing point diesel blending components through hydrogenation. Tail oil (TO) can easily be converted into diesel fraction (DF) and gasoline fraction (GF) with high selectivity. DF can be converted into GF only at higher temperatures, and GF hardly undergoes cracking to gas. The established kinetic model can accurately predict the content of TO, DF, GF, and gas of the products. Therefore, the results can provide a certain valuable reference for further development of industrial applications.

23. Jiang, J., Xie, K., Liu, Y., Sun, H., Yang, W., & Yang, H. (2022). Hydrogen production technology promotes the analysis and prospect of the hydrogen fuel cell vehicles development under the background of carbon peak and carbon neutrality in china. *ACS Omega, 7*(45), 40625-40637.

Abstract: Hydrogen fuel cell vehicles have always been regarded as the main direction for developing new energy vehicles in the future due to their advantages of zero emission, high cruising range, and strong environmental adaptability. Currently, although the related technologies have gradually matured, there are still many factors hindering its development. One of the main reasons is that the price of hydrogen fuel increases the cost of using vehicles, which puts it at a competitive disadvantage compared with traditional fuel vehicles and pure electric vehicles. Herein, we summarize the recent development status of hydrogen fuel cell vehicles at home and abroad, and analyze the cost and sustainability brought by the latest scientific research progress to the hydrogen production industry, which is derived from basic research on electrocatalysts used in industrial electrocatalytic water splitting with an alkaline electrolyte. Finally, the development of hydrogen fuel cell vehicles was analyzed and prospected, which is one of the main application fields of hydrogen in the future.; Hydrogen fuel cell vehicles have always been regarded as the main direction for developing new energy vehicles in the future due to their advantages of zero emission, high cruising range, and strong environmental adaptability. Currently, although the related technologies have gradually matured, there are still many factors hindering its development. One of the main reasons is that the price of hydrogen fuel increases the cost of using vehicles, which puts it at a competitive disadvantage compared with traditional fuel vehicles and

pure electric vehicles. Herein, we summarize the recent development status of hydrogen fuel cell vehicles at home and abroad, and analyze the cost and sustainability brought by the latest scientific research progress to the hydrogen production industry, which is derived from basic research on electrocatalysts used in industrial electrocatalytic water splitting with an alkaline electrolyte. Finally, the development of hydrogen fuel cell vehicles was analyzed and prospected, which is one of the main application fields of hydrogen in the future.

24. Sitar, R., Shah, J., Way, J. D., & Wolden, C. A. (2022). Efficient generation of H2/NH3 fuel mixtures for clean combustion. *Energy Fuels*, *36*(16), 9357-9364.

Abstract: Ammonia (NH3) is an attractive carbon-free fuel, though it often requires the addition of a promoter such as hydrogen (H2) to ensure efficient and complete combustion. Herein, we describe the construction and operation of a catalytic membrane reformer (CMR) for the efficient generation of H2/NH3 fuel mixtures. A fraction of the ammonia is decomposed, and the released hydrogen is extracted through a membrane, where it combines with the remaining ammonia, which is used as a sweep gas. The use of ammonia as a sweep stream increased hydrogen recovery by as much as 60% and reduced the CMR operating temperature to as low as T = 350 °C. Dynamic control of the H2/NH3 ratio is achieved by adjusting the sweep flowrate, and the rejection of N2 enhances fuel quality. The use of the sweep enables high H2 recovery under isobaric operation, producing high-pressure H2/NH3 fuel mixtures without the need for compression. A simple reactor model was developed that accurately captures reformer performance across the range of operating conditions explored, and the excellent durability of the CMR was demonstrated through nominally unchanged performance over >1500 h of operation. This compact reformer provides on-demand generation of H2/NH3 fuel mixtures from a single fuel source that may serve as drop-in replacements for hydrocarbons to provide clean combustion with minimal equipment modification. Finally, the CMR concept may be applied for hydrogen enrichment of other fuels, and we successfully demonstrate the generation of H2/CH4 mixtures using methane as the sweep gas.; Ammonia (NH3) is an attractive carbon-free fuel, though it often requires the addition of a promoter such as hydrogen (H2) to ensure efficient and complete combustion. Herein, we describe the construction and operation of a catalytic membrane reformer (CMR) for the efficient generation of H2/NH3 fuel mixtures. A fraction of the ammonia is decomposed, and the released

hydrogen is extracted through a membrane, where it combines with the remaining ammonia, which is used as a sweep gas. The use of ammonia as a sweep stream increased hydrogen recovery by as much as 60% and reduced the CMR operating temperature to as low as T = 350 °C. Dynamic control of the H2/NH3 ratio is achieved by adjusting the sweep flowrate, and the rejection of N2 enhances fuel quality. The use of the sweep enables high H2 recovery under isobaric operation, producing high-pressure H2/NH3 fuel mixtures without the need for compression. A simple reactor model was developed that accurately captures reformer performance across the range of operating conditions explored, and the excellent durability of the CMR was demonstrated through nominally unchanged performance over >1500 h of operation. This compact reformer provides on-demand generation of H2/NH3 fuel mixtures from a single fuel source that may serve as drop-in replacements for hydrocarbons to provide clean combustion with minimal equipment modification. Finally, the CMR concept may be applied for hydrogen enrichment of other fuels, and we successfully demonstrate the generation of H2/CH4 mixtures using methane as the sweep gas.

25. Tang, Y., Dong, J., Zhao, Y., Li, G., Chi, Y., Weiss-Hortala, E., . . . Ye, C. (2022). Hydrogen-rich and clean fuel gas production from co-pyrolysis of biomass and plastic blends with CaO additive. *ACS Omega, 7*(41), 36468-36478.

Abstract: The treatment and disposal of waste biomass and plastics are of great importance to achieve both waste management and resource recycling. In this work, pyrolysis of biomass and plastic blends were investigated to identify the influence of temperature and in situ CaO addition on the production of hydrogen-rich, HCl-free, and low tar content fuel gases. The results show that the increase in temperature and the use of CaO significantly improved both the quantity and quality of the fuel gas and mitigated the formation of tar compounds and HCl. Moreover, H2 yield was significantly improved from 0.30 to 3.68 mmol/g with the increase in temperature from 550 to 850 °C. Also, the use of in situ CaO significantly increased the H2 yield by 28–88%. The H2/CO ratio was also enhanced from 0.35 to 1.50 with the temperature increase and CaO addition. Tar removal efficiency reached approximately 70.09% with the use of CaO at 850 °C. The produced HCl gas could be effectively absorbed by CaO through dechlorination reactions to form CaClOH at a highest mitigation efficiency of 92.37%. The results could be used to develop clean and efficient

treatment technologies of waste biomass and plastics.; The treatment and disposal of waste biomass and plastics are of great importance to achieve both waste management and resource recycling. In this work, pyrolysis of biomass and plastic blends were investigated to identify the influence of temperature and in situ CaO addition on the production of hydrogen-rich, HCl-free, and low tar content fuel gases. The results show that the increase in temperature and the use of CaO significantly improved both the quantity and quality of the fuel gas and mitigated the formation of tar compounds and HCl. Moreover, H2 yield was significantly improved from 0.30 to 3.68 mmol/g with the increase in temperature from 550 to 850 °C. Also, the use of in situ CaO significantly increased the H2 yield by 28–88%. The H2/CO ratio was also enhanced from 0.35 to 1.50 with the temperature increase and CaO addition. Tar removal efficiency reached approximately 70.09% with the use of CaO at 850 °C. The produced HCl gas could be effectively absorbed by CaO through dechlorination reactions to form CaClOH at a highest mitigation efficiency of 92.37%. The results could be used to develop clean and efficient treatment technologies of waste biomass and plastics.

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