

Article

National Policies, Recent Research Hotspots, and Application of Sustainable Energy: Case of China, USA, and European Countries

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Abstract: This study tracks the variety of nations dealing with the issue of energy transition. Through process tracing and a cross-national case study, a comparison of energy policies, research hotspots, and technical aspects of three sustainable energy systems (solar cells, recharge batteries, and hydrogen production) was conducted. We provide an overview of the climate-change political process and identify three broad patterns in energy-related politics in the United States, China, and Europe (energy neo-liberalism, authoritarian environmentalism, and integrated-multinational negotiation). The core processes and optimization strategies to improve the efficiency of sustainable energy usage are analyzed. This study provides both empirical and theoretical contributions to research on energy transitions.

Keywords: energy policy; sustainable energy; solar cells; recharge battery; hydrogen production



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1. Introduction

In response to new concerns about climate change, the issues of energy transition have received much attention in the research area around the world. The adoption and innovation of sustainable energy are necessary, especially in light of the rapid consumption of fossil fuels [1–3]. To support the development and application of new energy, an examination of the political dynamics of energy transitions and tracing technical innovation in industrialized countries is necessary. There is a dearth of comprehensive literature on the politics that influence, constrain, and shape renewable energy policy. We need in-depth case studies to comprehend the political dynamics of energy transitions. Based on a longitudinal case study, this study traces the evolution of national energy-related policies and technological innovation in sustainable energy. This study focuses on the variations in the policy decisions taken by governments in response to climate change. We aim to categorize the energy transition policies that governments choose to implement. Through a systematic analysis of the national energy policies of the United States, China, and European countries, this article identifies three policy models that help explain political trends among authoritarian states and democracies. The study's findings contribute to the theoretical interpretation of institutionalized environmental governance systems.

Meanwhile, a tremendous research effort in nanomaterial science has been invested to develop clean energy conversion and storage technologies, which has resulted in great progress and the commercialization of solar cells, secondary batteries, and the hydrogen production [4–6]. The application of nanomaterials is mainly concentrated in these three fields, which represent the frontier application and development trends of sustainable energy. As we all know, the formulation of policies promotes the progress of technology, and, likewise, the achievements in technology will also boost the refinement and perfection of policies. However, technological progress and application in related fields face a series of critical constraints, such as excessive dependence on resources, environmental damage, low efficiency, or limited-service life. The best way to solve these constraints is to explore new

materials and design new structures to mitigate the negative effects of previous processes that promote the development of new energy. Furthermore, this study systematically introduced the classification and development of relevant materials, discussed the critical methods for solving the relevant technical bottlenecks through materials engineering, and enumerated the relevant potential applications. Therefore, the introduction in related fields helps us to systematically understand the underlying logic of relevant research, identify technological achievements and industrial application, and then promote the deep integration of policymaking and technological development of new energy.

Through a cross-disciplinary analysis of national policy and technical innovation, we aim to explore how political objectives, actors, and institutions have influenced the creation and development of each energy technology. This study provides a broad evaluation of the key sustainable energy technologies as well as the underpinned political patterns.

2. Theoretical Framework

2.1. Variation in National Energy Transition Politics

Over the past four decades, several countries have become committed to promoting sustainable energy. Although the importance of technical and economic aspects of the energy transition is acknowledged, the political dynamics that drive energy policymaking are “underdeveloped” [7]. Research on energy transition politics places a strong emphasis on institutional elements, longstanding social values, and culture [8]. To meet the objectives of energy transition outlined in laws and plans, each national entity utilizes several policy instruments or tools (such as taxes, subsidies, licenses, and control rules). On this premise, the evaluations of energy politics mainly focus on the specifics of certain policy instruments, whereas the instrument chosen will be likely rooted in a certain political structure. There is substantial heterogeneity within each political system. When attempting to identify a specific political pattern, making simplistic generalizations is not enough. It is necessary to pinpoint prevailing mechanisms that change over time, are integrated into larger social systems, and are routinely used to tackle certain environmental issues. This study shed new light on the national political patterns. Referring to the energy transition, these patterns have a strong foundation in the institutions of legislation and politics as well as in the cultures and shared experiences of different civilizations. The question is, what explains the variation of energy policies implemented by different countries? Our case study aims to explore institutional factors which steadily affect the policies that are being implemented to advance the energy transition.

2.2. Technological Innovation of Sustainable Energy

Solar cells are a clean, safe, and sustainable energy generation mode, through which solar energy, converted into electricity, can be used directly, transmitted through the grid connection, or stored in other forms [9,10]. Needless to say, solar cells have many advantages, but the key to their further development is to improve the photoelectric conversion efficiency, increase usage life, and reduce production costs [11]. Currently, solar cells can be divided into three generations, and the third generation includes organic solar cells, dye-sensitized solar cells, quantum dot solar cells, and perovskite solar cells. Due to their low cost, excellent optical properties, and simple preparation process, perovskite solar cells (PSCs) have become a hot topic in the field of photonics in recent years [12,13]. Therefore, this study focuses on the latest research trends of perovskite solar cells, analyzes the key factors restricting its development, and provides examples of its latest industrial applications. Furthermore, developing low-cost secondary batteries and combining them with solar cells is an effective way to efficiently utilize solar energy by storing surplus solar power generation for use in off-peak times.

Specifically, the electric transformation from other energy forms is often stored in robust, reliable, and cost-effective energy storage devices such as lithium-ion, lithium-sulfur batteries, and sodium-ion batteries [14–17]. At present, the lithium-ion battery is the most widely used; however, due to the scarcity of the lithium element, the cost of lithium-ion batteries is

increasing, which restricts their future development. Sodium-ion batteries, therefore, stand out because of their low cost and similar working principle to lithium-ion batteries. In advancing battery technologies, the primary attention is paid to developing and optimizing electrode materials that are capable of fast reversible ion insertion and extraction [18,19]. Therefore, this article focuses on the working mechanism of sodium ion battery as well as the selection and optimization strategy of its electrode materials.

Hydrogen is one of the most promising candidates to replace non-sustainable fuel sources and is used nowadays because it is high in energy density and can react with oxygen to generate electric energy in fuel cells without producing any pollution [20–22]. At present, most domestic hydrogen is produced from coal, natural gas, petroleum, and other fossil fuels, which undoubtedly has a certain impact on the environment [23]. Hydrogen production through the electrolysis of water with a high-performance catalyst electrode is expected to avoid the above problems. In this study, the principle of electrocatalytic hydrogen production and the classification of catalytic electrode materials are discussed, the core processes and methods to improve the efficiency of electrolysis are analyzed, and the latest applications are introduced. Meanwhile, as depicted in Figure 1, hydrogen can be produced electrocatalytically using electricity translated from clean energy sources such as solar cells, wind energy, and tidal energy, and is then stored and transported through special equipment to the hydrogenation station for ammonia production, oil refining, coke/iron production, and residential usage [24–26]. These technologies are mutually promoting, with close contact in the development of the mainstream new energy field, representing the efficiency of energy production, storage, and transportation that need to be systematically and comprehensively introduced based on promotion policies, theoretical analysis of technological innovation, and advanced applications.

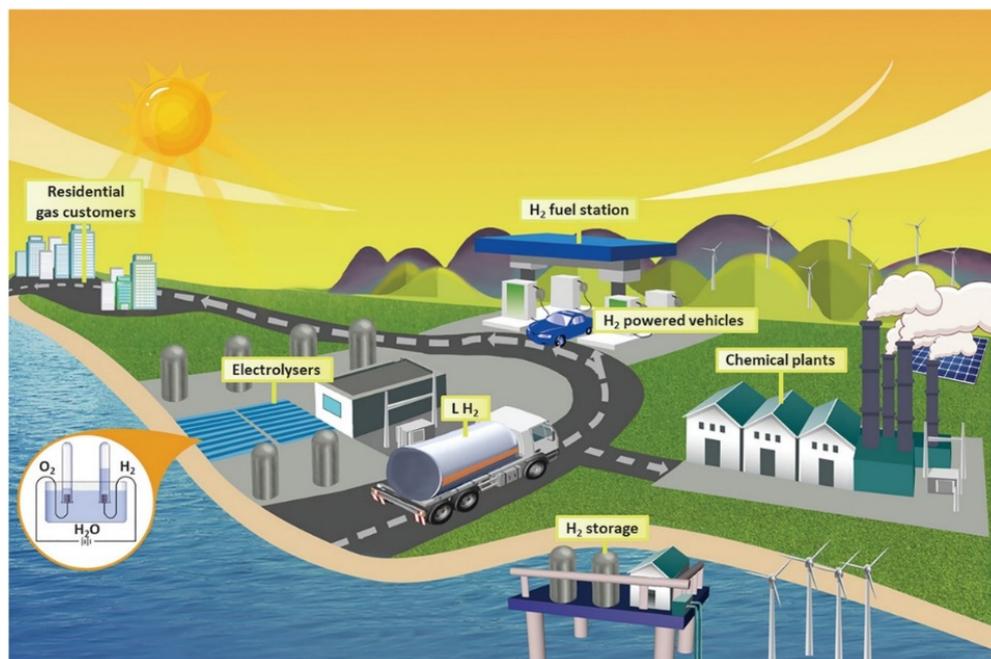


Figure 1. The blueprint of the future society's preparation, transportation, and usage of green hydrogen. Reprinted with permission from Ref. [26]. Copyright 2021, Wiley-VCH.

3. Research Method

3.1. Process Tracing and Case Study

This study conducts a cross-national analysis to trace the enactment and evolution of energy transition policy, the time span of which is over 20 years. To analyze energy-related policies implemented cross-nationally, we focused on the USA, China, and European countries. The sampling is based on the international impact of the energy transition initiative undertaken by a particular country. Europe was the first region to advocate energy transition.

European countries have reached a broad consensus on tackling climate change, setting legally binding climate and energy policies and increasing their decarbonization targets for 2030 to 2050. As main carbon emission countries, both China and the United States have important influences in the process of the energy transition. Energy has long been an important carrier of global politics and economy. Energy innovation is a determinant of power hierarchies among countries. Based on a comparative study of policy tools, political situations, technological innovation, and applications among these countries, this study aims to explore and predict the possible evolution of the worldwide energy structure.

We adopt process tracing as the research method to identify the political dynamics of policymaking. In the research area of political science, process tracing is used to explain causal mechanisms [27], that help examine the institutional factors' effect on a certain pattern of energy politics. In a comparative study of the energy political context of the USA, China, and EU countries, we clarify the sequence of events based on an analysis of the historical records. Then, this study identifies the critical juncture and timing of the event; thus, within-case inferences help examine the causal processes in which the political outcome occurred. This study applies both the inductive and deductive approaches to identify the political patterns beyond the specific national cases, which can be empirically tested in future studies.

To track the application of new energy technology in each country, this study focused on the three fastest-growing sustainable energy cases to discuss the recent research hotspots and applications in the fields of perovskite solar cells, sodium-ion batteries, and water electrocatalysts for hydrogen production. These energies are closely related to the latest experimental results involved in materials science. Based on the literature analysis and technological investigation, this study systematically explores the classification and development of relevant advanced materials. We discussed the critical methods for solving technical problems through materials engineering. Thus, this study evaluated the design methods and performance of new composite structures of each technology type.

3.2. Data Source

This study focuses on the politically driving dynamics that affect the energy transition in the USA, China, and European Countries. The data sources for each case study include laws and regulations, official policy files, news databases, and research articles. To identify the institutional attributes of the energy transition, we focus on variation in the national policies, including taxes, regulation, and subsidies. The analysis and discussion of the technical aspects in this study are derived from important relevant books, recent review papers, high-impact research articles, and technical reports.

4. National Policies

4.1. The United States: From Energy Neo-Realism to Conservative Neo-Liberalism

Energy politics of the United States is shaped by domestic party politics and displays cyclical changes and discontinuity. The energy-related policy is influenced by public demand, industrial interest groups, political actors, and the government's institutional capacities [8]. The evolution of energy politics in the past decade is reflected in variations of energy policies advocated by the three generations of presidents.

In 2013, Obama promoted the Presidential Climate Action Project, which aimed to show his leadership in climate and energy governance. The national "Clean Power Plan" was released in August 2015. However, when Republican Donald Trump took office in 2017, he set out to dismantle the Obama-era policies; for example, he put forward the first "America Energy Plan". This plan was designed such that US energy policy would reduce energy. Trump's energy policy focused on how to make American energy independent and ease environmental supervision. The specific policy implementation focused on promoting energy utilization, such as the relaxed regulation around fossil fuels' extraction and delivery. On 4 November 2020, the United States withdrew from the "Paris Agreement", which aimed to control greenhouse gas emissions. The Trump administration overthrew the

long-standing “energy neo-liberalism” of the 1970s. The Trump administration emphasized the national economic interests and formed “energy neo-realism”. The concept of “energy neo-realism” has two dimensions. One is “energy independence,” which maximizes US energy resources and reduces dependence on foreign oil; the second places emphasis on the achievement of energy saving through technological innovation. The Trump administration attempted to resurrect the fossil fuel economy and make the traditional fossil fuel industry the engine of economic growth.

Since 2021, Biden has continued to make the climate and energy revolution a core policy, focusing on multilateralism and trying to restore US leadership by promoting global carbon reduction. However, because fossil fuel capitalism has not changed, Biden has not “completely banned” fossil energy. Biden’s climate policy has a pragmatic and economic-oriented trend, which is regarded as a “conservative energy neo-liberalism” approach characterized by trade protection and the supremacy of national interests [28]. The “conservative energy neo-liberalism” which was advocated by the Biden administration aims to enhance the competitiveness of clean energy and promote the leadership of the United States in international climate governance. This type of “Clean Energy politics” is characterized as a kind of “political signal”, which is committed to enhancing the US’s global leadership in the promotion of sustainable energy. However, this “Clean Energy politics” also prompted the restructuring of domestic interests; therefore, its implementation may face resistance from Congress and state governments.

When tracking the historical record of US energy policy, the state engages in the utilization of sustainable energy. The United States was the first nation to propose a plan for promoting the energy economy of hydrogen, for example. The United States has a complete liquid hydrogen industry chain base, and it is the largest producer and consumer of liquid hydrogen in the world. In 1990, the Clinton administration carried out the Act to strengthen academic research on hydrogen and promote the “Hydrogen Research, Development, and Demonstration Act of 1990” [29]. He also carried out the “Hydrogen Future Act of 1996” [30]. These political measures focused on the research and development of sustainable energy technology; however, there was not much market integration of hydrogen energy. The Bush administration has incorporated hydrogen energy into the national energy strategy system since the 21st century, and the policy of the “National Vision of America’s Transition to a Hydrogen Economy-to 2030 and Beyond” [31] was drafted in 2002. In the same year as the publication of the “National Hydrogen Energy Roadmap” [32], a number of large-scale hydrogen energy research projects were initiated. In 2003, the United States had a leading role in the creation of an international partnership for hydrogen energy and fuel cells. At the same time, a global “Hydrogen Safety Committee” was formed to create a platform for sharing knowledge about hydrogen safety. This committee works on guiding the growth of the multifaceted global hydrogen industry. In the same year, the official “President’s Hydrogen Fuel Initiative” [33] was launched. This initiative aimed for the investment amount allocated to the development of hydrogen production to total USD 1.2 billion within five years, which is used for the storage and transportation of hydrogen technology. These laws have strengthened the role of hydrogen energy in the national legislation of energy policy.

In 2009, the American Hydrogen Energy Association, the US Fuel Cell Association (US-FCC), and other organizations collaborated to obtain national funding of 174 million dollars from the United States Congress. In 2012, President Barack Obama took several measures to promote the utilization of sustainable resources such as hydrogen energy and fuel cells with the funding of 60 billion dollars. In 2014, the US released the “Comprehensive Energy Strategy” [34], which laid out the developing trend of a national “low-carbon” energy structure. Congress established numerous policies in 2019, which are essential for the industrialization of hydrogen and fuel cells. The house and senate have passed legislation that reinstates and extends tax incentives for the usage of fuel cells in transportation and stationary applications. In 2021, the US Department of Energy invested USD 52.5 million to fund 31 projects to advance the second generation of clean hydrogen technologies and

support the announced “Hydrogen Energy Earth shot” [35] program, which aims to reduce costs and accelerate breakthroughs in clean hydrogen fields.

The photovoltaic sector policies mainly focus on financial subsidies, tax relief, operational limits, and other items. In line with the “American Energy Tax Act of 1978” [36], 25 percent of the total investments in the development of solar, wind, geothermal, and tidal power technologies is deductible from that annual Federal income tax. In 1992, the United States passed the “Energy Policy Act of 1992” [37], which provided the corresponding benefits, such as tax credits and subsidies for the utilization of renewable energy. The state provided qualified power companies with a 1.5-cent-per-kilowatt-hour tax credit. In 2004, the tax incentives of the United States increased by 0.3 cents per kilowatt-hour of electricity.

The “Energy Policy Act of 2005” [38] was enacted in 2005 to increase war-ready petroleum storage, safeguard the environment, and to strengthen energy security by diversifying energy sources and enhancing energy efficiency. The “Energy Independence and Security Act” [39] was enacted in 2007 to encourage a reduction in energy dependence and the attainment of supply security in the United States.

In 2008, the US Senate struck a consensus on a tax reduction package that prolonged the PV industries’ (ITC) tax reduction policies for two to six years. The Energy Committee of the US Senate passed the “Ten Million Solar Energy Roof Proposal” in 2010, which aim to invest special funds (250 million dollars in the sustainable energy industry in 2012, and at least 250 million dollars per year from 2013 to 2020) to subsidize the installation of solar systems on buildings, thereby driving the expansion of the American photovoltaic market over the next decade. The federal government established “Investment Tax Credit Policies” in 2015 to support the development of renewable energy. The firms and individuals who invested in solar power were subsequently eligible for federal tax credits equal to 30% of their investment. However, this policy expired on 31 December 2016, and was extended for five years. In US politics surrounding the energy transition, governmental bodies, particularly the courts, are crucial. “Law-centered practices” are a component of dominant American environmental governance systems, which include judicial rulings, regulations, and legislation [40]. Energy politics in the United States include law-centered procedures such as the approval of the legislation, the issue of regulations, and court judgments on disputes surrounding the application of these measures in specific situations, as well as federalism and multi-level governance, which include initiatives and innovations at both the national and subnational levels of government and the transmission of policy.

4.2. China: Authoritarian Environmentalism

China’s political responses to energy transition are supported by a model of authoritarian environmentalism. This is a political style characterized by the concentration of power within executive agencies governed by competent and moral elites seeking to improve environmental outcomes [41]. According to the initial articulation of the latent concept of the authoritative exercise of power [42], the “authoritarian environmentalism” was recently stated as having two dimensions [43]. One is a reduction in individual liberty, which limits people from engaging in unsustainable conduct and encourages them to follow more sustainable policies. The second one is a policymaking process that is restricted by relatively independent central state rules.

China is the world’s largest producer of hydrogen, with the potential to provide hydrogen that is clean and low in carbon emissions. In 2006, China published the “Outline of the National Medium and Long-Term Science and Technology Development Plan” (from 2006 to 2020) [44], proposing the goal of becoming the top-ranking, most innovative country by the year 2020. This plan focuses on the low-cost as well as the large-scale development and usage of renewable energy.

The National Council issued the “Energy Conservation and New Energy Vehicle Industry Development Plan” (from 2012 to 2020) [45], outlining specific measures for the development of new energy vehicles in China before 2020. In 2016, the National Development and Reform Commission and the National Energy Administration released the

“Energy Technology Revolution Innovation Action Plan” (from 2016 to 2030) [46]. This plan pinpoints the technological innovation of hydrogen energy and fuel cells. During the two sessions of 2019, the report on the work of the national government firstly highlights the necessity to encourage the building of charging, hydrogenation, and other facilities. In April 2020, the rule regarding hydrogen energy was included in the “Energy Law of the People’s Republic of China (Draft for Comment)” [47]. Hydrogen energy was identified as a potential future industry in the 14th “Five-Year Plan” for the national economic and social development, and also in the Chinese “Outline of Long-Term Goals for 2035” [48]. China is a major producer and marketer of solar cells, has the world’s largest solar power industrial chain, and is the world’s largest exporter of commodities, which is supported by the government. China has specifically addressed the installation of solar photovoltaic power, beginning with the “Eleventh Five-Year Plan” (from 2006 to 2010). During the period from the “Twelfth Five-Year Plan” to the “Thirteenth Five-Year Plan” (from 2011 to 2020), the solar industry was included on the list of growing strategic industries, with a focus on planning and helping to improve and optimize the energy system. During the “Fourteenth Five-Year Plan” period (from 2021 to 2025), the “Fourteenth Five-Year Plan” and the “Long-Term Goals for 2035” put the building of a modern energy system and the aggressive expansion of photovoltaic power generation at the top of the list of priorities. In March 2009, The People’s Republic of China’s Ministry of Finance and the Ministry of Housing and Urban–Rural Development issued the “Official Notice on Accelerating the Implementation and Applications of Solar Photovoltaic Buildings” policy [49]. This policy also aimed to support the applications of photovoltaic building and the implementation of the national “Solar Roof Plan”. The National Development and Reform Commission and the State Electricity Regulatory Commission published the “Notice on Renewable Energy Electricity Price Subsidies and Quota Trading Schemes from July to December of 2008” [50] in July to help pay for the prices of renewable electricity. In 2012, the National Energy Administration published the “Official Notice on Declaring a Demonstration Zone for the Large-Scale Application of Distributed Photovoltaic Power Generation” [51], indicating that distributed photovoltaic power generation was economically viable and met the requirements for large-scale applications. In 2013, the State Council issued the “Several Official Notices on Promoting the Healthy Development of the Photovoltaic Industry” [52], which presented constructive opinions based on the gradual expansion of the domestic application market for photovoltaic power generation and the general operational challenges faced by photovoltaic enterprises. Based on these opinions, the relevant departments, units, and regions have since developed a series of comprehensive policy support systems.

In 2014, the National Energy Administration released the “Notice on Further Implementing the Policies Related to Distributed Photovoltaic Power Generation” [53], which enhanced the application process and development of distributed photovoltaics. “Official Notice on the Price Policy of Photovoltaic Power Generation Project of 2018” [54] was issued to minimize the intensity of subsidies. This project investigates the business model for distributed photovoltaic power generation.

In 2019, the “Official Notice Referring to Actively Promoting the Utilization of Wind Power and Photovoltaic Power” was issued [55]. China proposed a series of policies to support the subsidy free grid parity of photovoltaic power, which can promote the high-quality development of renewable energy and enhance the competitiveness of wind power in the market. Afterward, the National Development and Reform Commission issued the “Notice on Problems Related to Improve the Feed-in Tariff Mechanism for Photovoltaic Power Generation” [56] in April of the same year. China advocated the eligible projects to determine electricity prices in a form of bidding. These projects are beneficial for achieving efficient resource utilization, promoting fair competition, and ensuring the survival of the fittest.

The “Notice on Matters Related to the Development and Construction of Wind Power and Photovoltaic Power Generation of 2021” [57] was issued to mandate the implementation of carbon peaking and carbon neutrality targets. These policies can ensure that non-fossil energy consumption will account for approximately 20% of primary energy

consumption until 2025. To reinvent the new energy development and utilization model, the “Implementation Plan on Promoting the High-quality Development of New Energy in the New Era” [58] was issued in 2022. This plan contains a national target, namely that the coverage rate of photovoltaic buildings in public institutions will reach 50 percent by 2025.

Authoritarian environmentalism can affect the choice of policy instruments or resource configuration. China’s energy governance relies on two main tools: laws and plans [40], especially the “top-down” implemented national “five-year plan” (FYP) that influences the promotion and use of sustainable energy. Energy governance is largely based on command-and-control regulation. In the centralized control of energy governance, the Chinese central government is playing a leading role by creating a “yardstick competition” [59] among local governments and adopting targeted accountability (TRS) schemes to address the energy transition.

4.3. European Countries: Integrated-Multinational Negotiation

The EU has been an advocate, facilitator, and leader in actively addressing global climate change. As Europe always advocates the deepening of political, economic, defensive, and secure integration and cooperation, the energy policy of EU countries is featured in the policy pattern of integrated-multinational negotiation. The integrated pattern of European energy transition policies is essentially formed through the continuous promotion of the judgment and compatibility of national interests. First, it highlights the significance of domestic politics in intergovernmental cooperation. Then, the national governments negotiate with other nations in order to exert pressure based on their predetermined national interests. Eventually, a regionally coordinated mechanism is constructed. However, as a non-EU country, Switzerland has different forms of cooperation in energy policy. Baal and Finger illustrated that, although Switzerland and the EU are highly interdependent in terms of energy due to geographical reasons, the level of policy coordination is relatively low because there is no formal EU–Swiss energy agreement [60]. The contemporary Swiss energy policy focuses on the 2050 Energy Strategy (ES50) [60]. In 2017, a referendum passed the bill, which reflects Switzerland’s efforts to become more sustainable by phasing out nuclear energy, supporting renewable energy, and making energy use more efficient.

Europe is also a leader in the development and deployment of hydrogen energy. In 1986, the “Energy in Europe” [61] identified renewable energy as the development direction for strengthening the European Union’s energy structure, laying the framework for the European Union’s energy strategy. Europe conducted a joint project titled the 2003 “European Research Area” in order to conduct cooperative research in the field of hydrogen energy utilization in Europe to ensure the diversification and efficiency of the European energy system. “The 2020 Climate and Energy Package” [62] was suggested by the European Council in 2007 as a series of legally enforceable rules and regulations to help the European Union meet its 2020 climate and energy goals. The European Parliament officially approved this plan in December 2008, and, since then, the European Union has taken the first steps toward energy transition.

Under the leadership of the German government, the leading European energy companies such as French Air Liquide Group, French Total Group, German Linde Group, and the Dutch Shell Group signed the “Memorandum of Cooperation on the H₂ Mobility Project” (2009), which aimed to construct large-scale hydrogen refueling stations in Europe.

In 2011, the European Union released the “Energy Roadmap 2050” [63], in which renewable energy played a crucial role. The European Union estimates that, by 2050, the proportion of renewable energy to total energy consumption will increase from the present 10% to more than 55%. The European Union also unveiled the “Roadmap for Transforming the EU into a Competitive, Low-carbon Economy by 2050” [64], ensuring that the Union meets its long-term goal of reducing emissions by 80 to 95 percent compared to 1990 levels by 2050.

“The 2030 Climate and Energy Policy Framework” [65] was adopted by the European Council in 2014. It drew from relevant documents such as the “2020 Climate and Energy Framework” and the “2050 Energy Roadmap”, and it reflected the European Union’s 2050

greenhouse gas emission targets, which were to increase the share of renewable energy in final energy consumption to 27 percent and improve energy efficiency by 27 percent. New jobs will be created in an effort to assist the development of a low-carbon economy in the European Union, improve the competitiveness of the energy system, enhance the security of the energy supply, and reduce dependency on energy imports.

In 2015 and 2016, the European Hydrogen Vehicle Program (Hydrogen Mobility Europe H2ME 1 and H2ME 2) was launched with a total expenditure of EUR 170 million to build 49 hydrogen filling stations. The European Joint Institution for Fuel Cells and Hydrogen (FCH-JU) released the “European Hydrogen Roadmap: A Sustainable Pathway for The European Energy Transition Resolution” [66] in February of 2019. Hydrogen energy became an essential tool for Europe to achieve carbon neutrality by the year 2050.

In December 2019, the European Commission unveiled the “European Green Deal” [67] (“Green New Deal”), which boosted the EU 2030 emission reduction objective from 40% less than in the year 1990 to at least 50% less and achieved a 55% reduction as a result. By 2050, it is anticipated that “recyclable” and “carbon neutral” products would be widespread across all industries, enabling the European Union to achieve net-zero greenhouse gas emissions.

As the central entity, the EU aims to create an internal energy market without technical and regulatory barriers. The dominant processes of energy governance in the EU involves constructing a general political system to target the free market circulation of sustainable energy among the Member States, improving the energy structure, and ensuring a steadily developed market structure, regulations, and infrastructure. As such, the Member States, considering their respective regional conditions, have the right and duty to implement these policies which contribute to the achievement of common energy transition goals.

5. Recent Research Hotspots

5.1. Solar Cells

Regarding solar cells, also known as photocells, when light shines on semiconductors, it provides energy for valence electrons in semiconductors and makes them free from binding, so as to make electrons move. In short, they use light energy and convert it into electrical energy for power generation [68,69]. Generally speaking, solar cells are divided into three generations based on the technological maturity and active layer difference. Among them, the third-generation solar cells are distinguished by their high energy conversion efficiency, high stability, cheap cost of production, and environmental friendliness. [70]. At present, it typically involves dye-sensitized solar cells, quantum dot solar cells, organic solar cells, and perovskite solar cells. Perovskite solar cells (PSCs) have gained significant attention in the field of photonics because of their low cost, good optical qualities, and simple manufacturing procedure [12,13].

At first, PSC composites with organic–inorganic hybrid perovskite material did not attract much attention due to their being less advantageous in stability and energy conversion efficiency (3.8%) [71]. Until 2012, N.G. Park et al. reported that PSCs achieved an energy conversion efficiency of more than 9% with 500 h of stability, at least in air, and then the relevant research work began to increase gradually [72]. In 2013, H.J. Snaith et al. made the PSCs by using a vacuum deposition method based on $\text{CH}_3\text{NH}_3\text{PbI}_{3-x}\text{Cl}_x$ for the first time, with an energy conversion efficiency that exceeded 15% [73]. After more than ten years of rapid development, in 2021, the energy conversion efficiency of the PSCs prepared by J. Seo et al. achieved 25.2% certification efficiency, which is comparable to the energy conversion efficiency of silicon-based solar cells [74]. The extremely considerable increase in efficiency from 2012 to 2021 (Figure 2a) was largely driven by the emergence of seminal reports of all-solid-state PSCs in 2012 [75]. According to S-Q analysis, the theoretical efficiencies depicted in Figure 2b show that the PSCs still have an 18.5% efficiency gap from the theoretical value [76]. However, in order to achieve the widespread application of high-performance PSCs, the issues of lead toxicity, material stability, low spectral absorption ability, and the development of large-area modules (Figure 2c,d) must be solved firstly and then develop the devices according to the process, as shown in Figure 2e [77].

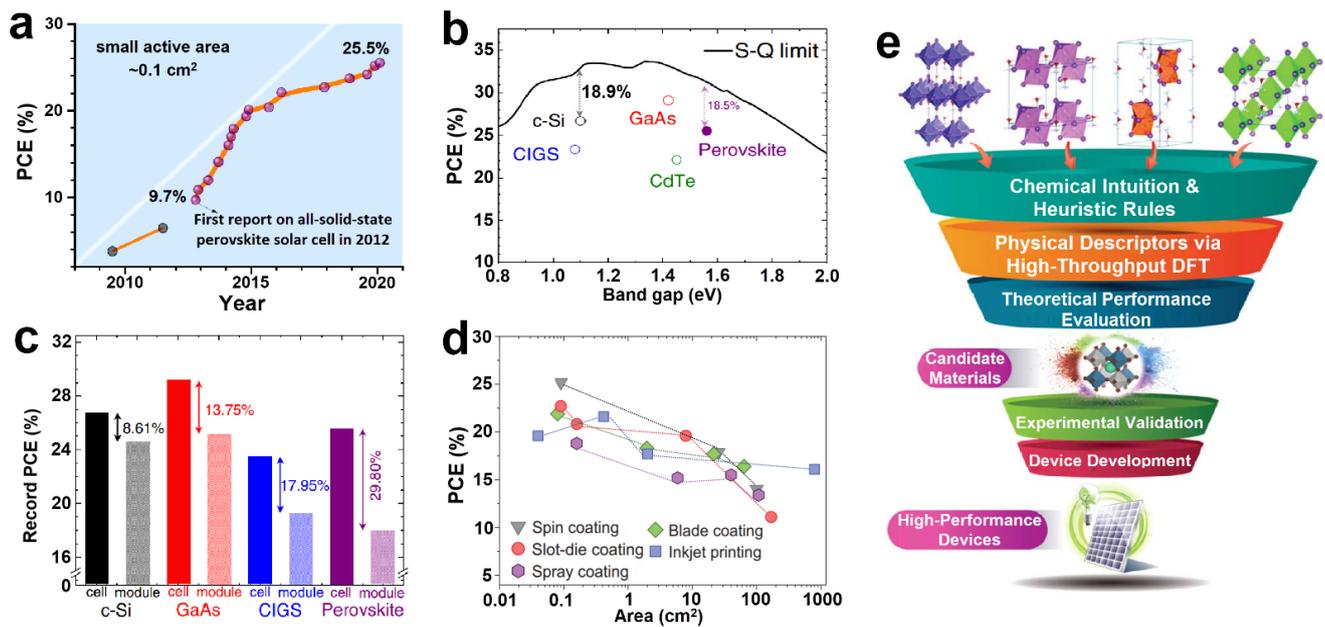


Figure 2. (a) The increasing trend of perovskite solar cell efficiency (PCE) from 2011 to 2020, reprinted with permission from Ref. [75]. Copyright 2020, American Chemical Society; (b) The S-Q limit line and the highest PCE of various solar cells; (c) the maximum PCEs of copper indium gallium selenide (CIGS), crystalline silicon (c-Si), gallium arsenide (GaAs), and organic–inorganic lead halide perovskites (Perovskite), as well as their modules; (d) the correlation between the PCEs of perovskite solar and active area, the date cited in this figure from the left to the right according to the PCE fabrication process (Spin coating: e.g., Ren A.+2020, Han G.S.+2019; Slot-die coating: e.g., Du M.+2020, Li J.+2021; Spray coating: Kim J.+2017, Rolston N.+2020, Heo J.H.+2016, Agresti A.+2019; Blade coating: Wu W.+2020, Li C.+2019, Deng Y.+2020, Deng Y.+2019; Inkjet printing: e.g., Li Z.+2020, Eggers H.+2019, Li P.+2018) and see Ref. [76] for details information in the figure, (b–d) reprinted with permission from Ref. [76]. Copyright 2021, Oxford University Press. (e) Simplified procedural outline of perovskite solar cell research roadmap, through high-throughput screening potential materials for further experimental verification and device manufacturing, reprinted with permission from Ref. [77]. Copyright 2021, IOP Publishing Ltd.

The fundamental way to solve lead toxicity in perovskite materials is to develop novel non-lead perovskite materials. Although efficient packaging equipment and later the collection of waste devices can effectively control the toxicity of lead, it will also increase the production and use the cost of solar cells [78,79]. Currently, non-lead perovskite materials mainly use low-toxic elements to replace lead, such as Sn, Bi, Sb, and Cu. Sn-based halide perovskite (MASnX₃, X = Cl, Br, I) is considered to be the most effective alternative [78–80]. Tetragonal CH₃NH₃SnI₃ perovskite, with a narrow optical band gap of 1.23 eV, has a similar structure to lead-based perovskite [80]. Moreover, the above non-lead materials face the problems of low efficiency and poor stability, and there is still a significant gap compared with lead-based perovskite [81]. Therefore, the partial substitution of lead is an effective way to weaken the lead pollution, and the incorporation of SCN[−] into the perovskite adsorption energy barrier of oxygen molecules can thermodynamically stabilize the crystal structure of perovskite, as shown in Figure 3 [82]. Although there are still stability problems, the maximum energy conversion efficiency of lead and Sn mixed perovskite has reached 21.2% [83].

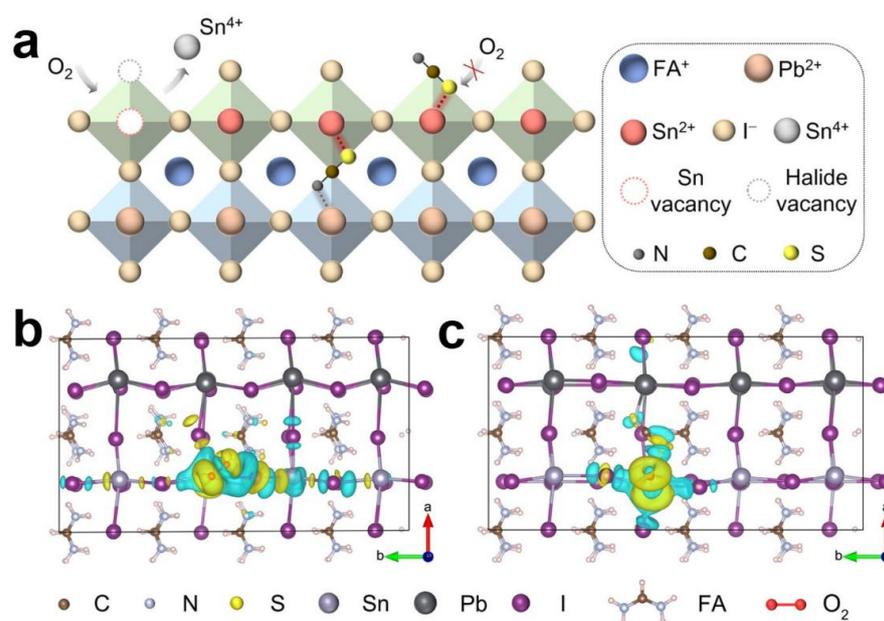


Figure 3. (a) Schematic diagram of mixed Sn–Pb antioxidation perovskite films; (b) an O₂ molecule was adsorbed on the surface of FASn_{0.5}Pb_{0.5}I₃ perovskite; (c) an O₂ molecule was adsorbed on the surface of FASn_{0.5}Pb_{0.5}I₃ perovskite doped with SCN⁻. Reprinted with permission from Ref. [82]. Copyright 2022, American Chemical Society.

The poor stability of PSCs is the bottleneck restricting their large-scale usage. The stability of perovskite devices largely depends on the interface between components in the device structure as well as the stability of different components (such as the metal electrode, charge transfer layer, and absorption layer). The property of being soluble in water and the decomposition of perovskite material are also critical factors for the stability of the PSCs [84–86]. Recently, some researchers have made many efforts to optimize the perovskite material to alleviate the instability problem by adding additives with functional groups such as amine or carbonyl, which can be covalent with perovskite [86]. When perovskite films are formed, the hydrophobic part of the additives coordinates with perovskite, and its functional groups are at the grain boundary or surface that can protect perovskite from water damage. Not only water molecules have an effect on the stability of PSCs materials, high temperature also influence the stability of devices that are prone to structural changes of perovskite materials [87]. For instance, MAPbI₃ perovskite will undergo a reversible phase change from the tetragonal phase to the cubic phase at a heating temperature of about 57 °C [88]. At present, the best choice is to improve the stability of materials by adding mixed cations. Park et al. revealed for the first time that incorporating organic–inorganic hybrid cations into perovskite light absorbers might improve stability. When Cs⁺ is partially substituted for formamidinium, the photostability of perovskite films was significantly improved [79].

Altering the band gap of perovskite materials by component modulation is another method that might be used to boost the performance of PSCs [89]. In order to broaden the spectral absorption range of PSCs, researchers used the adjustable energy band of perovskite materials to construct the solar cell structure, such as laminated PSCs and gradient band gap PSCs [89]. Furthermore, optimizing the preparation process of PSCs is the basis and premise used to enhance the electron transmission rate and decrease the energy loss of extracted charges that improve the conversion efficiency of PSCs [90]. Meanwhile, PSCs have a multilayer structure, and there are a large number of interface defects between perovskite the absorption layer and each functional layer that cause significant carrier recombination, which eventually affects the device charge transfer, open-circuit voltage, hysteresis effect, and so on [91,92].

To enhance the performance of the PSCs, it is thus required to passivate the interface's defects, as shown in Figure 4 [92]. The device's performance and service life may also be increased by effectively purifying the interface between the perovskite absorption layer and the hole transport layer. Therefore, by designing and exploring new materials and processes, optimizing device structure, and combining theory with experiment, the all-around performance of PSCs can be gradually improved, and large-scale practical applications can be realized.

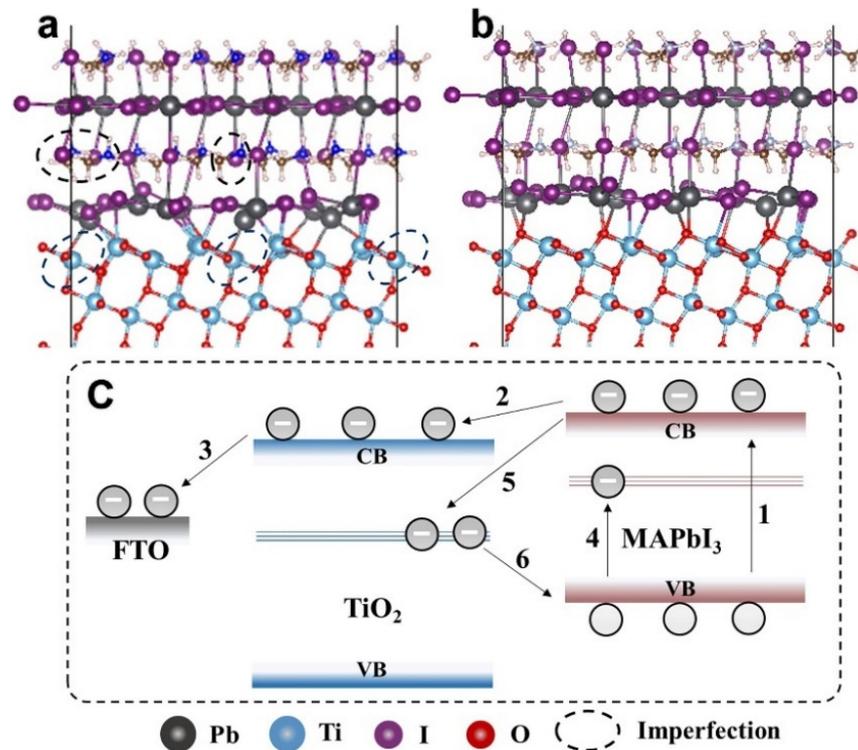


Figure 4. Carrier transport process and interface structure optimization (a) with defects on the surface of TiO₂ and (b) with perfect TiO₂; (c) transport process of interface carrier. Reprinted with permission from Ref. [92]. Copyright 2021, Elsevier.

5.2. Rechargeable Batteries

A lithium-ion battery is a kind of high-specific energy secondary battery that is important and widely used in current commercial applications. However, due to the limitation of lithium resources, the cost of lithium-ion batteries has dramatically increased, which will become a severe constraint for its more expansive and massive applications in the future [93]. Therefore, sodium-ion batteries (SIBs) offer several benefits, such as rich resources, low-cost, high-energy conversion efficiency, high half-cell potential (0.3 V higher than lithium-ion battery), no over discharge characteristics, and compatibility with aluminum foil that affords them great application potential in new energy fields [94]. Research on sodium-ion batteries began as early as the 1970s and, with the development of material science, it has witnessed a spurt of growth in the recent year [95,96]. The operating concept of SIBs is similar to that of lithium-ion batteries, which was proposed by Armand et al. in 1980 as a “rocking chair battery” model [97]. According to the structure and electrolyte of sodium-ion battery, this kind of battery can be divided into sodium sulfur battery, organic sodium-ion battery, aqueous sodium-ion battery, and solid sodium-ion battery. The conventional SIBs consist of a sandwich structure of anode and cathode and polymer separator with a liquid electrolyte surrounding [98]. Normally, both anode and cathode electrodes are a composite of active material powders, adhesives, and conductive additives in proportion, and are separated using a porous separator that is usually made of glass fibers or porous polymers

that allow ions to pass through but prevents electrons that achieve short circuit prevention (Figure 5) [97].

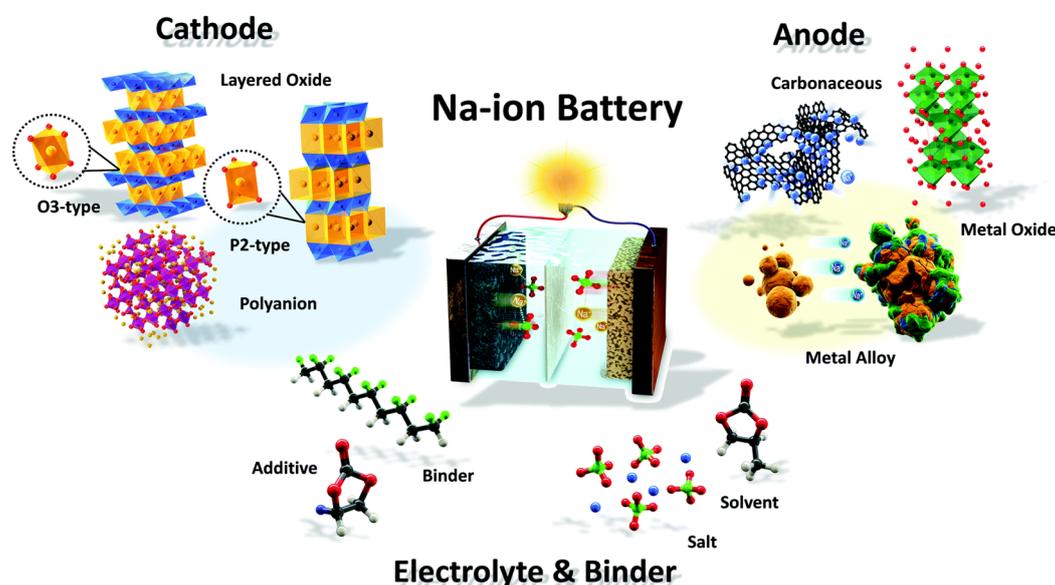


Figure 5. A sodium-ion battery system is shown schematically. Reprinted with permission from Ref. [97]. Copyright 2017, Royal Society of Chemistry.

Sodium ions are extracted from the anode material and combined with the cathode material for energy storage during the charging process; meanwhile, electric energy is transformed into chemical energy through an electrochemical redox reaction on the electrode materials' surfaces. However, compared with lithium-ion, sodium-ion has stronger solvation with a size of 1.02 Å, which is larger than that of lithium-ion (0.76 Å), and the electrochemical potential of sodium-ion (−2.71 V, Na⁺/Na) is smaller than that of lithium-ion (−3.04 V, Li⁺/Li). Therefore, the electrode material of a sodium-ion battery will produce more volume fluctuations throughout the charge and discharge process, resulting in more severe problems such as electrode collapse and crushing. At the same time, from the perspective of dynamics, the insertion and extraction speed of larger sodium ions in electrode materials is slower than that of lithium ions, which present SIBs with more significant challenges in their cycle life and rate performance [99–101]. Moreover, the energy density of the sodium-ion battery is primarily determined by the capacity of the anode and cathode materials, and the capacity of the anode is often much higher than that of the cathode, therefore the cathode material primarily limits the performance of the battery (Figure 6) [97].

In the research phase, four typical cathode materials for SIBs have been identified: transition metal compounds, organic compounds, Prussian blue derivatives, and polyanionic compounds, therefore it is urgent to explore high-performance cathode materials based on those materials for SIBs. Table 1 depicted the characteristics of the four kinds of electrode cathode materials [12,102–104]. Among those materials, organic materials have the disadvantages of poor electronic conductivity, a low-voltage platform, and a general electrochemical charging and discharging capacity, which limits its development direction as the mainstream cathode material of high-capacity and high-voltage SIBs [105]. Polyanionic compounds mainly include the following four kinds: phosphate, fluorophosphate, fast sodium-ion conductor phosphate, and pyrophosphate. These materials have substantial drawbacks, such as limited specific capacity, poor rate characteristics, and low discharge platform potential, thus further optimization is needed [106]. Therefore, Prussian blue derivatives and transition metal compounds can meet the commercial requirements of sodium-ion batteries and have more excellent commercial value in this stage.

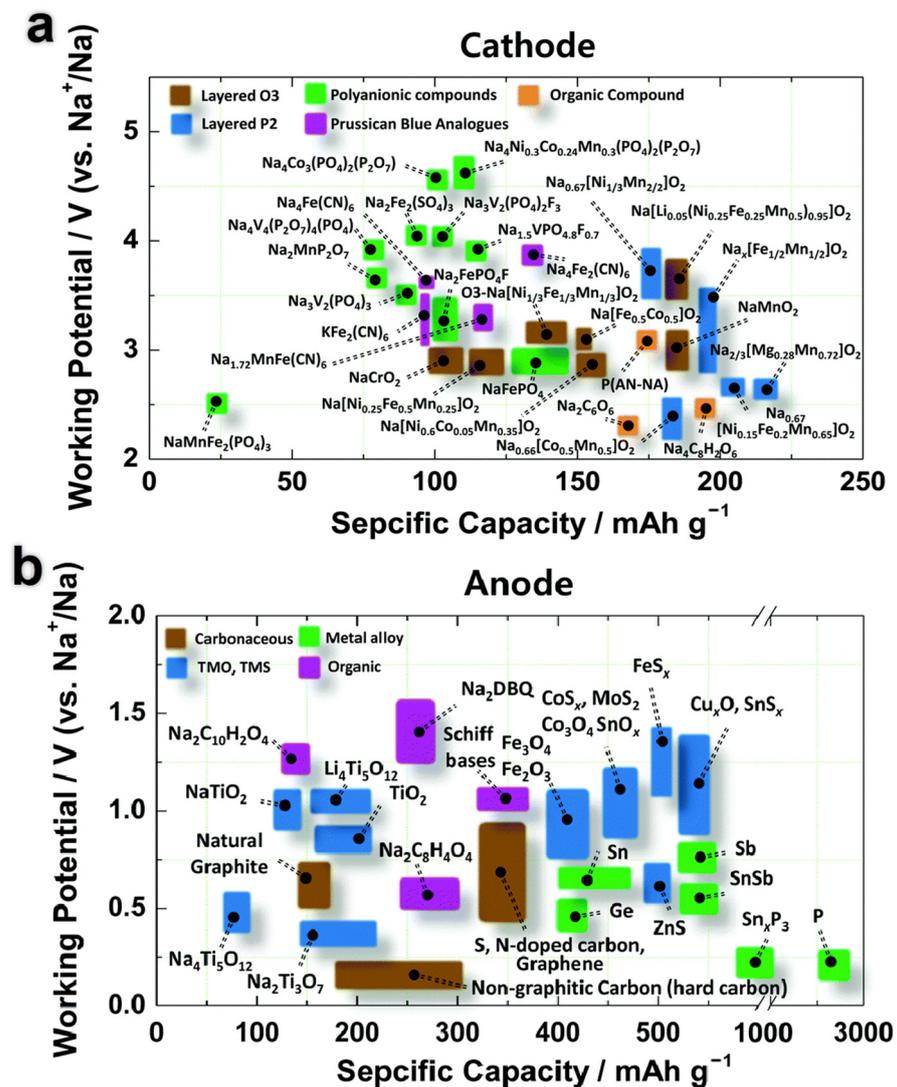
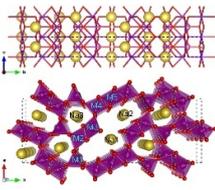
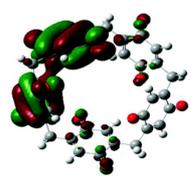
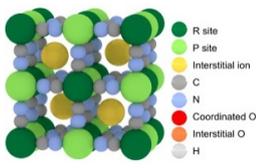
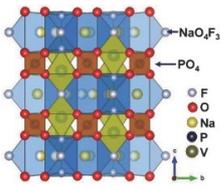


Figure 6. Working potential versus specific capacity of recent advances in sodium-ion battery research: (a) cathode, (b) anode. Reprinted with permission from Ref. [97]. Copyright 2017, Royal Society of Chemistry.

There are also several fundamental problems that should be solved in the development of SIBs. Firstly, although the development of SIBs can learn from and transplant lithium-ion battery research methodologies and procedures, novel positive materials with high energy density and power density, as well as negative materials with minimal volume changes in the process of circulation, are required [107,108]. Furthermore, enhancing the cycle stability of the electrode materials is an important method for improving the performance of SIBs and a vital step toward commercializing SIBs on a large scale [109,110]. In addition, the synthesis methods of electrode materials for SIBs are relatively simple. The traditional solid-phase and gel-sol methods are the primary preparation methods, therefore new synthesis strategies and theory methods should be developed for better capacity and a large voltage window [111]. With the progress of the above technologies, sodium-ion batteries can first replace lead-acid batteries with high pollution and low energy density and then play a more significant role in more aspects.

Table 1. Characteristics of the four kinds of electrode cathode materials: transition metal compounds (Reprinted with permission from Ref. [12]. Copyright 2019, Elsevier); organic compounds (Reprinted with permission from Ref. [102]. Copyright 2019, Royal Society of Chemistry); Prussian blue derivatives (Reprinted with permission from Ref. [103]. Copyright 2019, Wiley-VCH) and polyanionic compounds (Reprinted with permission from Ref. [104]. Copyright 2019, American Chemical Society).

	Transition Metal Compounds	Organic Compounds	Prussian Blue Derivatives	Polyanionic Compounds
Structure				
Advantage	High reversible specific capacity High energy density High odds performance Easy technology transformation	High theoretical capacity Low cost Environmentally benign Structural versatility	The working voltage is adjustable High reversible specific capacity High energy density Low synthesis temperature	High working voltage Good thermal stability Good circulation Good air stability
Shortcoming	Easy to absorb moisture The cycle performance is slightly poor	Poor conductivity Low voltage platform	Poor conductivity Low coulomb efficiency	Low reversible capacity ratio Some contain toxic elements

5.3. Hydrogen Production

China has already a specific foundation in the hydrogen energy industry, with a national hydrogen production capacity of more than 20 million tons. Currently, nearly 70% of domestic hydrogen is produced from coal, natural gas, petroleum, and other fossil fuels, about 30% is produced from industrial by-product gas, and less than 1% is produced from electrolytic water [112].

Hydrogen production via the conversion of natural gas (including naphtha, heavy oil, refinery gas and coke oven gas) is a traditional technology that has been commonly used in large-scale hydrogen supply occasions (more than 5000 Nm³/h) [113]. In areas rich in natural gas, hydrogen production from natural gas is the best choice with low investment and consumption, which is very suitable for small- and medium-sized occasions, such as for the conversion of coal (including coke and petroleum coke) to hydrogen. This technology with a complex process and low cost is usually suitable for medium production units (greater than 1000 Nm³/h) and areas without natural gas resources and large-scale units. Hydrogen production by methanol or ammonia cracking: this cracking process is relatively simple, easy to operate, and has strong competitiveness in areas with sufficient methanol supply with small hydrogen demand (below 200 Nm³/h).

Those three technologies presented above are currently mainstream hydrogen production methods; however, all of them are based on traditional fossil energy. As a result, extensive research is being performed to harvest energy from water by converting water into H₂ [114,115], and electrocatalysis-driven water splitting is one of the most promising carbon-free methods with minimum environmental effect. Real-time energy storage and efficient transportation can also be achieved by integrating solar cell, wind, or water-generated electric power with the technology of electrolysis water. The hydrogen production by water electrocatalysts has a high purity and is very suitable for fuel cell and hydrogen storage. However, H₂ synthesis via electrolysis is still not economical because of the absence of adequate electrocatalysts [116,117]. At present, metal oxides and alloys made of precious metals such as Pt, Ru, and the Rh group are regarded as the most active catalysts in the hydrogen evolution reaction (HER); however, they are scarce and expensive. Therefore, the key to creating electrolytic water technology is the effective utilization of modified noble metals or the invention of active, long-lasting, and earth-abundant electrocatalysts for water-splitting [118,119].

5.3.1. Noble Metal-Based Electrocatalysts

Modifying noble metal is one of the most straightforward and efficient approaches for designing high-efficiency water-splitting electrocatalysts [120,121]. Various techniques have been developed to enhance atomic utilization efficiency, stability, and loading quantity (such as alloying with nonprecious metals [121,122], single atomization [123,124], and doping heteroatoms into noble metals [125]). Feng et al. [126] fabricated a highly efficient alloy type RuCo electrocatalyst based on carbon dots (RuCo@CD) for overall water-splitting with outstanding durability in a broad pH range. In order to manufacture the composite electrode, bulk and surface electronic structures of Ru were rationally changed, resulting in improved HER and OER electrocatalytic activity. As shown in Figure 7, a low overpotential of 11 mV in 0.5 M H₂SO₄, 51 mV in 1.0 M KOH, and 67 mV in neutral 1.0 M PBS solutions at 10 mA cm⁻² is required for HER activity in the RuCo@CD catalyst.

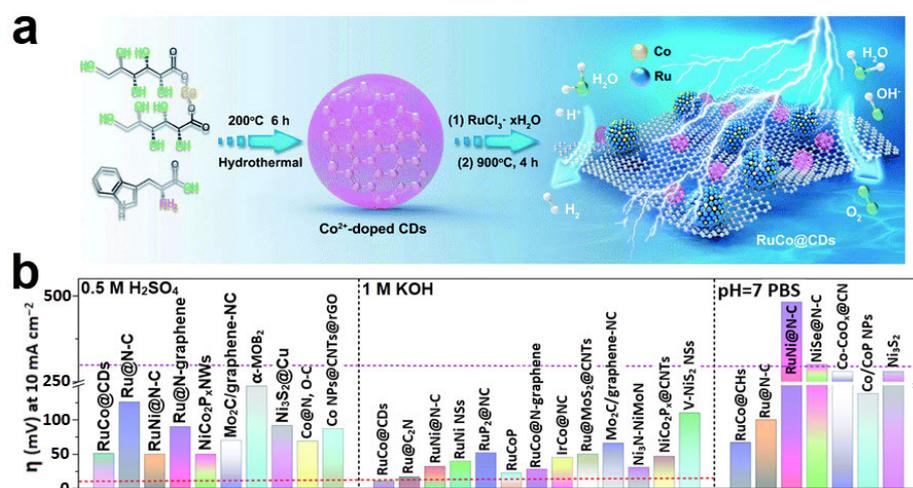


Figure 7. (a) Schematic diagram of the fabrication of the RuCo@CD catalyst; (b) the HER electrocatalyst performance of RuCo@CDs compared with recently related reports. Data were taken from the literature [126]. Reprinted with permission from Ref. [126]. Copyright 2020, Royal Society of Chemistry.

An alkaline overall water-splitting electrode using cation exchange approach was developed by Xu et al. [127] using single-atom site catalysts (SACs) of Rh on CuO nanowire (CuO NAs) arrays. The poor electrochemical performance of CuO NAs has been greatly improved by adding a single atom of Rh. This is due to the large specific surface area of the electrode and the high efficiency of noble metal. As depicted in Figure 8, at 10 mA cm⁻² in 1 M KOH, the lowest overpotential of Rh SAC-CuO NAs/CF is only 197 mV for OER and 44 mV for HER (similar to the HER performance of Pt/C/CF of 42 mV at 10 mA cm⁻²).

5.3.2. Transition Metal Electrocatalysts

Similar to noble metals, transition metals (Ni, Fe, Mo, Co, etc.) have an electron distribution in the d orbital that is under-filled, making them the perfect materials to replace noble metal catalysts [128]. Transition metal catalysts mainly include transition metal sulfides, nitrides, phosphates, selenides, borides, oxides, carbides, tellurides, and transition metal alloys [128,129]. At present, transition metal catalysts are mainly modified through electronic environment regulation, nanostructure optimization, and multi-component synergy to improve the catalytic performance [130,131]. Compared with transition metal-based materials such as Co, Fe, and Mo, the HER performance of nickel-based catalysts showed stable Gibbs free energy and lower overpotential at the same current density (Figure 9) [132]. Electrolytic water in an alkaline media has demonstrated exceptional stability and catalytic activity for Cu-based catalysts because of their rich content, low toxicity, and high intrinsic activity [133]. Meanwhile, transition metal carbides have good stability, phosphide is cheap and stable, and chalcogenide can improve the electronic

structure of catalysts, which are the focus of current research. Based on these transition metal catalysts, doping other elements to regulate the electronic structure and synergy with other elements, such as Pt/Ni(OH)₂ heterostructure, is also an efficient method for enhancing the activity and stability of nickel-based catalysts [134]. Moreover, changing the structure of the catalysts and increasing catalytic activity by exposing more active sites, such as the development of nanosheets, nanowires, and nanoarrays, is also an area of research interest in the field of electrocatalysis.

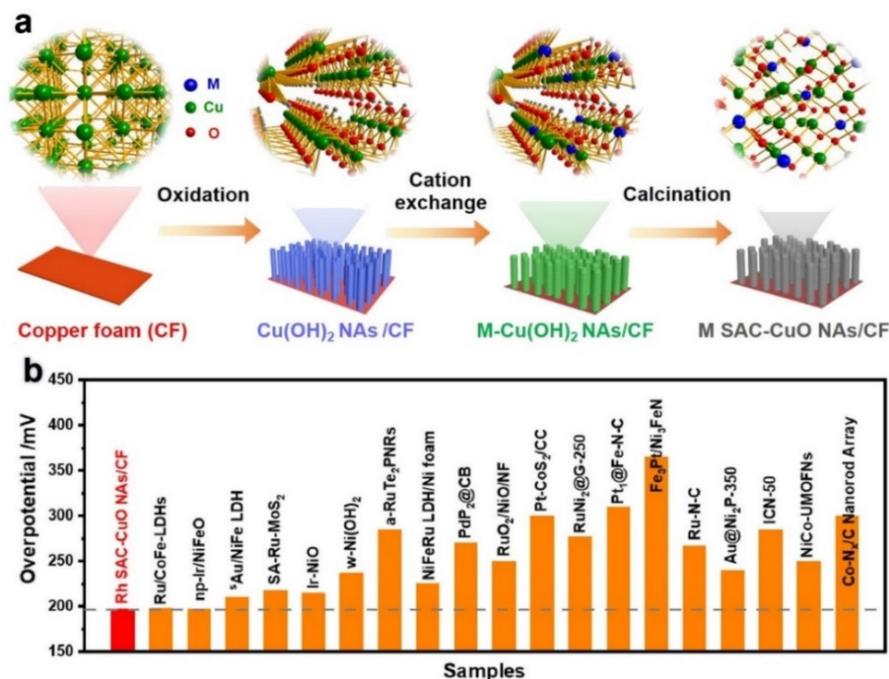


Figure 8. (a) Schematic illustration of fabrication process and atom structure of M SCA-CuO NAs/CF electrocatalytic electrode by single-atom Rh doping; (b) the OER electrocatalyst performance of M SCA-CuO NAs/CF compared with recently related reports at 10 mA cm⁻². Data were taken from the literatures [127]. Reprinted with permission from Ref. [127]. Copyright 2020, Royal Society of Chemistry.

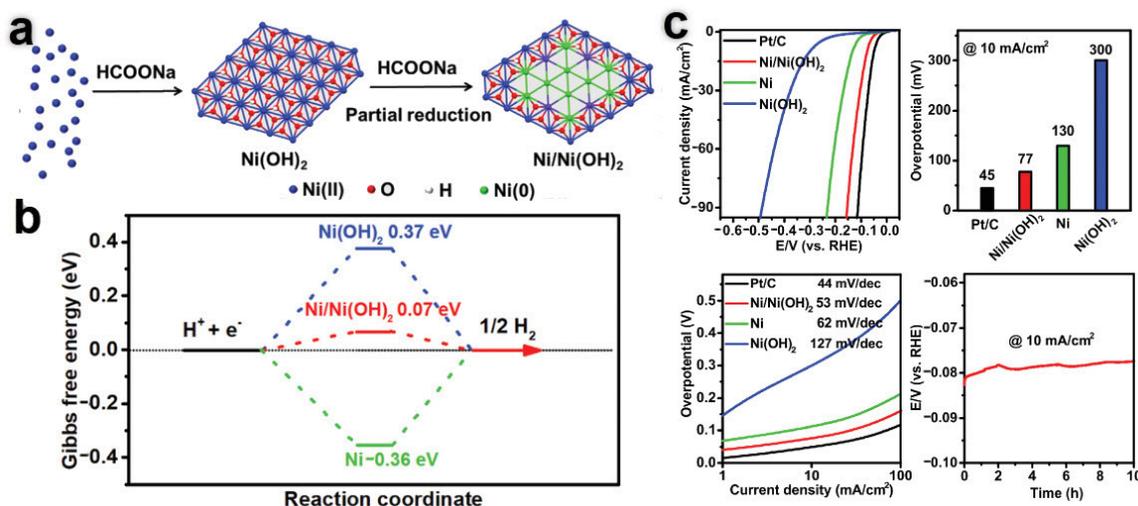


Figure 9. (a) Schematic diagram of fabrication Ni/Ni(OH)₂ ultrathin nanosheets; (b) the relationship between free energy and the reaction coordinate of HER calculated from simulated models of Ni, Ni(OH)₂ and Ni/Ni(OH)₂; (c) the HER performances of Ni, Ni(OH)₂, Ni/Ni(OH)₂ nanosheets and Pt/C. Reprinted with permission from Ref. [132]. Copyright 2020, Wiley-VCH.

5.3.3. Nonmetallic Electrocatalysts

Nonmetallic catalysts mainly refer to carbon materials, which have the advantages of a wide source of raw materials, low cost, adjustable electronic environment, and stable performance. However, the intrinsic activity of carbon materials in HER and OER cannot meet the needs of industrial applications. Nonmetals such as B, N, P, S or other functional groups are mainly doped into carbon materials through a multivariate approach to improve the catalytic activity of carbon materials. As shown in Figure 10a–c, the defect manufacturing and doping of carbon materials through material engineering for OER and HER electrode and Figure 10d–f reflect the electrocatalytic property of defective graphene, all of which indicate that the modification and doping of carbon material can effectively improve the electrochemical performance of the electrode [135,136].

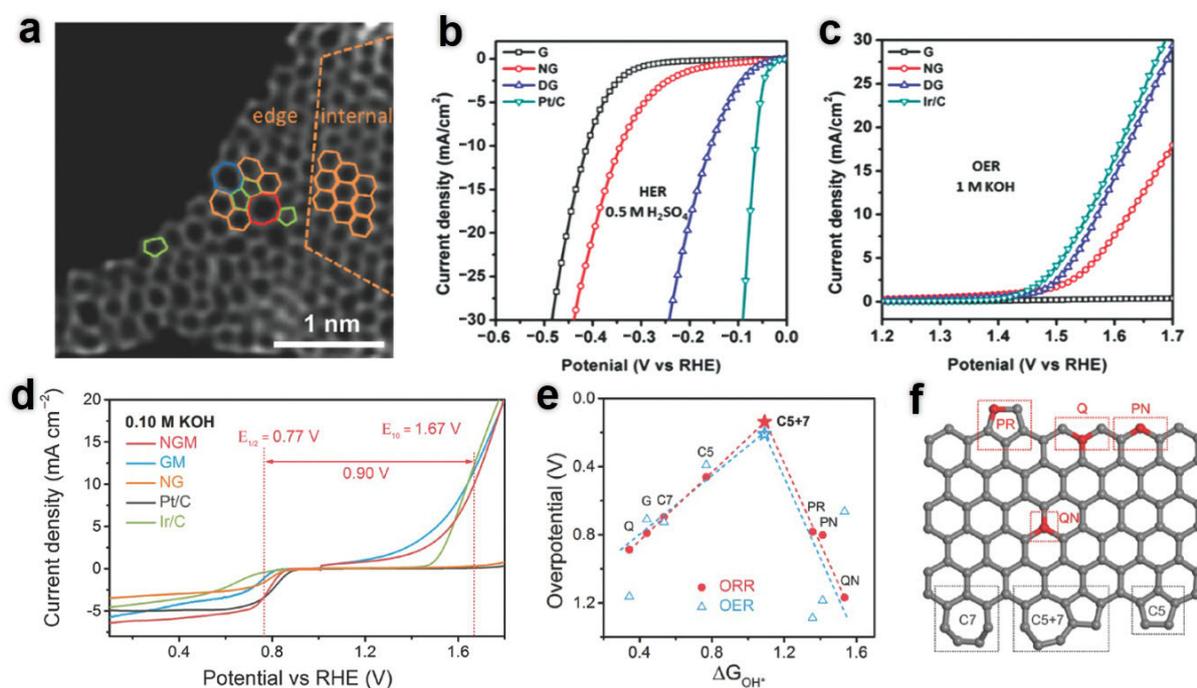


Figure 10. Defect manufacturing and doping of carbon materials through material engineering for the electrocatalytic electrode (a) HAADF-STEM image, (b) OER, and (c) HER of N-doped defected graphene. (a–c) Reprinted with permission from Ref. [135]. Copyright 2016, Wiley-VCH. (d) ORR and OER polarization curves (e) the volcano plot of the OER overpotential on different sites and (f) corresponding models of defective graphene. (d–f) Reprinted with permission from Ref. [136]. Copyright 2016, Wiley-VCH.

6. Applications of the above Technologies

6.1. Solar Cells

The upscaling of PSCs has become the next stage as a result of recent advancements in the efficiency and stability of PSCs. Roll-to-roll (R2R) procedures for the uniform creation of a precursor wet film and full conversion to perovskite phase have been specifically developed to achieve this goal, which would be a breakthrough in accomplishing the commercialization of PSCs [137]. As shown in Figure 11, Kim et al. successfully demonstrated the R2R production of all of the layers (with the exception of the electrodes) using a complete pilot scale in the PSCs process. Through tBuOH: EA bathing, the uniform, highly crystalline formamidinium (FA)-based perovskite was produced, achieving power conversion efficiencies (PCEs) of 19.1% for gravure-printed flexible PSCs and 23.5% for glass-based, spin-coated PSCs, respectively [137].

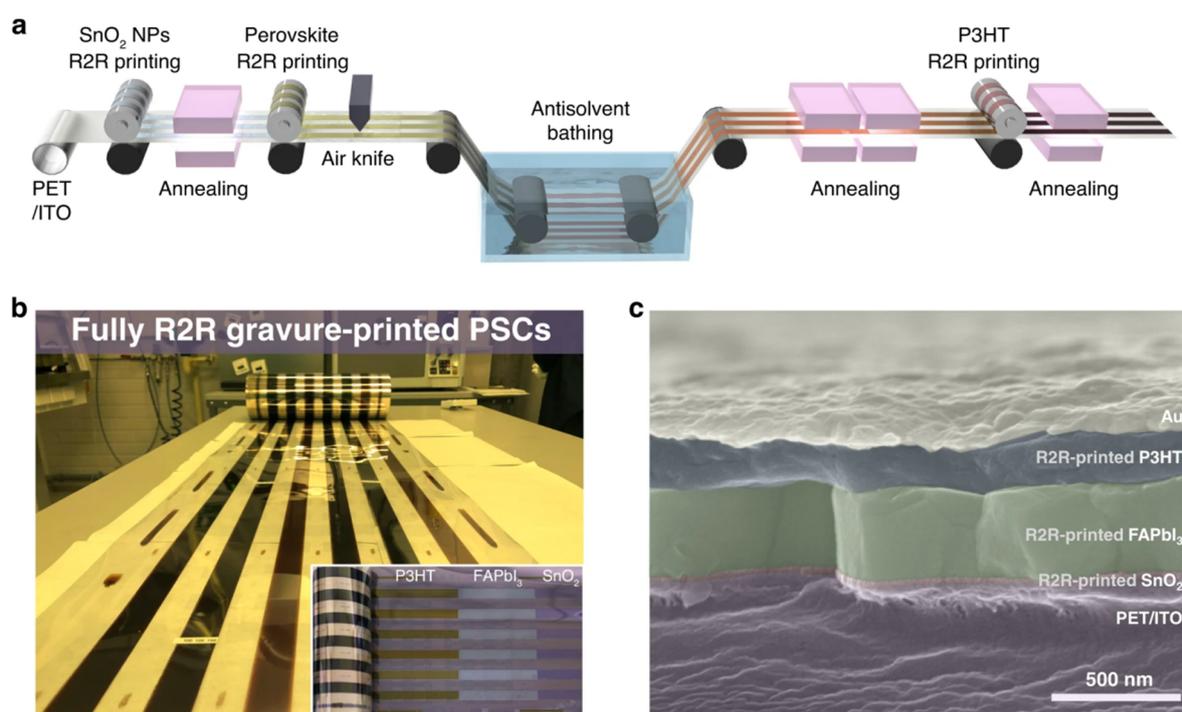


Figure 11. Computer image of all layers (excluding electrodes) are produced R2R on a pilot size in the PSCs process: (a) diagram of R2R processing for flexible PSC manufacture; (b) image of PSCs with complete R2R processing; (c) cross-sectional SEM image of PSCs by full R2R printing. Reprinted with permission from Ref. [137]. Copyright 2019, The Nature Publishing Group.

Recently, large-area PSC modules have been fabricated by several PV companies. A rigid perovskite mini module was realized by Microquanta Semiconductor (Hangzhou, China), which obtained an active area of 17.8 cm² with a PCE of 17.4% (Figure 12a) [6]. The perovskite modules with an area of 169 cm² and a GFF of 90% that exhibited an active area efficiency of 11.1% (total efficiency of 10%) were fabricated by Solliance (the Netherlands), using laser ablation to define the cells [138]. Those processing steps are compatible with the roll-to-roll process with flexible substrates and were realized at temperatures below 120 °C (Figure 12b) [6]. Figure 12c depicted perovskite solar modules with flexible substrates that were fabricated through inkjet printing by Saule Technologies (Poland), allowing free-form design patterns [6]. Recently, Oxford PV announced a perovskite–Si tandem solar cell with an area of 1 cm² that achieved a record certified PCE of 27.3% [6]. Huazhong University of Science and Technology (HUST) in China developed a printed triple mesoscopic PSC with a surface area of 100 cm², and the PSCs achieved an efficiency of more than 10% (Figure 12d). Based on those PSCs, the solar panel was assembled with an area of 7.0 m² in early 2015 [139]. Recently, Wonder Solar has released a 110 m² perovskite PV system by stacking screen-printed triple mesoscopic PSC modules with an area of 3600 cm² (Figure 12e) [6].

6.2. Batteries

Prussian blue analogues (PBAs) have sparked widespread interest for their potential use in energy storage and conversion owing to their ease of synthesis, low cost, and remarkable electrochemical performance [122]. Peng et al. scaled up the synthesis of the Fe-PBAs by employing a 100 L reactor and a 500 L reactor (Figure 13a–g) and increased the specific capacity of Fe-PBA-based sodium-ion from 80 mAh g⁻¹ to more than 100 mAh g⁻¹ by improving fabrication techniques [140]. The second generation of SIBs based on Na_{1.56}Fe[Fe(CN)₆]3.1H₂O were able to achieve a specific capacity of 116 mAh g⁻¹ at 10 mA g⁻¹ with a capacity retention of 83% at the current density of 500 mA g⁻¹, as shown in Figure 13h [140,141].

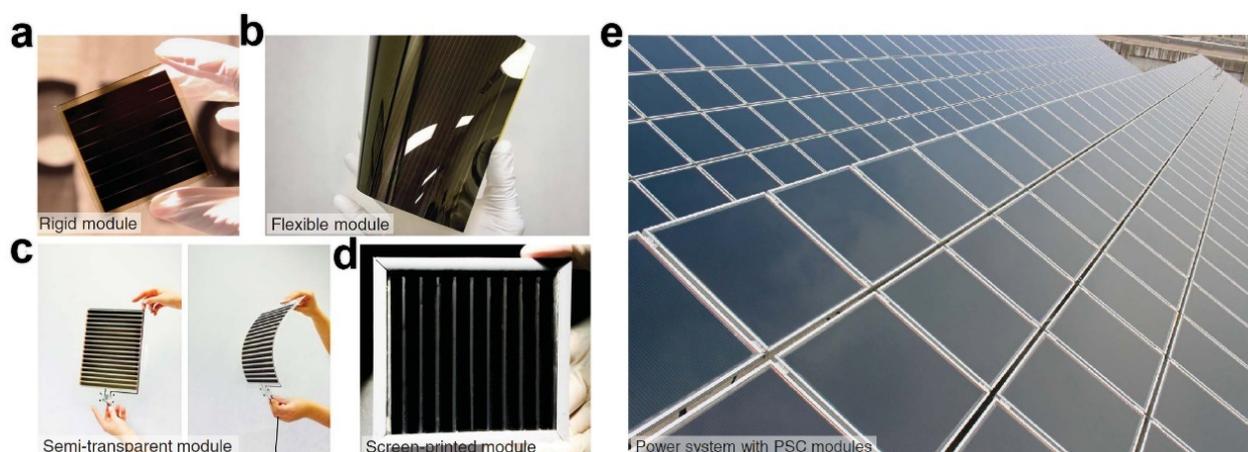


Figure 12. PSC modules: (a) rigid perovskite mini-module [Courtesy of Microquanta Semiconductor (China)]; (b) R2R processed flexible module [Courtesy of Solliance Solar Research (The Netherlands)]; (c) inkjet printing technique for Semitransparent module [Courtesy of Saule Technologies (Poland)]; (d) screen-printed module fabricated by Wuhan National Laboratory at HUST, reprinted with permission from Ref. [139]. Copyright 2017, Wiley-VCH; (e) Printable PSC modules for a power system. Reprinted with permission from Ref. [6]. Copyright 2018, American Association for the Advancement of Science.

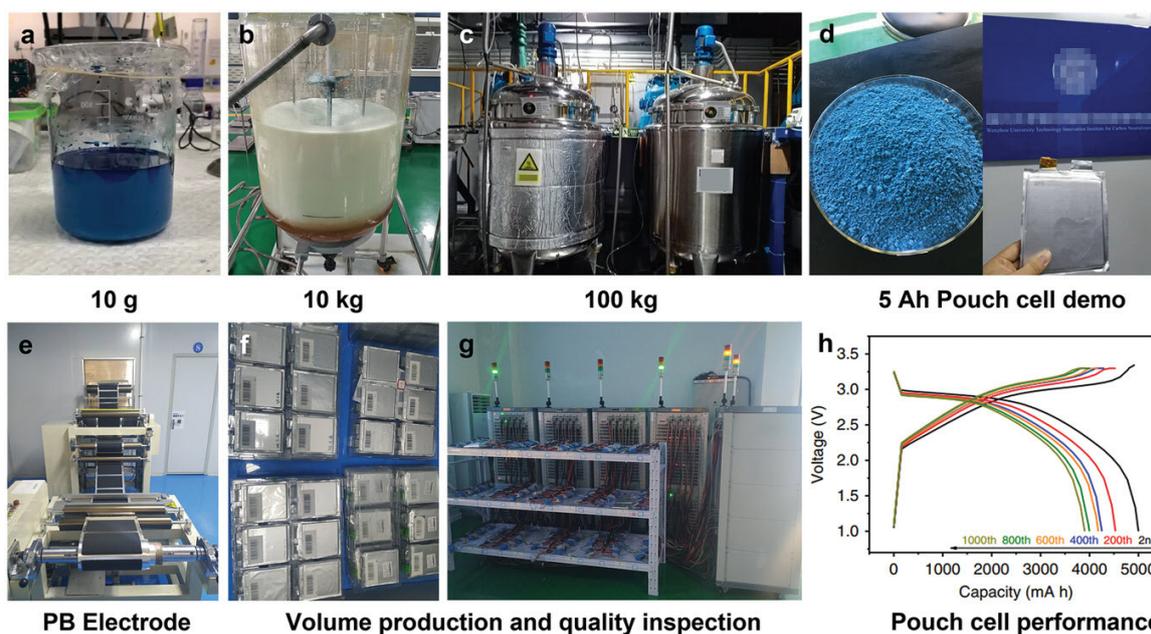


Figure 13. Different preparation quantity of (a) 10 g, (b) 10 kg, and (c) 100 kg of PBAs; (d–g) production line of sodium-ion pouch cell; (h) electrochemical performance of pouch cell. Reprinted with permission from Ref. [140]. Copyright 2020, Wiley-VCH.

A facile heat treatment was carried out by Wang et al. to remove water from PBAs cathode based on $\text{Na}_{2-x}\text{FeFe}(\text{CN})_6$ improved the performance of the fabricated sodium-ion soft package [142]. It is necessary to prevent rehydration due to contact with air during the battery manufacturing process and within the set charge cut-off voltage, the cycling performance of a well packaged sodium-ion battery can achieve more than 2000 times. Figure 14a demonstrates that a 100 L reactor was used to produce $\text{Na}_{2-x}\text{FeFe}(\text{CN})_6$ cathode on a large scale for practical application in SIBs with a yield about 4 kg. Figure 14b,c presented the powder of $\text{Na}_{2-x}\text{FeFe}(\text{CN})_6$ before and after heat treatment, respectively.

Figure 14d exhibits the sodium-ion cell based on $\text{Na}_{2-x}\text{FeFe}(\text{CN})_6$ as the cathode material and hard carbon as anode material connected with a lamp. Figure 14e shows that the sodium-ion cell also has good charge-discharge and cycling performance.

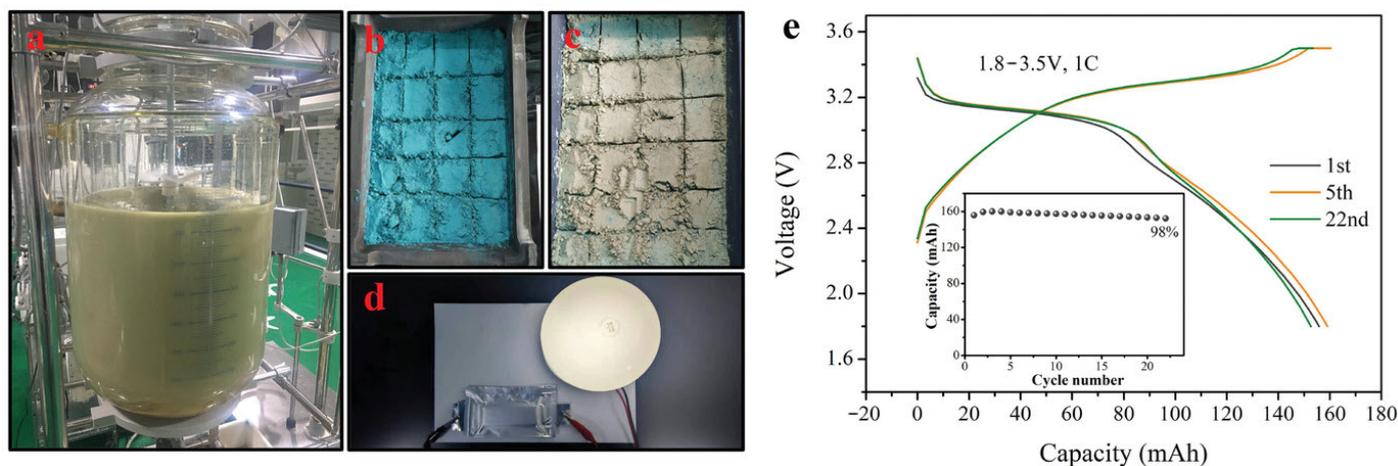


Figure 14. (a) 100 L reactor was used to produce $\text{Na}_{2-x}\text{FeFe}(\text{CN})_6$ in large scale; Powder of $\text{Na}_{2-x}\text{FeFe}(\text{CN})_6$ before (b) and after (c) heat treatment; (d) the sodium-ion cell based on $\text{Na}_{2-x}\text{FeFe}(\text{CN})_6$ lights a lamp; (e) charge-discharge properties of the battery cell. Reprinted with permission from Ref. [142]. Copyright 2022, Wiley-VCH.

To explore the performance of sodium-ion full batteries based on transition metal, $\text{Na}_3\text{V}(\text{PO}_4)_3$ (NVP) was fabricated as the cathode and the MoS_2 /carbon materials (SMSC-1-Mo-2) as the anode, as shown in Figure 15a [143]. The constructed SIB-full cell (SMSC-1-Mo-2/NVP) is recycled three times to avoid a side reaction between the electrode and electrolyte [143]. All of the CV and charge–discharge tests for the voltage window of SMSC-1-Mo-2//NVP are settled from 0.5 V to 3.2 V. From the CV curve of SMSC-1-Mo-2//NVP in Figure 15b, the cathodic sweep in CV showed two broad peaks at 1.58 and 2.52 V, and the anodic sweep showed two peaks in 1.32 and 1.81 V. The sodium-ion battery obtained a discharge capacity of 600 mAh g^{-1} and a charge specific capacity of 630 mAh g^{-1} at a current density of 0.05 A g^{-1} , with a CE of 95.2% based on SMSC-1-Mo-2 mass and performance, as displayed in Figure 15c. Figure 15d depicted that, even under large current densities from 0.1 to 4.0 A g^{-1} , the SMSC-1-Mo-2//NVP showed a discharge capacity of 394, 365, 337, 296, 251, and 201 mAh g^{-1} after five cycles, respectively. The cycling performance of the battery shown in Figure 15e indicates that the specific capacity of the full battery maintains 330 mAh g^{-1} after 100 cycles at 1.0 A g^{-1} . In Figure 15f, an LED bulb was efficiently powered by SMSC-1-Mo-2//NVP sodium-ion battery.

6.3. Hydrogen Production

In the short term, hydrogen production from coal is still the main source of hydrogen in China; in the medium term, hydrogen production from industrial by-products is expected to become the main process of hydrogen supply; however, the existing problems also make it unable to be used for a long time. In the long run, with a decline in renewable energy price, clean and efficient “green hydrogen” will become the mainstream process of hydrogen production. In the future, “green hydrogen” can be produced in large quantities by water splitting through electricity that is converted by solar, geothermal, or tidal energies, or by wind. The overall market for hydrogen consumption in 2021 is estimated to be about 115 billion, with a quick increase to 155 billion by 2022, indicating that hydrogen is becoming increasingly popular as an energy carrier [26].

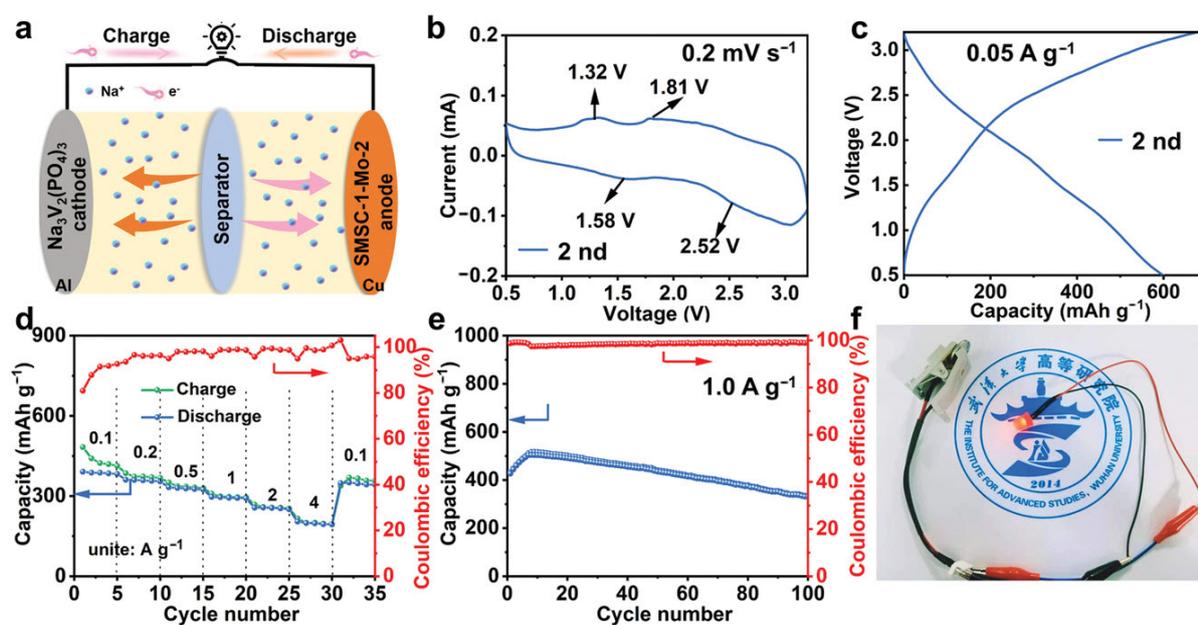


Figure 15. The performance properties of the SIB-full cell based on transition metal: (a) schematic diagram of sodium-ion battery (SMSC-1-Mo-2//NVP) with SMSC-1-Mo-2 as anode and $\text{Na}_3\text{V}_2(\text{PO}_4)_3$ as cathode; (b) CV, (c) charge-discharge curves, (d) rate capability, and (e) cycling performance of SMSC-1-Mo-2//NVP; (f) image of an LED bulb was powered by SMSC-1-Mo-2//NVP battery. Reprinted with permission from Ref. [143]. Copyright 2022, Wiley-VCH.

Lin et al. described a phosphate bimetallic of 2D NiFeP-based metal organic framework (MOF) nanosheet compounds with super-low Ru doping as the electrocatalyst on nickel foam (Ru-NiFeP/NF) for overall water-splitting electrodes [144]. MOFs with the unique characteristic of a large surface area have a 3D extension of space supported by organic ligands and are connected with metal ions point which have the potential to challenge the dominance of carbon-based materials [145]. By comparing the theoretical and actual amounts of gas created by the water-splitting device, the Faradaic efficiency of Ru-NiFeP/NF electrocatalysts as both an anode and cathode, for the entire water-splitting device in 1 M KOH, was achieved. The anode and cathode were kept apart by a piece of Nafion membrane, and the quantity of H_2 and O_2 created in the experiment was determined using the water drainage technique under the H-type electrolytic cell, as seen in Figure 16a [144]. The amount of O_2 and H_2 produced by the water-splitting device at 20 mA cm^{-2} was calculated theoretically and experimentally, and it was monitored and recorded every ten minutes. Figure 16b depicted that the gas quantified in the experiment is completely consistent with the theoretical value, indicating that the Faraday efficiency of OER and HER is close to 100%. By reading the displacement of the measuring cylinder, Figure 16c,d reflected the images of the volume of O_2 to H_2 at the various time periods of 10, 20, 30, 40, 50, and 60 min, and the volume ratio of oxygen and hydrogen is very close to 1:2 [144]. This study demonstrates that the Ru-NiFeP/NF electrocatalysis electrode with a nano porous structure prepared through the combination of morphologically controllable transition metals and precious metals with high electrochemical activity has a relatively low price and good application prospects.

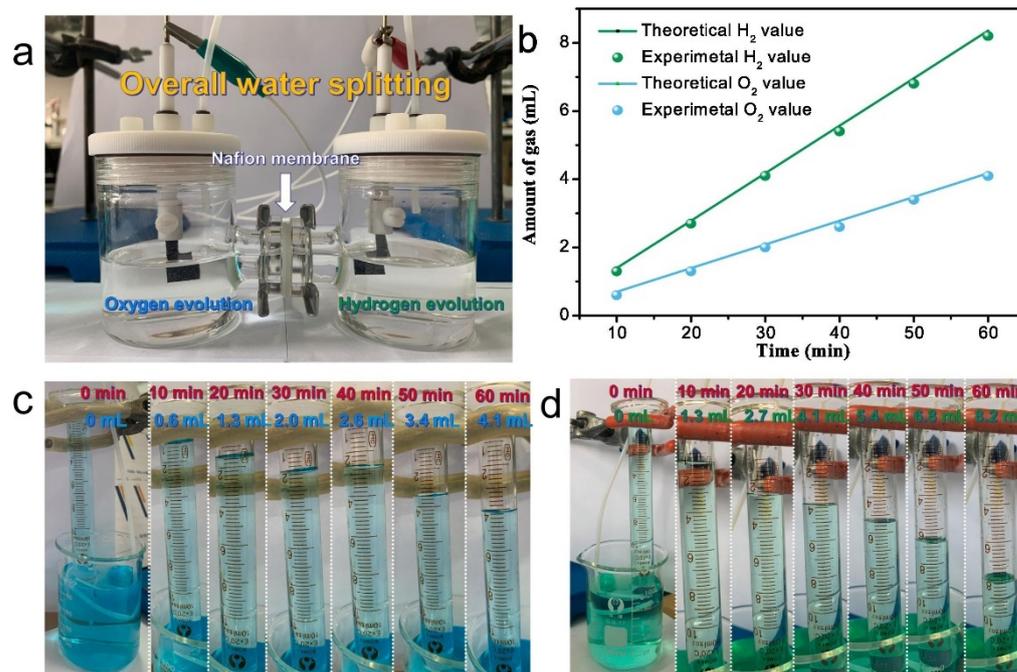


Figure 16. (a) Ru-NiFeP/NF electrocatalysts as both anode and cathode for overall water-splitting device in 1 M KOH. (b) The theoretical and experimental amount of gas generated by the water-splitting device at 20 mA cm^{-2} . (c) Oxygen and (d) hydrogen were collected at ten minutes intervals. Reprinted with permission from Ref. [144]. Copyright 2021, Elsevier.

7. Discussion and Limitation

The photoelectric conversion efficiency of PSCs has now surpassed 26%; moreover, if its drawbacks are of unsatisfactory stability under real usage scenario and difficulties in making large aperture area are solved, it will have a large influence on energy generation and consumption [146]. To acquire an enhanced light absorption ability and excellent electrical characteristics with good stability, the new PSCs' working mechanisms and innovative material preparation processes should be explored to construct novel device architectures [147]. For recharge batteries, although lithium-ion batteries have received unprecedented policy support in recent years, the development of bottleneck of lithium-ion batteries due to a resource shortage of Li element is obvious [148]. Other battery systems, such as sodium-ion, lithium-sulfur, potassium ion, zinc ion, or aluminum ion batteries should receive more attention, as they may have the opportunity to partially replace lithium-ion batteries [149]. In this study, sodium-ion batteries are used as an example. The energy density and cycle stability of SIBs should be enhanced by introducing novel materials with excellent structures to increase the capacity of sodium ions and decrease the volume expansion of active materials during sodium storage, thereby expanding their range of practical applications [150]. Furthermore, a large number of rechargeable batteries have been produced, and the substances in them have a certain impact on the environment [151]. Policymaking processes should also encourage the recycling of batteries and create a closed-loop system for using resources in the battery industry, which is conducive to the benign development of the energy storage industry [152]. For electrolytic water hydrogen production, this study focused on the mainstream research direction of electrocatalytic materials for hydrogen production and introduced and analyzed the manufacturing methods, working principles, and applications of these electrocatalytic electrodes according to their material systems. Further study in this field should concentrate on fundamental research using system theoretical calculations and should promote the creation of low-cost, efficient, stable, and long-term electrode materials [153].

It is advantageous for all nations to improve the pattern of energy utilization through the extensive presentation of policies of various nations and regions that realize mutual

learning, understanding, and promotion. This research also encourages us to make full use of solar energy and turn it into hydrogen or electricity before sending it to each power-using device such as batteries. This would inspire us to use energy in ways that are low-carbon and good for the environment. In-depth theoretical analysis and research on new materials and device architectures based on an understanding of how different devices work is the key to achieving the widespread use of these technologies, and this, in turn, promotes policy optimization and formulation.

The limitation of this study is that it contributes to the theoretical comparative analysis of national energy policy. The three political patterns summarized by this study could be further extended and improved to facilitate the paradigm of future empirical research. Whether there is a causal relationship between technological innovation and the policy mechanism underpinning it should be further studied through a long-term tracking investigation. Meanwhile, more details and applications of the above techniques should be further analyzed, and other kinds of new energy technologies are also the basis for formulating the relevant policies.

8. Conclusions

Currently, traditional energy sources such as coal, natural gas, and oil still occupy a dominant position in energy usage. The government implements energy transition policies for energy-related climate change. We examined three types of policymaking models to explain regulatory instruments in different countries. Variations in political institutions can affect technical innovation and application, wherein the enactment of regulations, subsidies, and supportive policies is essential for the energy transition. As sustainable technologies have scaled up over time, policies needed to be extended and expanded to stimulate the development and application of relevant technologies in a benign direction.

The USA, China, and European countries may encounter a series of problems in the process of the energy transition. When tracing the evolution of energy-related policies, we find that the well-developed institutional capacity affects the choice of policy instrument. The variation of national energy transition politics is deeply rooted in the national culture and in historical contexts. The policymakers need to negotiate and balance the various interests of different stakeholders when producing policy innovation. To ensure the security of sustainable energy supply and consumption, some problems should be addressed now, such as how to integrate the energy market, how to solve the problems related to the insufficient construction of emerging energy infrastructure, and how to balance the cost of improving energy efficiency and the loss of fossil energy enterprises. In terms of technology, the energy transition faces the demand of continuous research and the long-term development of various energy technologies. We conclude that, to complete the transition to renewable energy, persistent political backing for these technologies through long-term advocacy alliances is required.

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References

1. Larcher, D.; Tarascon, J.M. Towards greener and more sustainable batteries for electrical energy storage. *Nat. Chem.* **2015**, *7*, 19–29. [[CrossRef](#)]
2. Hosenuzzaman, M.; Rahim, N.A.; Selvaraj, J.; Hasanuzzaman, M.; Malek, A.B.M.A.; Nahar, A. Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. *Renew. Sust. Energ. Rev.* **2015**, *41*, 284–297. [[CrossRef](#)]
3. Liu, C.F.; Yuan, J.F.; Masse, R.; Jia, X.X.; Bi, W.C.; Neale, Z.; Shen, T.; Xu, M.; Tian, M.; Zheng, J.Q.; et al. Interphases, Interfaces, and Surfaces of Active Materials in Rechargeable Batteries and Perovskite Solar Cells. *Adv. Mater.* **2020**, *33*, 1905245. [[CrossRef](#)] [[PubMed](#)]
4. Armand, M.; Tarascon, J.M. Building better batteries. *Nature* **2008**, *451*, 652–657. [[CrossRef](#)] [[PubMed](#)]
5. Salanne, M.; Rotenberg, B.; Naoi, K.; Kaneko, K.; Taberna, P.L.; Grey, C.P.; Dunn, B.; Simon, P. Efficient storage mechanisms for building better supercapacitors. *Nat. Energy* **2016**, *1*, 16070. [[CrossRef](#)]
6. Rong, Y.; Hu, Y.; Mei, A.; Tan, H.; Saidaminov, M.I.; Seok, S.I.; McGehee, M.D.; Sargent, E.H.; Han, H. Challenges for commercializing perovskite solar cells. *Science* **2018**, *361*, eaat8235. [[CrossRef](#)]
7. Hughes, L.; Lipsky, P.Y. The politics of energy. *Annu. Rev. Political Sci.* **2013**, *16*, 449–469. [[CrossRef](#)]
8. Hughes, L.; Urpelainen, J. Interests, institutions, and climate policy: Explaining the choice of policy instruments for the energy sector. *Environ. Sci. Policy* **2015**, *54*, 52–63. [[CrossRef](#)]
9. Lewis, N.S. Light work with water. *Nature* **2001**, *414*, 589–590. [[CrossRef](#)] [[PubMed](#)]
10. Grätzel, M. Photoelectrochemical cells. *Nature* **2001**, *414*, 338–344. [[CrossRef](#)]
11. Li, S.L.; Xu, Q. Metal-organic frameworks as platforms for clean energy. *Energy Environ. Sci.* **2013**, *6*, 1656–1683. [[CrossRef](#)]
12. Jia, C.; Zhao, X.; Lai, Y.H.; Zhao, J.; Wang, P.C.; Liou, D.S.; Wang, P.; Liu, Z.; Zhang, W.; Chen, W.; et al. Highly flexible, robust, stable and high efficiency perovskite solar cells enabled by van der Waals epitaxy on mica substrate. *Nano Energy* **2019**, *60*, 476–484. [[CrossRef](#)]
13. Yang, D.; Yang, R.; Priya, S.; Liu, S.F. Recent Advances in Flexible Perovskite Solar Cells: Fabrication and Applications. *Angew. Chem. Int. Ed. Engl.* **2019**, *58*, 4466–4483. [[CrossRef](#)] [[PubMed](#)]
14. Yu, C.J.; Pak, Y.C.; Kim, C.H.; Kim, J.S.; Ri, K.C.; Ri, K.H.; Choe, S.H.; Cottenier, S. Structural and electrochemical trends in mixed manganese oxides $\text{Na}_x(\text{M}_{0.44}\text{Mn}_{0.56})\text{O}_2$ (M = Mn, Fe, Co, Ni) for sodium-ion battery cathode. *J. Power Sources* **2021**, *511*, 230395. [[CrossRef](#)]
15. Li, M.; Zhu, K.; Zhao, H.; Meng, Z.; Wang, C.; Chu, P.K. Construction of $\alpha\text{-MnO}_2$ on Carbon Fibers Modified with Carbon Nanotubes for Ultrafast Flexible Supercapacitors in Ionic Liquid Electrolytes with Wide Voltage Windows. *Nanomaterials* **2022**, *12*, 2020. [[CrossRef](#)]
16. Li, S.; Leng, D.; Li, W.; Long, Q.; Fan, Z. Recent Progress in Developing Li_2S Cathodes for Li-S Batteries. *Energy Storage Mater.* **2020**, *27*, 279–296. [[CrossRef](#)]
17. Li, S.; Fan, Z. Encapsulation methods of sulfur particles for lithium-sulfur batteries: A review. *Energy Storage Mater.* **2021**, *34*, 107–127. [[CrossRef](#)]
18. Li, L.; Zheng, Y.; Zhang, S.; Yang, J.; Shao, Z.; Guo, Z. Recent progress on sodium ion batteries: Potential high-performance anodes. *Energy Environ. Sci.* **2018**, *11*, 2310–2340. [[CrossRef](#)]
19. Xiang, X.; Zhang, K.; Chen, J. Recent Advances and Prospects of Cathode Materials for Sodium-Ion Batteries. *Adv. Mater.* **2015**, *27*, 5343–5364. [[CrossRef](#)] [[PubMed](#)]
20. Marbán, G.; Valdés-Solís, T. Towards the hydrogen economy? *Int. J. Hydrogen Energy* **2007**, *3*, 1625–1637. [[CrossRef](#)]
21. Borgschulte, A.; Züttel, A.; Wittstadt, U. Hydrogen Production. In *Hydrogen as a Future Energy Carrier*; John Wiley & Sons: Hoboken, NJ, USA, 2008; pp. 149–164.
22. Schlapbach, L.; Züttel, A. Hydrogen-storage materials for mobile applications. *Nature* **2001**, *414*, 353–358. [[CrossRef](#)] [[PubMed](#)]
23. Vayssieres, L. On Solar Hydrogen & Nanotechnology. *J. Phys-Condens Mat.* **2010**, *20*, 1005–1008.
24. Gupta, R.B. *Hydrogen Fuel: Production, Transport, and Storage*; CRC Press: Boca Raton, FL, USA, 2008.
25. Barreto, L.; Makihiro, A.; Riahi, K. The hydrogen economy in the 21st century: A sustainable development scenario. *Int. J. Hydrogen Energy* **2003**, *28*, 267–284. [[CrossRef](#)]
26. Yu, Z.; Duan, Y.; Feng, X.U.; Yu, X.; Yu, S. Clean and Affordable Hydrogen Fuel from Alkaline Water Splitting: Past, Recent Progress, and Future Prospects. *Adv. Mater.* **2021**, *33*, 2007100. [[CrossRef](#)]
27. Trampusch, C.; Palier, B. Between X and Y: How process tracing contributes to opening the black box of causality. *New Polit. Econ.* **2016**, *2*, 437–454. [[CrossRef](#)]
28. Liu, H. The impact of conservative neo-liberalism on American climate policy. *J. Fujian Norm. Univ. (Philos. Soc. Sci. Ed.)* **2022**, *2*, 52–170.
29. Spark, M. *Matsunaga Hydrogen Research, Development, and Demonstration Act of 1990*. COM/1990/1115; Congress: American, 1990. Available online: <https://www.congress.gov/bill/101st-congress/senate-bill/639> (accessed on 31 July 2022).
30. *Hydrogen Future Act of 1996*. COM/1996/1009; Congress: American, 1996. Available online: https://www.hydrogen.energy.gov/pdfs/hydrogen_future_act_1996.pdf (accessed on 31 July 2022).
31. United States Department of Energy. *A National Vision of America's Transition to a Hydrogen Economy-to 2030 and Beyond*; COM/2002/0212; United States Department of Energy: Washington, DC, USA, 2002. Available online: https://www.hydrogen.energy.gov/pdfs/vision_doc.pdf (accessed on 31 July 2022).

32. United States Department of Energy. *National Hydrogen Energy Roadmap*; COM/2002/1031; United States Department of Energy: Washington, DC, USA, 2002. Available online: https://www.hydrogen.energy.gov/pdfs/national_h2_roadmap.pdf (accessed on 31 July 2022).
33. The White House. *The President's Hydrogen Fuel Initiative*; COM/2003/0128; The White House: Washington, DC, USA, 2003; Available online: <https://georgewbush-whitehouse.archives.gov/news/releases/2003/01/20030130-20.html> (accessed on 31 July 2022).
34. The Council of Economic Advisers. *The All-of-the-Above Energy Strategy*; COM/2014/0529; The Council of Economic Advisers: Washington, DC, USA, 2014. Available online: https://obamawhitehouse.archives.gov/sites/default/files/docs/aota_report_updated_july_2014.pdf (accessed on 31 July 2022).
35. United States Department of Energy. *Hydrogen Energy Earth Shot Initiative*; COM/2021/0607; United States Department of Energy: Washington, DC, USA, 2021. Available online: <https://www.energy.gov/policy/energy-earthshots-initiative> (accessed on 31 July 2022).
36. Congress. *Energy Tax Act*; COM/1977/0321; Congress of the United States: Washington, DC, USA, 1977. Available online: <https://www.congress.gov/bill/95th-congress/house-bill/5263> (accessed on 31 July 2022).
37. United States Department of Energy. *The Energy Policy Act of 1992*; COM/1992/1024; United States Department of Energy: Washington, DC, USA, 1992. Available online: <https://www.energy.gov/gc/epact-1992-usc> (accessed on 31 July 2022).
38. United States Department of Energy. *The Energy Policy Act of 2005*; COM/2005/0808; United States Department of Energy: Washington, DC, USA, 2005. Available online: <https://www.energy.gov/gc/epact-2005-usc> (accessed on 31 July 2022).
39. *Energy Independence and Security Act of 2007*; COM/2007/1219; Congress of the United States: Washington, DC, USA, 2007. Available online: <https://www.epa.gov/greeningepa/energy-independence-and-security-act-2007> (accessed on 31 July 2022).
40. Young, O.R.; Guttman, D.; Qi, Y.; Bachus, K.; Belis, D.; Cheng, H.; Zhu, X. Institutionalized governance processes: Comparing environmental problem-solving in China and the United States. *Global Environ. Chang* **2015**, *31*, 163–173. [CrossRef]
41. Gilley, B. Authoritarian environmentalism and China's response to climate change. *Environ. Polit.* **2012**, *21*, 287–307. [CrossRef]
42. Richard, L.B. An Inquiry into the Human Prospect. *J. Econ. Issues* **1984**, *18*, 941–994.
43. Beeson, M. The coming of environmental authoritarianism. *Environ. Polit.* **2010**, *19*, 276–294. [CrossRef]
44. The State Council of the People's Republic of China. *Outline of National Medium and Long-Term Science and Technology Development Plan (2006–2020)*; COM/2006/0209; The State Council of the People's Republic of China: Beijing, China, 2006. Available online: http://www.gov.cn/gongbao/content/2006/content_240244.htm (accessed on 31 July 2022).
45. The State Council of the People's Republic of China. *Energy Conservation and New Energy Vehicle Industry Development Plan (2012–2020)*; COM/2012/0709; The State Council of the People's Republic of China: Beijing, China, 2012. Available online: http://www.gov.cn/zwzkg/2012-07/09/content_2179032.htm (accessed on 31 July 2022).
46. The National Development and Reform Commission and the National Energy Administration. *Energy Technology Revolution Innovation Action Plan (from 2016 to 2030)*; COM/2016/0601; The National Development and Reform Commission and the National Energy Administration: Beijing, China, 2016. Available online: http://www.gov.cn/xinwen/2016-06/01/content_5078628.htm (accessed on 31 July 2022).
47. The National Development and Reform Commission and the National Energy Administration. *Energy Law of the People's Republic of China (Draft for Comment)*; COM/2020/0410; The National Development and Reform Commission and the National Energy Administration: Beijing, China, 2020. Available online: http://www.nea.gov.cn/2020-04/10/c_138963212.htm (accessed on 31 July 2022).
48. The National People's Congress. *The 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of Long-Term Goals for 2035*; COM/2021/0312; The National People's Congress: Beijing, China, 2021. Available online: http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm (accessed on 31 July 2022).
49. Urban-Rural Development of the People's Republic of China. *The Opinions on Accelerating the Implementation and Applications of Solar Photovoltaic Buildings*; COM/2009/0329; Urban-Rural Development of the People's Republic of China: Beijing, China, 2009. Available online: http://www.gov.cn/zwzkg/2009-03/26/content_1269282.htm (accessed on 31 July 2022).
50. The State Electricity Regulatory Commission. *The Notice on Renewable Energy Electricity Price Subsidies and Quota Trading Schemes from July to December of 2008*; COM/2009/0701; The State Electricity Regulatory Commission: Beijing, China, 2009. Available online: http://www.gov.cn/zwzkg/2009-07/01/content_1354370.htm (accessed on 31 July 2022).
51. National Energy Administration. *The Notice on Declaring a Demonstration Zone for the Large-Scale Application of Distributed Photovoltaic Power Generation*; COM/2012/0928; National Energy Administration: Beijing, China, 2012. Available online: http://www.gov.cn/zwzkg/2012-09/28/content_2235051.htm (accessed on 31 July 2022).
52. The State Council of the People's Republic of China. *The Several Opinions on Promoting the Healthy Development of the Photovoltaic Industry*; COM/2013/0715; The State Council of the People's Republic of China: Beijing, China, 2013. Available online: http://www.gov.cn/zwzkg/2013-07/15/content_2447814.htm (accessed on 31 July 2022).
53. National Energy Administration. *The Notice on Further Implementing the Policies Related to Distributed Photovoltaic Power Generation*; COM/2014/0902; National Energy Administration: Beijing, China, 2014. Available online: http://zfxgk.nea.gov.cn/auto87/201409/t20140904_1837.htm (accessed on 31 July 2022).
54. National Energy Administration. *The Notice on the Price Policy of Photovoltaic Power Generation Project of 2018*; COM/2018/0531; National Energy Administration: Beijing, China, 2018. Available online: http://www.gov.cn/zhengce/zhengceku/2018-12/31/content_5433580.htm (accessed on 31 July 2022).

55. National Energy Administration. *The Notice on Actively Promoting the Work Related to the Subsidy-free Grid Parity of Wind Power and Photovoltaic Power Generation*; COM/2019/0110; National Energy Administration: Beijing, China, 2019. Available online: http://www.nea.gov.cn/2019-01/10/c_137731320.htm (accessed on 31 July 2022).
56. National Development and Reform Commission. *The Notice on Problems Related to Improve the Feed-in Tariff Mechanism for Photovoltaic Power Generation*; COM/2019/0428; National Development and Reform Commission: Beijing, China, 2019. Available online: https://www.ndrc.gov.cn/xxgk/zcfb/tz/201904/t20190430_962433.html?code=&state=123 (accessed on 31 July 2022).
57. National Energy Administration. *The Notice on Matters Related to the Development and Construction of Wind Power and Photovoltaic Power Generation of 2021*; COM/2021/0511; National Energy Administration: Beijing, China, 2021. Available online: http://zfxgk.nea.gov.cn/2021-05/11/c_139958210.htm (accessed on 31 July 2022).
58. The State Council of the People's Republic of China. *Implementation Plan on Promoting the High-Quality Development of New Energy in the New Era*; COM/2022/0514; The State Council of the People's Republic of China: Beijing, China, 2022. Available online: http://www.gov.cn/zhengce/content/2022-05/30/content_5693013.htm (accessed on 31 July 2022).
59. Li, X.; Yang, X.; Wei, Q.; Zhang, B. Authoritarian environmentalism and environmental policy implementation in China. *Resour. Conserv. Recy.* **2019**, *145*, 86–93. [[CrossRef](#)]
60. Van Baal, P.A.; Finger, M. The Effect of European Integration on Swiss Energy Policy and Governance. *Politics Gov.* **2019**, *7*, 6–16. [[CrossRef](#)]
61. Commission of the European Communities. *Energy in Europe*; COM/1986/0905; Commission of the European Communities: Luxembourg, 1986. Available online: http://aei.pitt.edu/79850/1/5_Sept_1986.pdf (accessed on 31 July 2022).
62. European Commission. *2020 Climate and Energy Package*; COM (2007); European Commission: Brussels, Belgium, 2007. Available online: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2020-climate-energy-package_en (accessed on 31 July 2022).
63. European Commission. *Energy Roadmap 2050*; COM (2011); European Commission: Luxembourg, 2011. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf (accessed on 31 July 2022).
64. European Commission. *The Roadmap for Transforming the EU into a Competitive, Low-Carbon Economy by 2050*; COM/2011/0308; European Commission: Brussels, Belgium, 2011. Available online: https://ec.europa.eu/clima/system/files/2016-12/2050_roadmap_en.pdf (accessed on 31 July 2022).
65. European Commission. *The 2030 Climate and Energy Framework*; COM/2014/0122; European Commission: Brussels, Belgium, 2014. Available online: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2030-climate-energy-framework_sl (accessed on 31 July 2022).
66. Fuel Cells and Hydrogen Joint Undertaking. *European Hydrogen Roadmap: A Sustainable Pathway for the European Energy Transition*; COM/2019/0212; Fuel Cells and Hydrogen Joint Undertaking: Brussels, Belgium, 2019. Available online: https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf (accessed on 31 July 2022).
67. European Commission. *A European Green Deal*; COM/2019/1211; European Commission: Brussels, Belgium, 2019. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed on 31 July 2022).
68. Shi, B.; Duan, L.; Zhao, Y.; Luo, J.; Zhang, X. Semitransparent Perovskite Solar Cells: From Materials and Devices to Applications. *Adv. Mater.* **2020**, *32*, 1806474.1–1806474.12. [[CrossRef](#)]
69. Li, T.; Yang, Y.; Li, G.; Chen, P.; Gao, X. Two-Terminal Perovskite-Based Tandem Solar Cells for Energy Conversion and Storage. *Small* **2021**, *17*, 2006145. [[CrossRef](#)]
70. Badawy, W.A. A review on solar cells from Si-single crystals to porous materials and quantum dots. *J. Adv. Res.* **2015**, *6*, 123–132. [[CrossRef](#)]
71. Kojima, A.; Teshima, K.; Shirai, Y.; Miyasaka, T. Organometal Halide Perovskites as Visible-Light Sensitizers for Photovoltaic Cells. *J. Am. Chem. Soc.* **2009**, *131*, 6050–6051. [[CrossRef](#)] [[PubMed](#)]
72. Kim, H.S.; Lee, C.R.; Im, J.H.; Lee, K.B.; Moehl, T.; Marchioro, A.; Moon, S.J.; Humphry-Baker, R.; Yum, J.H.; Moser, J.E. Lead Iodide Perovskite Sensitized All-Solid-State Submicron Thin Film Mesoscopic Solar Cell with Efficiency Exceeding 9%. *Sci. Rep.* **2012**, *2*, 591. [[CrossRef](#)] [[PubMed](#)]
73. Liu, M.; Johnston, M.B.; Snaith, H.J. Efficient planar heterojunction perovskite solar cells by vapour deposition. *Nature* **2013**, *501*, 395–398. [[CrossRef](#)] [[PubMed](#)]
74. Yoo, J.J.; Seo, G.; Chua, M.R.; Park, T.G.; Lu, Y.; Rotermund, F.; Kim, Y.K.; Moon, C.S.; Jeon, N.J.; Correa-Baena, J.P.; et al. Efficient perovskite solar cells via improved carrier management. *Nature* **2021**, *590*, 587–593. [[CrossRef](#)] [[PubMed](#)]
75. Kim, J.Y.; Lee, J.W.; Jung, H.S.; Shin, H.; Park, N.G. High-Efficiency Perovskite Solar Cells. *Chem. Rev.* **2020**, *120*, 7867–7918. [[CrossRef](#)]
76. Wang, Y.; Duan, C.; Lv, P.; Ku, Z.; Lu, J.; Huang, F.; Cheng, Y.B. Printing strategies for scaling-up perovskite solar cells. *Natl. Sci. Rev.* **2021**, *8*, 24. [[CrossRef](#)]
77. Huang, Y.T.; Kavanagh, S.R.; Scanlon, D.O.; Walsh, A.; Hoyer, R. Perovskite-inspired materials for photovoltaics and beyond—from design to devices. *Nanotechnology* **2021**, *32*, 132004. [[CrossRef](#)] [[PubMed](#)]
78. Lyu, M.; Yun, J.H.; Chen, P.; Hao, M.; Wang, L. Addressing Toxicity of Lead: Progress and Applications of Low-Toxic Metal Halide Perovskites and Their Derivatives. *Adv. Energy Mater.* **2017**, *7*, 1602512. [[CrossRef](#)]
79. Park, B.W.; Philippe, B.; Zhang, X.; Rensmo, H.; Boschloo, G.; Johansson, E. Bismuth Based Hybrid Perovskites A₃Bi₂I₉ (A: Methylammonium or Cesium) for Solar Cell Application. *Adv. Mater.* **2016**, *27*, 6806–6813. [[CrossRef](#)] [[PubMed](#)]

80. Ma, L.; Hao, F.; Stoumpos, C.C.; Phelan, B.T.; Wasielewski, M.R.; Kanatzidis, M.G. Carrier Diffusion Lengths of over 500 nm in Lead-Free Perovskite $\text{CH}_3\text{NH}_3\text{SnI}_3$ Films. *J. Am. Chem. Soc.* **2016**, *138*, 14750–14755. [[CrossRef](#)]
81. Chakrabarti, T.; Saha, M.; Khanda, A.; Sarkar, S.K. Modeling of Lead-Free $\text{CH}_3\text{NH}_3\text{SnI}_3$ -Based Perovskite Solar Cell Using ZnO as ETL. In *Advances in Communication, Devices and Networking*; Bera, R., Sarkar, S., Chakraborty, S., Eds.; Lecture Notes in Electrical Engineering; Springer: Singapore, 2018; Volume 462, pp. 125–131.
82. Wang, L.; Wang, Z.X.; Li, H.; Chang, B.; Pan, L.; Xie, Z.; Yin, L. Pseudohalide anions to suppress oxidative degradation for efficient formamidinium-based Sn–Pb halide perovskite solar cells. *ACS Appl. Mater. Interfaces* **2022**, *14*, 18302–18312. [[CrossRef](#)]
83. Lin, R.; Xiao, K.; Qin, Z.; Han, Q.; Zhang, C.; Wei, M.; Saidaminov, M.I.; Gao, Y.; Xu, J.; Xiao, M.; et al. Monolithic all-perovskite tandem solar cells with 24.8% efficiency exploiting comproportionation to suppress Sn(II) oxidation in precursor ink. *Nat. Energy* **2019**, *4*, 864–873.
84. Giuri, A.; Munir, R.; Listorti, A.; Esposito Corcione, C.; Gigli, G.; Rizzo, A.; Amassian, A.; Colella, S. Implication of polymeric template agent on the formation process of hybrid halide perovskite films. *Nanotechnology* **2021**, *32*, 265707. [[CrossRef](#)]
85. Han, Q.; Yang, S.; Wang, L.; Yu, F.; Zhang, C.; Wu, M.; Ma, T. The sulfur-rich small molecule boosts the efficiency of carbon-based CsPbI_2Br perovskite solar cells to approaching 14%. *Sol. Energy* **2021**, *216*, 351–357. [[CrossRef](#)]
86. Zhao, Y.; Wei, J.; Li, H.; Yan, Y.; Zhou, W.; Yu, D.; Zhao, Q. A polymer scaffold for self-healing perovskite solar cells. *Nat. Commun.* **2016**, *7*, 10228. [[CrossRef](#)]
87. Zhao, Y.C.; Heumueller, T.; Zhang, J.Y.; Luo, J.S.; Kasian, O.; Langner, S.; Kupfer, C.; Liu, B.; Zhong, Y.; Elia, J.; et al. A bilayer conducting polymer structure for planar perovskite solar cells with over 1400 h operational stability at elevated temperatures. *Nat. Energy* **2022**, *7*, 144–152. [[CrossRef](#)]
88. Enomoto, J.; Sato, R.; Yokoyama, M.; Kimura, T.; Oshita, N.; Umemoto, K.; Asakura, S.; Masuhara, A. Highly luminescent MAPbI_3 perovskite quantum dots with a simple purification process via ultrasound-assisted bead milling. *RSC Adv.* **2022**, *12*, 5571–5576. [[CrossRef](#)]
89. Fan, R.; Zhou, N.; Zhang, L.; Yang, R.; Meng, Y.; Li, L.; Guo, T.; Chen, Y.; Xu, Z.; Zheng, G.; et al. Toward Full Solution Processed Perovskite/Si Monolithic Tandem Solar Device With PCE Exceeding 20%. *Solar RRL* **2017**, *1*, 1700149. [[CrossRef](#)]
90. Chen, Q.; Zhou, H.; Hong, Z.; Luo, S.; Duan, H.S.; Wang, H.H.; Liu, Y.; Li, G.; Yang, Y. Planar Heterojunction Perovskite Solar Cells via Vapor-Assisted Solution Process. *J. Am. Chem. Soc.* **2014**, *136*, 622–625. [[CrossRef](#)] [[PubMed](#)]
91. Zhou, H.P.; Chen, Q.; Li, G.; Luo, S.; Song, T.B.; Duan, H.S.; Hong, Z.R.; You, J.B.; Liu, Y.S.; Yang, Y. Interface engineering of highly efficient perovskite solar cells. *Science* **2014**, *345*, 542–546. [[CrossRef](#)] [[PubMed](#)]
92. Huang, H.; Yan, H.; Duan, M.; Ji, J.; Liu, X.; Jiang, H.; Liu, B.; Sajid, S.; Cui, P.; Li, Y.; et al. TiO_2 surface oxygen vacancy passivation towards mitigated interfacial lattice distortion and efficient perovskite solar cell. *Appl. Surf. Sci.* **2021**, *544*, 148583. [[CrossRef](#)]
93. Chu, S.; Cui, Y.; Liu, N. The path towards sustainable energy. *Nat. Mater.* **2017**, *16*, 16–22. [[CrossRef](#)]
94. Yin, X.; Sarkar, S.; Shi, S.; Huang, Q.-A.; Zhao, H.; Yan, L.; Zhao, Y.; Zhang, J. Recent Progress in Advanced Organic Electrode Materials for Sodium-Ion Batteries: Synthesis, Mechanisms, Challenges and Perspectives. *Adv. Funct. Mater.* **2020**, *30*, 1908445. [[CrossRef](#)]
95. Pan, H.L.; Yong-Sheng, H.U.; Hong, L.I.; Chen, L.Q. Recent progress in structure study of electrode materials for room-temperature sodium-ion stationary batteries. *Sci. Sin. Chim.* **2014**, *44*, 1269.
96. Li, M.; Zhu, K.L.; Meng, Z.Y.; Hu, R.H.; Wang, J.L.; Wang, C.R.; Chu, P.K. Efficient coupling of MnO_2/TiN on carbon cloth positive electrode and $\text{Fe}_2\text{O}_3/\text{TiN}$ on carbon cloth negative electrode for flexible ultra-fast hybrid supercapacitors. *RSC Adv.* **2021**, *11*, 35726–35736. [[CrossRef](#)]
97. Hwang, J.Y.; Myung, S.T.; Sun, Y.K. Sodium-ion batteries: Present and future. *Chem. Soc. Rev.* **2017**, *46*, 3529–3614. [[CrossRef](#)] [[PubMed](#)]
98. Zhao, C.; Lu, Y.; Chen, L.; Hu, Y.S. Flexible Na batteries. *InfoMat* **2020**, *2*, 126–138. [[CrossRef](#)]
99. Yabuuchi, N.; Kubota, K.; Dahbi, M.; Komaba, S. Research Development on Sodium-Ion Batteries. *Chem. Rev.* **2014**, *114*, 11636–11682. [[CrossRef](#)] [[PubMed](#)]
100. Zhao, F.; Han, N.; Huang, W.; Li, J.; Ye, H.; Chen, F.; Li, Y. Nanostructured CuP_2/C composites as high-performance anode materials for sodium ion batteries. *J. Mater. Chem. A* **2015**, *3*, 21754–21759. [[CrossRef](#)]
101. Simon, P.; Gogotsi, Y.; Dunn, B. Where Do Batteries End and Supercapacitors Begin? *Science* **2014**, *343*, 1210–1211. [[CrossRef](#)] [[PubMed](#)]
102. Yan, B.; Wang, L.; Huang, W.; Zheng, S.; Hu, P.; Du, Y. High-capacity organic sodium ion batteries using a sustainable C4Q/CMK-3/SWCNT electrode. *Inorg. Chem. Front.* **2019**, *6*, 1977–1985. [[CrossRef](#)]
103. Senthilkumar, B.; Murugesan, C.; Sharma, L.; Lochab, S.; Barpanda, P. An Overview of Mixed Polyanionic Cathode Materials for Sodium-Ion Batteries. *Small Methods* **2019**, *3*, 1800253. [[CrossRef](#)]
104. Wheeler, S.; Capone, I.; Day, S.; Tang, C.; Pasta, M. Low-Potential Prussian Blue Analogues for Sodium-Ion Batteries: Manganese Hexacyanochromate. *Chem. Mater.* **2019**, *31*, 2619–2626. [[CrossRef](#)]
105. Amin, K.; Mao, L.; Wei, Z. Recent Progress in Polymeric Carbonyl-Based Electrode Materials for Lithium and Sodium Ion Batteries. *Macromol. Rapid Comm.* **2019**, *40*, 1800565. [[CrossRef](#)]
106. Liu, R.; Liang, Z.; Gong, Z.; Yang, Y. Research Progress in Multielectron Reactions in Polyanionic Materials for Sodium-Ion Batteries. *Small Methods* **2019**, *3*, 1800221. [[CrossRef](#)]

107. Desai, A.V.; Morris, R.E.; Armstrong, A.R. Advances in Organic Anode Materials for Na-/K-Ion Rechargeable Batteries. *ChemSusChem* **2020**, *13*, 4866–4884. [[CrossRef](#)] [[PubMed](#)]
108. Li, M.; Meng, Z.; Feng, R.; Zhu, K.; Zhao, F.; Wang, C.; Wang, J.; Wang, L.; Chu, P.K. Fabrication of Bimetallic Oxides ($M\text{Co}_2\text{O}_4$; $M=\text{Cu, Mn}$) on Ordered Microchannel Electro-Conductive Plate for High-Performance Hybrid Supercapacitors. *Sustainability* **2021**, *13*, 9896. [[CrossRef](#)]
109. Feng, R.C.; Li, M.; Wang, Y.; Lin, J.; Zhu, K.L.; Wang, J.L.; Wang, C.R.; Chu, P.K. High-performance multi-dimensional nitrogen-doped $\text{N}+\text{MnO}_2/\text{TiC}/\text{C}$ electrodes for supercapacitors. *Electrochim. Acta* **2021**, *370*, 137716. [[CrossRef](#)]
110. Deng, J.; Luo, W.B.; Chou, S.L.; Liu, H.K.; Dou, S.X. Sodium-Ion Batteries: From Academic Research to Practical Commercialization. *Adv. Energy Mater.* **2018**, *8*, 1701428. [[CrossRef](#)]
111. Tang, W.; Liang, R.; Li, D.; Yu, Q.H.; Hu, J.H.; Cao, B.; Fan, C. Highly Stable and High Rate-Performance Na-Ion Batteries Using Polyanionic Anthraquinone as the Organic Cathode. *ChemSuschem* **2019**, *12*, 2181–2185. [[CrossRef](#)]
112. Lee, J.E.; Jeon, K.-J.; Show, P.L.; Lee, I.H.; Jung, S.-C.; Choi, Y.J.; Rhee, G.H.; Lin, K.-Y.A.; Park, Y.-K. Mini review on H_2 production from electrochemical water splitting according to special nanostructured morphology of electrocatalysts. *Fuel* **2022**, *308*, 122048. [[CrossRef](#)]
113. Schneider, S.; Bajohr, S.; Graf, F.; Kolb, T. State of the Art of Hydrogen Production via Pyrolysis of Natural Gas. *ChemBioEng Rev.* **2020**, *7*, 150–158. [[CrossRef](#)]
114. Yang, H.; Xu, G.; Wei, X.; Cao, J.; Yang, L.; Chu, P.K. Ultrafast hetero-assembly of monolithic interwoven V_2O_5 nanobelts/carbon nanotubes architectures for high-energy alkali-ion batteries. *J. Power Sources* **2018**, *395*, 295–304. [[CrossRef](#)]
115. Zhang, J.; Zhang, Q.; Feng, X. Support and Interface Effects in Water-Splitting Electrocatalysts. *Adv. Mater.* **2019**, *31*, 1808167. [[CrossRef](#)] [[PubMed](#)]
116. Shan, J.; Ling, T.; Davey, K.; Zheng, Y.; Qiao, S.Z. Transition-Metal-Doped RuIr Bifunctional Nanocrystals for Overall Water Splitting in Acidic Environments. *Adv. Mater.* **2019**, *31*, 1900510.1–1900510.7. [[CrossRef](#)]
117. Jin, Y.; Wang, H.; Li, J.; Yue, X.; Cui, Y. Porous MoO_2 Nanosheets as Non-noble Bifunctional Electrocatalysts for Overall Water Splitting. *Adv. Mater.* **2016**, *28*, 3785–3790. [[CrossRef](#)] [[PubMed](#)]
118. Liu, Y.; Ali, R.; Ma, J.; Jiao, W.; Jian, X. Graphene-Decorated Boron–Carbon–Nitride-Based Metal-Free Catalysts for an Enhanced Hydrogen Evolution Reaction. *ACS Appl. Energ. Mater.* **2021**, *4*, 3861–3868. [[CrossRef](#)]
119. Li, M.; Li, S.; Wang, J.L.; Wang, C.R.; Li, W.; Chu, P.K. NiFeP nanoflakes composite with CoP on carbon cloth as flexible and durable electrocatalyst for efficient overall water splitting. *Nanotechnology* **2019**, *30*, 485402. [[CrossRef](#)] [[PubMed](#)]
120. Li, S.; Feng, R.C.; Li, M.; Zhao, X.; Zhang, B.H.; Liang, Y.; Ning, H.P.; Wang, J.L.; Wang, C.R.; Chu, P.K. Needle-like CoO nanowire composites with NiO nanosheets on carbon cloth for hybrid flexible supercapacitors and overall water splitting electrodes. *RSC Adv.* **2020**, *10*, 37489. [[CrossRef](#)]
121. Su, J.; Yang, Y.; Xia, G.; Chen, J.; Jiang, P.; Chen, Q. Ruthenium-cobalt nanoalloys encapsulated in nitrogen-doped graphene as active electrocatalysts for producing hydrogen in alkaline media. *Nat. Commun.* **2017**, *8*, 14969. [[CrossRef](#)] [[PubMed](#)]
122. Huang, X.; Zhao, Z.; Cao, L.; Chen, Y.; Zhu, E.; Lin, Z.; Li, M.; Yan, A.; Zettl, A.; Wang, Y.M.; et al. High-performance transition metal-doped Pt_3Ni octahedra for oxygen reduction reaction. *Science* **2015**, *348*, 1230–1234. [[CrossRef](#)]
123. Yang, H.; Shang, L.; Zhang, Q.; Shi, R.; Waterhouse, G.I.N.; Gu, L.; Zhang, T. A universal ligand mediated method for large scale synthesis of transition metal single atom catalysts. *Nat. Commun.* **2019**, *10*, 4585. [[CrossRef](#)]
124. Li, P.; Wang, M.; Duan, X.; Zheng, L.; Cheng, X.; Zhang, Y.; Kuang, Y.; Li, Y.; Ma, Q.; Feng, Z.; et al. Boosting oxygen evolution of single-atomic ruthenium through electronic coupling with cobalt-iron layered double hydroxides. *Nat. Commun.* **2019**, *10*, 1711. [[CrossRef](#)]
125. Zhang, X.; Luo, Z.; Yu, P.; Cai, Y.; Du, Y.; Wu, D.; Gao, S.; Tan, C.; Li, Z.; Ren, M.; et al. Lithiation-induced amorphization of $\text{Pd}_3\text{P}_2\text{S}_8$ for highly efficient hydrogen evolution. *Nat. Catal.* **2018**, *1*, 460–468. [[CrossRef](#)]
126. Feng, T.; Yu, G.; Tao, S.; Zhu, S.; Ku, R.; Zhang, R.; Zeng, Q.; Yang, M.; Chen, Y.; Chen, W. A highly efficient overall water splitting ruthenium-cobalt alloy electrocatalyst across a wide pH range via electronic coupling with carbon dots. *J. Mater. Chem. A* **2020**, *8*, 9638–9645. [[CrossRef](#)]
127. Xu, H.; Liu, T.; Bai, S.; Li, L.; Zhu, Y.; Wang, J.; Yang, S.; Li, Y.; Shao, Q.; Huang, X. Cation Exchange Strategy to Single-Atom Noble-Metal Doped CuO Nanowire Arrays with Ultralow Overpotential for H_2O Splitting. *Nano Lett.* **2020**, *20*, 5482–5489. [[CrossRef](#)] [[PubMed](#)]
128. Anxolabehere-Mallart, E.; Costentin, C.; Fournier, M.; Nowak, S.; Robert, M.; Saveant, J.M. Boron-capped tris (glyoximate) cobalt clathrochelate as a precursor for the electrodeposition of nanoparticles catalyzing H_2 evolution in water. *J. Am. Chem. Soc.* **2012**, *134*, 6104–6107. [[CrossRef](#)]
129. Zhang, H.; Yang, X.H.; Zhang, H.J.; Ma, J.L.; Huang, Z.Y.; Li, J.; Wang, Y. Transition-Metal Carbides as Hydrogen Evolution Reduction Electrocatalysts: Synthetic Methods and Optimization Strategies. *Chem.—Eur. J.* **2021**, *27*, 5074–5090. [[CrossRef](#)] [[PubMed](#)]
130. Qian, H.; Li, K.; Mu, X.; Zou, J.; Xie, S.; Xiong, X.; Zeng, X. Nanoporous NiFeMoP alloy as a bifunctional catalyst for overall water splitting—ScienceDirect. *Int. J. Hydrogen Energ.* **2020**, *45*, 16447–16457. [[CrossRef](#)]
131. Tian, J.; Liu, Q.; Cheng, N.; Asiri, A.M.; Sun, X. Self-supported Cu3P nanowire arrays as an integrated high-performance three-dimensional cathode for generating hydrogen from water. *Angew. Chem. Int. Ed.* **2015**, *126*, 9731–9735. [[CrossRef](#)]

132. Dai, L.; Chen, Z.; Li, L.; Yin, P.; Zhang, H. Ultrathin Ni(0)-Embedded Ni(OH)₂ Heterostructured Nanosheets with Enhanced Electrochemical Overall Water Splitting. *Adv. Mater.* **2020**, *32*, 1906915. [[CrossRef](#)]
133. Zhang, X.; Cui, X.; Sun, Y.; Qi, K.; Jin, Z.; Wei, S.; Li, W.; Zhang, L.; Zheng, W. Nanoporous Sulfur-Doped Copper Oxide (Cu₂O_xS_{1-x}) for Overall Water Splitting. *ACS Appl. Energ. Mater.* **2018**, *10*, 745–752. [[CrossRef](#)] [[PubMed](#)]
134. Zeb, A.; Sahar, S.; Qazi, U.Y.; Odda, A.H.; Ullah, N.; Liu, Y.N.; Qazi, I.A.; Xu, A.W. Intrinsic peroxidase-like activity and enhanced photo-Fenton reactivity of iron-substituted polyoxometallate nanostructures. *Dalton T.* **2018**, *47*, 7344–7352. [[CrossRef](#)]
135. Jia, Y.; Zhang, L.; Du, A.; Gao, G.; Chen, J.; Yan, X.; Brown, C.L.; Yao, X. Defect Graphene as a Trifunctional Catalyst for Electrochemical Reactions. *Adv. Mater.* **2016**, *28*, 9532–9538. [[CrossRef](#)]
136. Tang, C.; Wang, H.F.; Chen, X.; Li, B.-Q.; Hou, T.Z.; Zhang, B.; Zhang, Q.; Titirici, M.-M.; Wei, F. Topological Defects in Metal-Free Nanocarbon for Oxygen Electrocatalysis. *Adv. Mater.* **2016**, *28*, 6845–6851. [[CrossRef](#)] [[PubMed](#)]
137. Kim, Y.Y.; Yang, T.Y.; Suhonen, R.; Kempainen, A.; Hwang, K.; Jeon, N.J.; Seo, J. Roll-to-roll gravure-printed flexible perovskite solar cells using eco-friendly antisolvent bathing with wide processing window. *Nat. Commun.* **2020**, *11*, 5146. [[CrossRef](#)] [[PubMed](#)]
138. Giacomo, F.D.; Shanmugam, S.; Fledderus, H.; Bruijnaers, B.J.; Verhees, W.; Dorenkamper, M.S.; Veenstra, S.C.; Qiu, W.; Gehlhaar, R.; Merckx, T. Up-scalable sheet-to-sheet production of high efficiency perovskite module and solar cells on 6-in. substrate using slot die coating. *Sol. Energ. Mat. Sol. C.* **2017**, *181*, 53–59. [[CrossRef](#)]
139. Hu, Y.; Si, S.; Mei, A.; Rong, Y.; Liu, H.; Li, X.; Han, H. Stable large-area (10 × 10 cm²) printable mesoscopic perovskite module exceeding 10% efficiency. *Solar RRL* **2017**, *1*, 1600019. [[CrossRef](#)]
140. Peng, J.; Zhang, W.; Liu, Q.; Wang, J.; Chou, S.; Liu, H.; Dou, S. Prussian blue analogues for sodium-ion batteries: Past, present and future. *Adv. Mater.* **2022**, *34*, 2108384. [[CrossRef](#)] [[PubMed](#)]
141. Li, W.J.; Han, C.; Chou, S.L.; Wang, J.Z.; Li, Z.; Kang, Y.M.; Liu, H.K.; Dou, S.X. Graphite-Nanoplate-Coated Bi₂S₃ Composite with High-Volume Energy Density and Excellent Cycle Life for Room-Temperature Sodium–Sulfide Batteries. *Chem. Eur. J.* **2016**, *22*, 590. [[CrossRef](#)] [[PubMed](#)]
142. Wang, W.; Gang, Y.; Peng, J.; Hu, Z.; Yan, Z.; Lai, W.; Zhu, Y.; Appadoo, D.; Ye, M.; Cao, Y.; et al. Effect of Eliminating Water in Prussian Blue Cathode for Sodium-Ion Batteries. *Adv. Funct. Mater.* **2022**, *32*, 2111727. [[CrossRef](#)]
143. Zhang, X.; Weng, W.; Gu, H.; Hong, Z.; Xiao, W.; Wang, F.; Li, W.; Gu, D. Versatile Preparation of Mesoporous Single-Layered Transition-Metal Sulfide/Carbon Composites for Enhanced Sodium Storage. *Adv. Mater.* **2022**, *34*, 2104427. [[CrossRef](#)]
144. Lin, Y.; Zhang, M.; Zhao, L.; Wang, L.; Gong, Y. Ru doped bimetallic phosphide derived from 2D metal-organic framework as active and robust electrocatalyst for water splitting. *Appl. Surf. Sci.* **2021**, *536*, 147952. [[CrossRef](#)]
145. Ye, L.K.; Rouhani, F.; Kaviani, H.; Miao, Q.; Cai, X.Q.; Morsali, A.; Hu, M.L. Effect of Proton Conduction on the Charge Storage Mechanism of a MOF as a Supercapacitor Electrode. *J. Phys. Chem. C* **2021**, *125*, 22951–22959. [[CrossRef](#)]
146. Lin, R.; Xu, J.; Wei, M.; Wang, Y.R.; Qin, Z.Y.; Liu, Z.; Wu, J.L.; Xiao, K.; Chen, B.; Park, S.M.; et al. All-perovskite tandem solar cells with improved grain surface passivation. *Nature* **2022**, *603*, 73–78. [[CrossRef](#)] [[PubMed](#)]
147. Zhao, Y.; Ma, F.; Qu, Z.H.; Yu, S.Q.; Shen, T.; Deng, H.X.; Chu, X.B.; Peng, X.X.; Yuan, Y.B.; Zhang, X.W.; et al. Inactive (PbI₂)₂RbCl stabilizes perovskite films for efficient solar cells. *Science* **2022**, *377*, 531–534. [[CrossRef](#)] [[PubMed](#)]
148. Sun, C.K.; Zhang, X.; Li, C.; Wang, K.; Sun, X.Z.; Ma, Y.W. Recent advances in prelithiation materials and approaches for lithium-ion batteries and capacitors. *Energy Stor. Mater.* **2020**, *32*, 497–516. [[CrossRef](#)]
149. Wang, Y.R.; Chen, R.P.; Chen, T.; Lv, H.L.; Zhu, G.Y.; Ma, L.B.; Wang, C.X.; Jin, Z.; Liu, J. Emerging non-lithium ion batteries. *Energy Stor. Mater.* **2016**, *4*, 103–129. [[CrossRef](#)]
150. Liang, Y.R.; Lai, W.H.; Miao, Z.C.; Chou, S.L. Nanocomposite Materials for the Sodium–Ion Battery: A Review. *Small* **2017**, *14*, 1702514. [[CrossRef](#)]
151. Bossche, P.V.D.; Vergels, F.; Mierlo, J.V.; Matheys, J.; Autenboer, W.V. SUBAT: An assessment of sustainable battery technology. *J. Power Sources* **2006**, *162*, 913–919. [[CrossRef](#)]
152. Joshi, B.V.; Vipin, B.; Ramkumar, J.; Amit, R.K. Impact of policy instruments on lead-acid battery recycling: A system dynamics approach. *Resour. Conserv. Recy.* **2021**, *169*, 105528. [[CrossRef](#)]
153. Chen, Y.N.; Xu, S.M.; Li, Y.C.; Jaco, R.J.; Kuang, Y.; Liu, B.; Wang, Y.; Pastel, G.; Salamanca-Riba, L.; Zachariah, M.; et al. FeS₂ Nanoparticles Embedded in Reduced Graphene Oxide toward Robust, High-Performance Electrocatalysts. *Adv. Energy Mater.* **2017**, *7*, 1700482. [[CrossRef](#)]