applied sciences

MDPI

Review

A Comprehensive Review of Energy Regeneration and Conversion Technologies Based on Mechanical–Electric–Hydraulic Hybrid Energy Storage Systems in Vehicles

Bingyin Feng [1,2,3,*], Huijuan Xu [1], Aobing Wang [1], Lijun Gao [1], Yanjun Bi [1] and Xin Zhang [1]

1 Hebei Key Laboratory of Man-Machine Environment Thermal Control Technology and Equipment, Hebei Vocational University of Technology and Engineering, Xingtai 054000, China; xuhuijuan_xpc@163.com (H.X.); wab_509@163.com (A.W.); gaoli_jun@foxmail.com (L.G.); biyanjun_xpc@163.com (Y.B.); zx_xtpc@163.com (X.Z.)
2 Department of Automotive Engineering, Hebei Vocational University of Technology and Engineering, Xingtai 054000, China
3 Hebei Special Vehicle Modification Technology Innovation Center, Hebei Vocational University of Technology and Engineering, Xingtai 054000, China
* Correspondence: fengbingyins@163.com

Abstract: The primary purpose of this paper is to investigate energy regeneration and conversion technologies based on mechanical–electric–hydraulic hybrid energy storage systems in vehicles. There has been renewed interest in hydraulic storage systems since evidence has been presented that shows that they have the distinct advantages of high energy output and energy recuperation compared to electrical energy recovery systems, which are widely applied in electric vehicles; however, they are known to be high-cost, with a complicated structure and not zero carbon. In this paper, we first review recent research on hydraulic energy regeneration and conversion technologies. Secondly, as the main part of this paper, the latest technological progress and breakthroughs of the mechanical–electric–hydraulic hybrid energy storage systems in vehicles—which are divided into four categories: passenger, minibus and bus, commercial vehicle and special vehicle—are analyzed and discussed in depth. In addition, the current research status of energy management techniques is presented and summarized. Finally, prospects and challenges are suggested and explained. It is evident from the literature review that the mechanical–electric–hydraulic hybrid systems perform excellently in vehicles. Clearly, this review will be helpful to understand, explore and define the hydraulic vehicle of the future concerning energy optimization and environmental friendliness.

Keywords: hydraulic vehicle; renewable energy; hybrid energy storage system; energy management

Citation: Feng, B.; Xu, H.; Wang, A.; Gao, L.; Bi, Y.; Zhang, X. A Comprehensive Review of Energy Regeneration and Conversion Technologies Based on Mechanical–Electric–Hydraulic Hybrid Energy Storage Systems in Vehicles. *Appl. Sci.* **2023**, *13*, 4152. https://doi.org/10.3390/app13074152

Received: 2 March 2023
Revised: 18 March 2023
Accepted: 19 March 2023
Published: 24 March 2023

1. Introduction

The rising levels of carbon dioxide due to the burning of fossil fuels have become one of the most concerning issues in the world and have caused more and more extensive negative impacts on human production and life, such as not only the economy, the deterioration in environmental conditions and seasonal anomalies but also climate change, namely global warming, resources and energy [1–4]. In the last few years, carbon dioxide emission levels have been increasing at a rate of about 1% per year, with the exception that the levels remained almost the same during the COVID-19 pandemic as the year before it [5–8]. Governments and economists from various countries are highly concerned and committed to reducing carbon dioxide emissions and have formulated various policies [9], and countries have also formulated temporary policies during the epidemic accordingly [10].

In recent years, China has been one of the biggest carbon dioxide (CO_2) emitters, accounting for around 33% of global carbon dioxide emissions [11–14]. Therefore, the Chinese government has proposed a dual-carbon plan in order to achieve carbon neutrality before 2060 [11,12]. The industrial, building, transport and agricultural sectors are responsible for over 88% of total carbon emissions in China [8]. Transport is one of the biggest leading sources of China's emissions, taking up 8%, while it is also the major final consumer of almost 30% of the world's energy and over 60% of the world's oil products [9,14]. In the coming years, carbon emissions in the field of transportation will continue to rise and it is difficult to change the energy structure in the transport sector [15]. Hence, improving efficiency of low-carbon and zero-carbon transport is the only possibility for future transport development. In the short term, the feasible technical path in the transport sector is to develop electric vehicles [16]. Figure 1 illustrates the measures and technological development of CO_2 emissions removal in the field of transport [9].

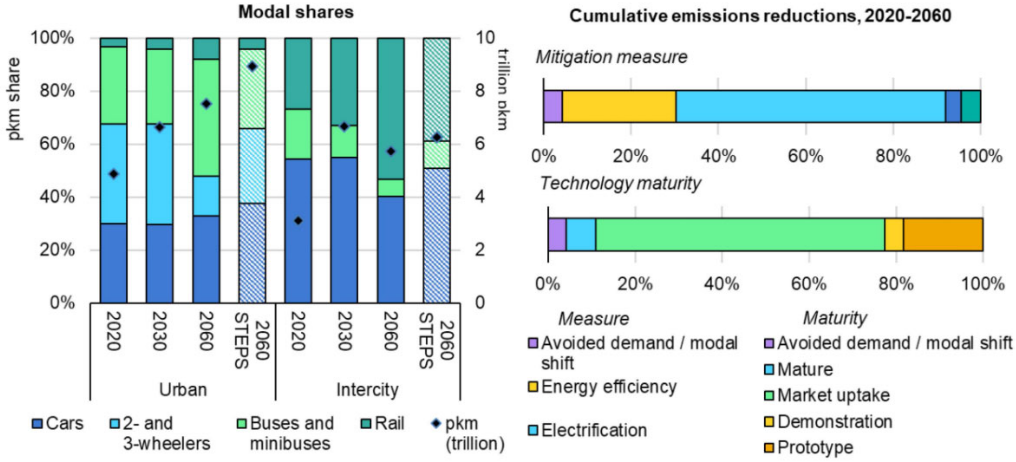


Figure 1. Measures and technological progress of CO_2 emissions reductions [9].

It can be concluded from Figure 1 that electrification is the key to decarbonizing transport. In addition, electrification is usually considered the platform for autonomous driving due to its inherent requirement of use of the electric motor [17–19]. Moreover, the change from autonomous vehicles to connected and automated vehicles is the mainstream trend for intelligent vehicles in the future [20]. Green energy vehicles mainly include battery electric vehicles (EV), hybrid electric vehicles (HEV) and fuel cell electric vehicles (FCEV). However, there are some primary problems in electric vehicles (EV), including battery failure [21], battery life [22], battery safety issues [23,24] and, especially, a limited driving range due to the low energy density [25], long charging time and high cost [26,27], which are also characteristics of fuel cell electric vehicles (FCEV). In addition, FCEVs cannot utilize braking energy [28] and are difficult to control due to their several energy sources [29]. Therefore, energy conservation is so important for vehicles that researchers are also looking for other energy optimization and utilization methods for vehicles, including booming autonomous vehicles [17–19]. The energy recovery and conversion technology based on mechanical–electric–hydraulic hybrid energy storage systems is a potential and very promising solution and has also been extensively studied [30–34]. It can be concluded that hydraulic vehicles show better performance than conventional and hybrid electric vehicles in terms of frequent start/stop, high power output and energy recovery, especially for medium and heavy trucks. Ref. [35] shows the development process of the hydraulic hybrid technology of EPA, and more details are listed in Section 2.2.

The main types of general hydraulic-powered vehicles based on mechanical–electric–hydraulic hybrid energy storage systems are series types, parallel types and series–parallel types in form of the vehicle structures [34,36,37]. Some researchers have completed comprehensive research on the application of hydraulic energy renewal and conversion technology in passenger cars, in passenger cars and trucks, and with a focus on trucks, as seen in Table 1.

Table 1. Types, kinds, structures and technologies of hydraulic hybrid vehicles.

Types	Kinds of Vehicle	Structure	Technologies
Passenger vehicle	Car [38] SUV [39]	Series hydraulic hybrid Power-split drivetrain	Braking energy regeneration Braking energy regeneration
Minibus and bus	Bus [40]	Series–parallel power split hybrid	Braking energy regeneration
Commercial truck	Light commercial vehicle [41] Heavy trucks [42]	Series hydraulic hybrid Parallel hydraulic hybrid	Braking energy regeneration Braking energy regeneration
Special vehicle	Mining truck [43] Multi-purpose vehicle [44,45] Urban delivery [46]	Parallel hydraulic hybrid Series hydraulic hybrid Series hydraulic hybrid	Braking energy regeneration Braking energy regeneration Braking energy regeneration

To sum up the above, energy regeneration and conversion technology, based on mechanical–electric–hydraulic hybrid energy storage systems in vehicles, is a hydrostatic transmission that transmits the power in a vehicle (called a hydraulic vehicle or a hydraulic hybrid vehicle), transforming the mechanical energy of the vehicle during braking or coasting into hydraulic energy (stored in a hydraulic accumulator [47]) or electric energy (stored in a battery [48]), as illustrated in Figure 2. In this hydraulic electric vehicle, the battery and accumulator can work simultaneously or independently.

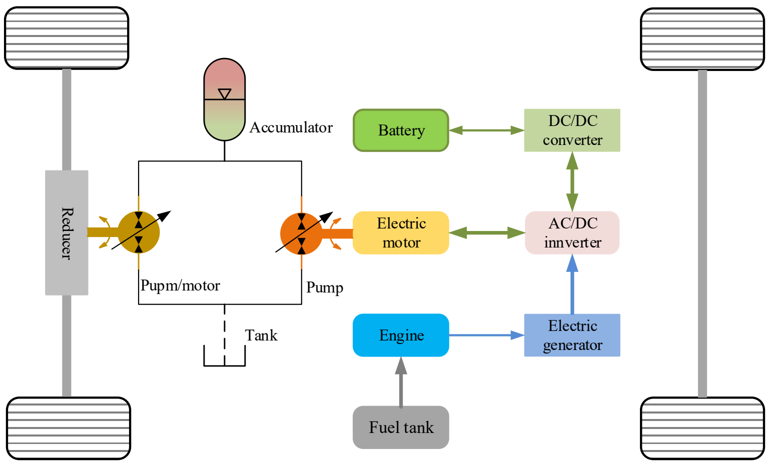


Figure 2. Working process of the energy recuperation and conversion technology of hydraulic vehicles [47,48].

However, a comprehensive and detailed review of the configuration and energy management of the current status and development of different kinds of hydraulic vehicles is still limited in the related literature. Moreover, hydraulic vehicles will also be developed and used in new scenarios as the mechanical–electric–hydraulic hybrid energy storage technology evolves. Therefore, an elaborate review of the current research on mechanical–electric–hydraulic hybrid technology in vehicles is timely and required.

This paper briefly introduces the development background, concept, characteristics and working process of hydraulic energy recovery and conversion technology, which indicates that hydraulic energy recovery and conversion technology has very important research and application value. Next, Section 2 introduces the general principle and working process of hydraulic energy recovery and conversion technology. Section 3 summarizes the research status of hydraulic energy recovery and conversion technology in different vehicles, including passenger cars, buses, trucks and special vehicles. Section 4 discusses current energy management strategies for hydraulic energy recovery and conversion technologies in vehicles. Section 5 describes the future challenges and coping strategies of hydraulic vehicles based on mechanical–electric–hydraulic hybrid energy storage systems, and conclusions appear in Section 6.

2. General Principle and Operation of Hydraulic Energy Regeneration and Conversion Technologies

2.1. General Idea of Hydraulic Energy Regeneration and Conversion Technologies

Hydraulic energy regeneration and conversion technology has better energy utilization efficiency than other technologies, particularly in the case of vehicles that experience frequent braking, acceleration, and driving on a long slope, as can be deduced from Ref. [49]. The basic idea of hydraulic energy recovery and conversion technology applied to vehicles is primarily to recover and convert the energy consumed by the vehicle during braking [50–52], coasting or driving downhill [53], and convert the mechanical energy yielded when the vehicle moves into hydraulic energy or electrical energy; when the vehicle starts, accelerates or goes uphill, the stored hydraulic energy is discharged to propel the vehicle or support the driving of the vehicle [48,54–57]. The hydraulic accumulator is the core component of hydraulic energy recovery and conversion technology, and its characteristic parameter determines the effective energy and efficiency of braking energy recovery [58,59].

There are two application carriers for vehicle-based hydraulic energy recovery and conversion technology: one is the common pressure rail (CPR) and the other is the variable pressure rail (VPR). In 1977, the theoretical basis of the CPR rotary load control was founded in Germany, which marked the birth of the CPR [60]. The CPR system is generally composed as illustrated in [61], as shown in Figure 3a [55,62,63].

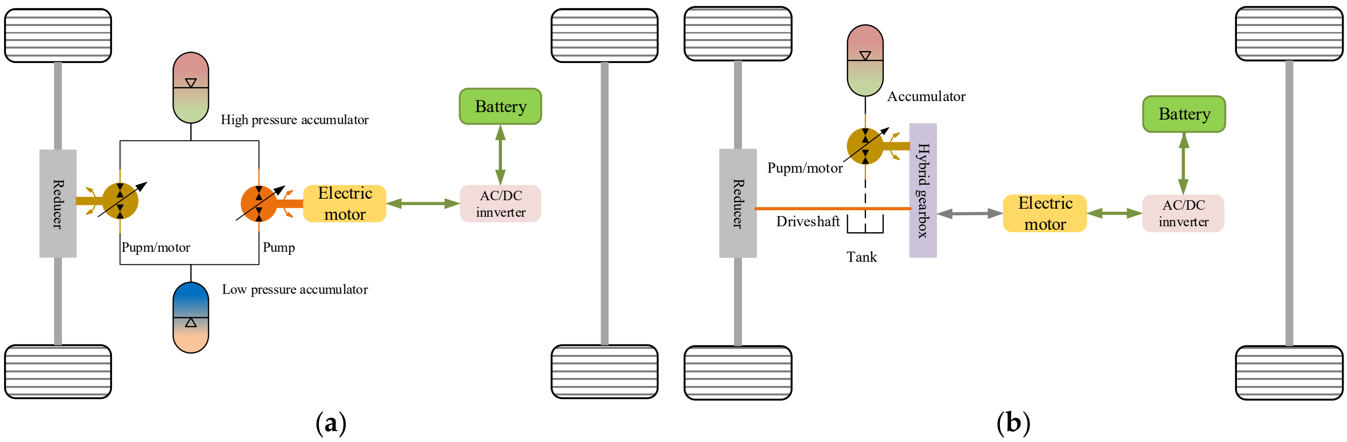


Figure 3. General principle of hydraulic energy regeneration and conversion technologies [55,62–65]: (**a**) common pressure rail (CPR); (**b**) variable pressure rail (VPR).

In the constant pressure network system, the pressure of the oil source is almost maintained unchanging. However, the constant pressure of the constant pressure network is also a disadvantage [55], as it limits the range of braking energy recovery and utilization to some extent. Therefore, the non-constant voltage network has been proposed to address this drawback. The VPR system is similar in composition, as portrayed in Figure 3b, but the hydraulic circuit pressure can be changed according to the system demand [64,65].

2.2. Prototype and Design of Hydraulic Energy Regeneration and Conversion Technologies

Both CPR and VPR can be divided into series, parallel and series–parallel structures and energy flows, as shown in Figure 4 [53,64–68]. It can be seen that the series structure means that the energy yielded by the engine is transformed into hydraulic energy by the hydraulic pump, and then it is recycled into mechanical energy used to move the vehicle through the hydraulic motor, as shown in Figure 4. Moreover, the parallel structure means that the mechanical driveline and the hydraulic driveline can drive the vehicle alone, and furthermore, the series–parallel structure allows the mechanical drive route and the hydraulic drive route to transform the form of energy by hybrid transmission and the pump/motor when necessary.

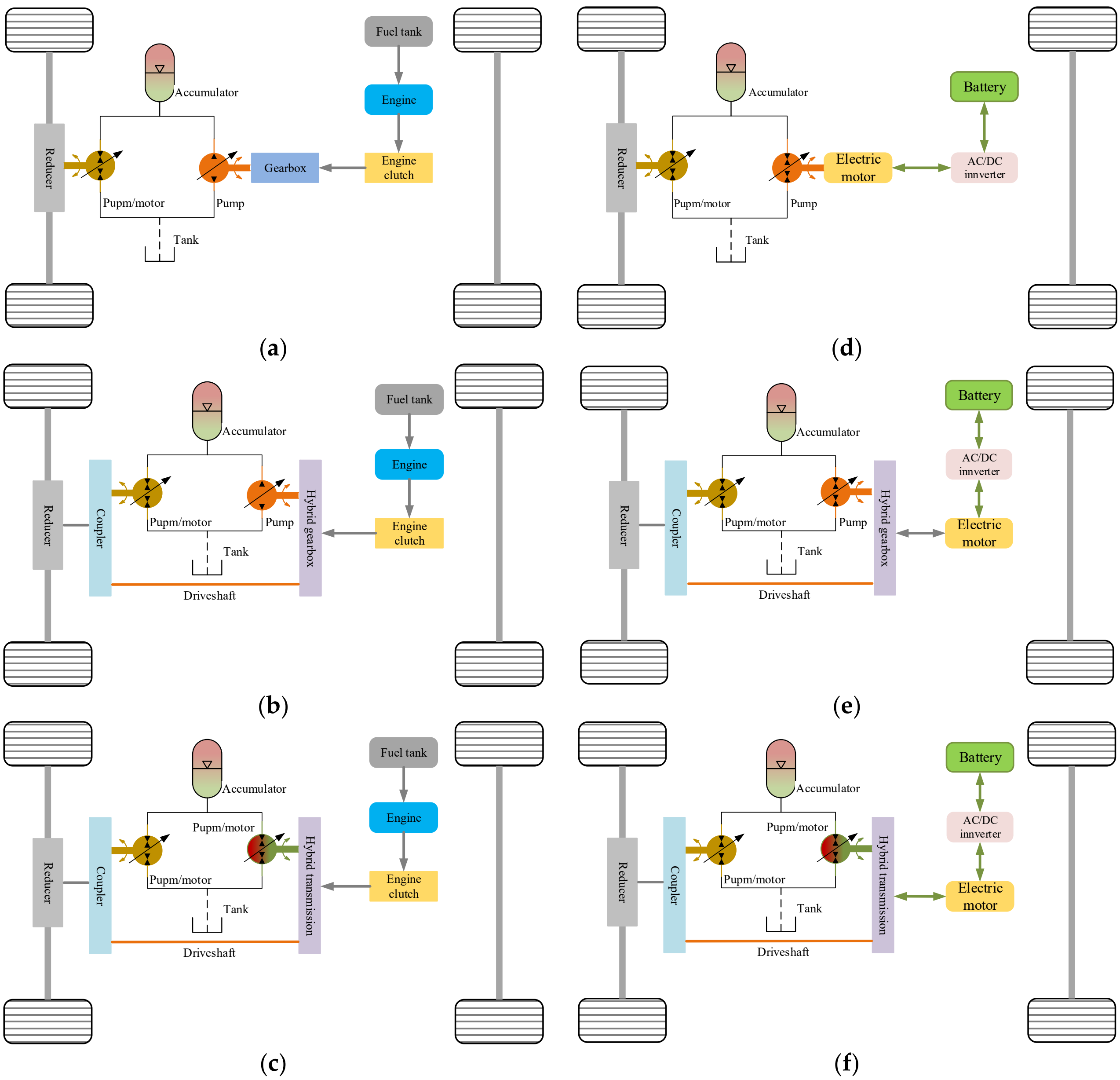


Figure 4. Diagrams of energy flow in previously typical developed series (**a**,**d**), parallel (**b**,**e**), and series–parallel (**c**,**f**) hydraulic hybrid vehicles [53,64–68].

Hydraulic hybrid vehicles have their own unique characteristics because of their different structures. In Figure 4a,d, the series hydraulic hybrid vehicle has only one power element (engine or electric motor), one or two hydraulic accumulators and one independent driveline route. In parallel hydraulic hybrid vehicles, there is at least one power element and two relatively independent driveline routes, as shown in Figure 4b,e. Different from the previous two, Figure 4c,f shows that series–parallel hydraulic hybrid vehicles have at least two power elements and at least two relatively independent driveline routes. Moreover, the relatively independent driveline route has some connections that are used for energy conversion in some scenarios.

As for the hydraulic vehicle control system, the general control process is that the top controller, i.e., the control unit, receives the speed or power information from the system input, then calculates the corresponding power distribution and generates control commands; finally, the bottom controller, i.e., the control units 1 and 2, adjusts the output flow or pressure of the hydraulic pump and hydraulic motor, as shown in Figure 5.

Table 2 lists the details of the characteristics, advantages and disadvantages of the three hydraulic hybrid vehicle configurations. It is not difficult to infer that the configuration of the series hydraulic hybrid is the simplest, the parallel hydraulic hybrid is moderately complex and the series–parallel hydraulic vehicle is the most complex. Obviously, the same is true for the controller.

Table 2. Summary of the configuration characteristics of the hybrid hydraulic vehicles.

Item	Series	Parallel	Series–Parallel
Power element number Hydraulic accumulator Hydraulic actuator Hybrid degree	1 √ √ Light	≤2 √ √ Medium–full	≥2 √ √ Medium–full
Strengths	High engine efficiency Easy control Simple construction	High technical maturity Increased transmission efficiency Elevated reliability	Good emission reduction Increased transmission efficiency Increased engine efficiency
Weaknesses	Inferior efficiency Inadequate reliability High cost	Complicated management Inferior efficiency Finite energy-saving	High cost Complex management Complex structure

2.3. Technical Routes and Technical Indicators

The earliest hydraulic power energy recovery and conversion technology was studied by the EPA, researchers and other institutions in the 1970s, and in 1988, various hybrid options were investigated by the EPA in order to explore the cost-effectiveness potential for hydraulic hybrid vehicles. A diesel full-series hydraulic hybrid test chassis was first demonstrated in 2000, and then a parallel hydraulic hybrid was developed in a Ford F-550 work truck, which achieved a 20–30% improvement in fuel efficiency in 2003. In subsequent projects, the world's first full-series hydraulic drivetrain of the delivery truck was designed and manufactured in Washington in June 2006; the revolutionary yard hostler with a series hydraulic hybrid in April 2009; and a series HHV minivan in January 2011. The EPA's HHV technology provides the possibility for multiple drivetrains or hardware configurations, depending on which will be the most durable, efficient, clean and cost-effective option.

The development of the EPA's hydraulic hybrid vehicle technology represents, to a certain extent, the process of early hydraulic hybrid vehicles, which is related to the research and development of hydraulic hybrid vehicles, as shown in Table 3. Therefore, it can be concluded that HHVs have the advantages of a lower cost and higher power density; the latter is particularly advantageous as it makes HHVs recover much more of the available kinetic energy [69], which makes them more competitive than HEVs in certain application scenarios, as mentioned before and in Table 3.

Table 3. Types, configurations and main features of hydraulic hybrid vehicles over time in EPA.

Year	Types	Configuration	Effect or Improvement
2000	Passenger vehicle test chassis	Full-series HHV	Uses a small 1.9 L diesel engine. Improves fuel economy without expensive lightweight materials.
2003 2004	Ford F-550 truck SUV	Parallel HHV Full-series HHV	Improves energy efficiency by 20–30%. Achieves 85% better fuel economy.
2006	Delivery truck	Full-series HHV	Achieves 60–70% improvement in fuel economy.
2009	Yard hostler	Series HHV	Improves fuel economy from 50% to over 60%.
2011	Light-duty vehicles	Series HHV	Increases fuel economy by up to 60% in city. Drives with an overall improvement of 30 to 35%.

The related hydraulic hybrid vehicle technology has also been extensively studied, as can be confirmed by the following studies: passenger cars [38], buses [40], heavy-duty trucks [42], and special trucks [43]. However, hydraulic accumulators have a lower energy density than HEVs, which makes some vehicle configurations, such as BEVs, more difficult [70].

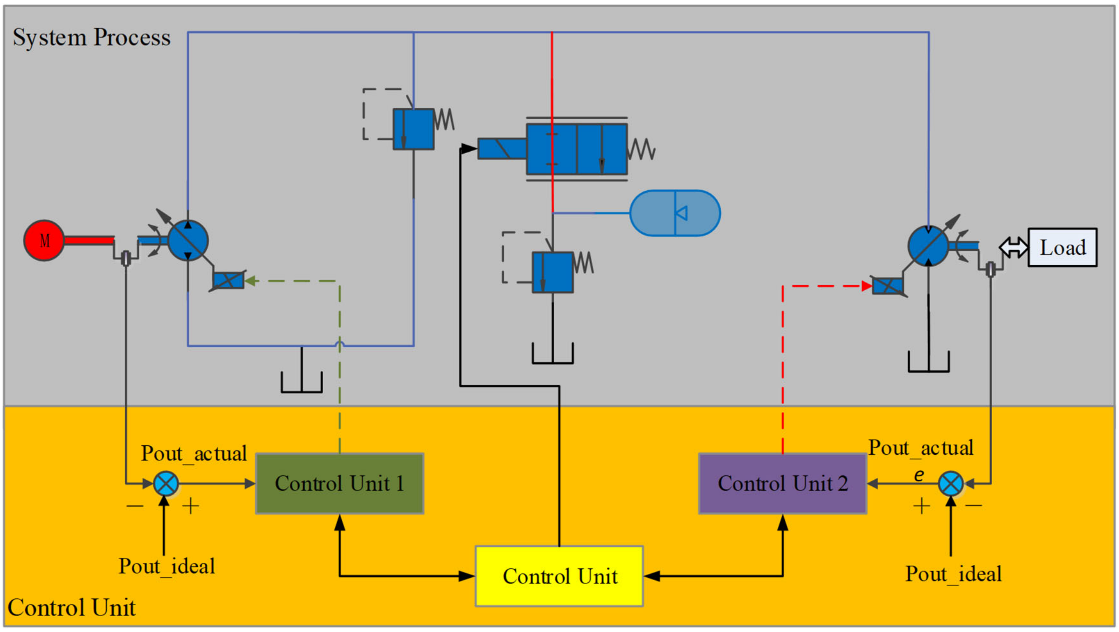


Figure 5. General control of hydraulic energy regeneration and conversion technologies [30,38,41].

The above are the early technical routes of hydraulic hybrid vehicles, that is, one is a series hydraulic hybrid vehicle and the other is a parallel hydraulic hybrid vehicle, and they have the common characteristic that the prime mover is an internal combustion engine. However, these hydraulic hybrid vehicles still have problems, such as petroleum consumption, emitting carbon dioxide, and polluting the environment, due to the engine. Meanwhile, driven by electric vehicle and hybrid hydraulic technologies, a novel HHV technical route, also called hydraulic electric synergy vehicles, has been increasingly investigated [48,49,53,71], of which the primary propulsion may be a power battery, as shown in Figure 6. Furthermore, the secondary regulation technology will shift from a constant voltage network to a variable voltage network in the future [64,65].

Researchers have carried out an in-depth study about the evaluation indicators of hydraulic hybrid vehicles, such as NVH characteristics, drivability and vehicle characteristics. Although different from traditional fuel vehicles, what we are most concerned about is the energy utilization effect of hydraulic hybrid vehicles. Ref. [56] used a Simulink model to assess the efficiency and energy consumption of a hydraulic–electric vehicle, as shown in Figure 7. Through this demonstration, we can see that the author not only calculates the losses but also states the nature of the losses and where and when they happen. Therefore, when using this method, it is easy to identify the components that will be most advantageous to improve. In addition, the fluid behavior and energy efficiency inside high-pressure hoses are studied in-depth [72], which provides a good research direction for the efficiency improvement of hydraulic vehicles.

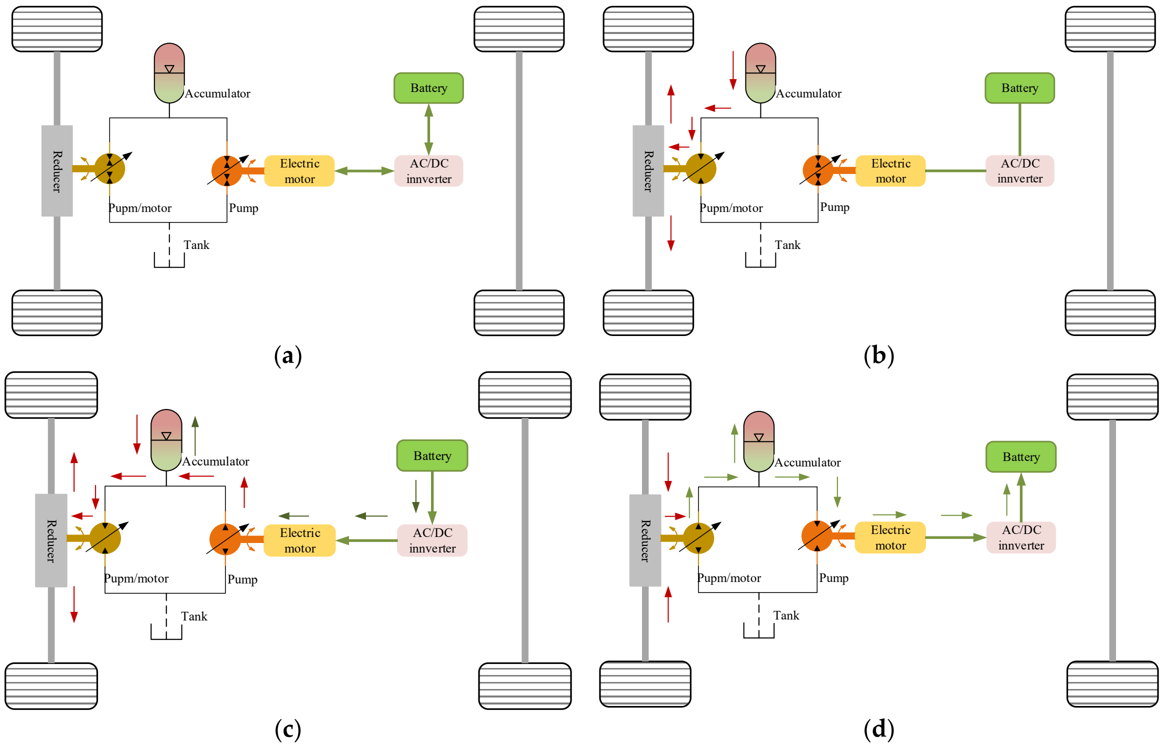


Figure 6. Configuration and energy flow of hydraulic electric hybrid vehicles [48,49,53,71]: (**a**) series hybrid; (**b**) launch; (**c**) acceleration and cruising; (**d**) regeneration.

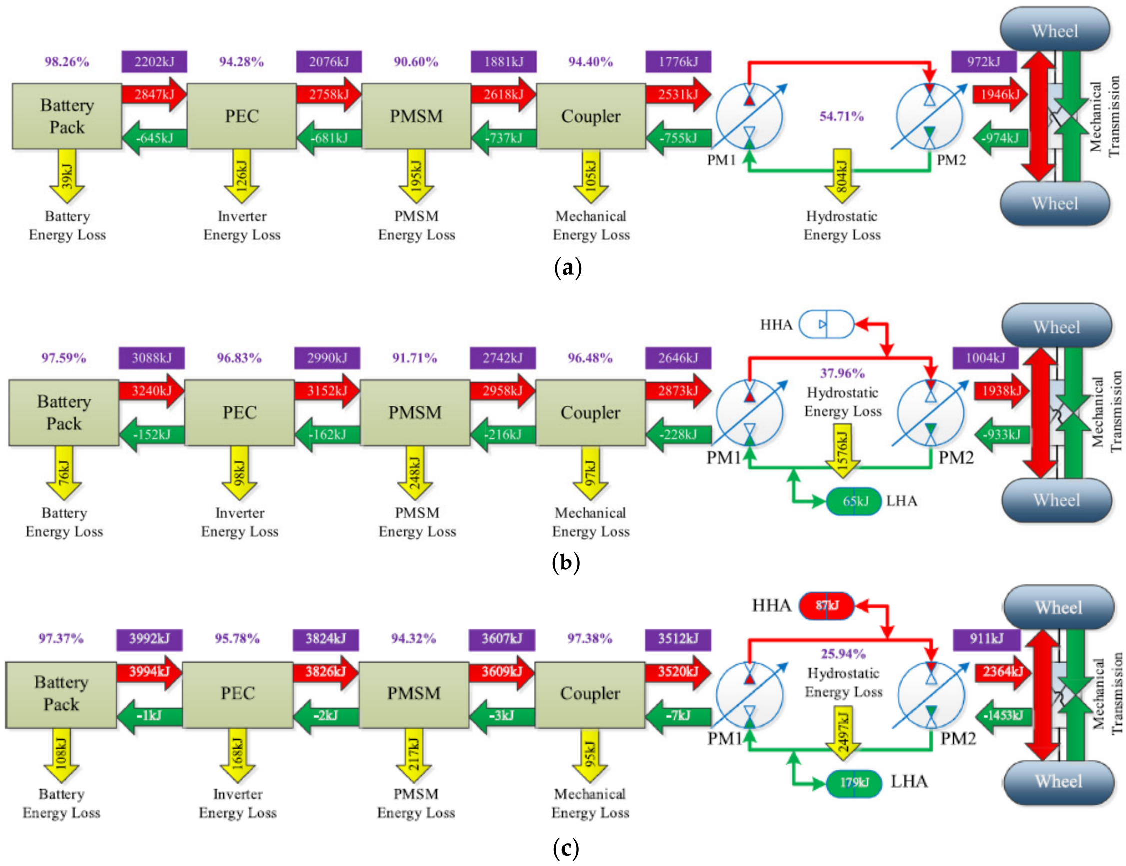


Figure 7. Configuration of energy flow and loss in the proposed hydraulic electric vehicle [56]: (**a**) battery mode; (**b**) battery-accumulator mode; (**c**) accumulator mode.

3. Investigation Status and Development of Different Kinds of Hydraulic Vehicles

3.1. Passenger Vehicle

The EPA demonstrated its first and only diesel full-series hydraulic hybrid test chassis in passenger cars in 2000, which showed that there is no need for expensive lightweight materials to improve fuel economy, and a diesel full-series hydraulic hybrid SUV was presented in 2004, achieving an 85% better fuel economy. Subsequently, many researchers and institutions began to study hydraulic hybrid passenger vehicles.

In aiming to achieve the optimum energy utilization efficiency of hydraulic hybrid vehicles, the parameter matching of the system is a key problem. R. Ramakrishnan et al. [38] designed a series of hydraulic vehicles that, during braking, can regenerate more mechanical energy into hydraulic energy by adjusting the hydraulic parameters, such as the pre-charge pressure of the accumulator and hydraulic pump/motor maximum displacement, to acquire the maximum output power of the proposed system. Related simulation results show there is a remarkable advancement in the output power when decreasing the pre-charge pressure from 12 to 2 bar and increasing the maximum volume of the pump/motor from 80 to 96 cc/rev. The author also used the same systems to continue to optimize the parameters so that the same systems maximize the output of the system power [71]. He reported that the output power is increased by 25%, which gives it much higher energy efficiency and makes it a greener vehicle. In Ref [73], they designed a strategy to improve the efficiency of the series hydraulic/electric vehicle. In addition, Meng, Z et al. [74] also conducted a study of parameter-matching of the proposed electric-hydraulic system. The simulation results demonstrated that the proposed system could effectively enhance the economic performance.

Wu W et al. [75] introduced their hydraulic hybrid propulsion system, which is made of CPR, HFPE and a hydraulic motor, as shown in Figure 8. Then, they studied the parameter design and proposed a novel way to match the powertrain of the hydraulic hybrid vehicle effectively and flexibly.

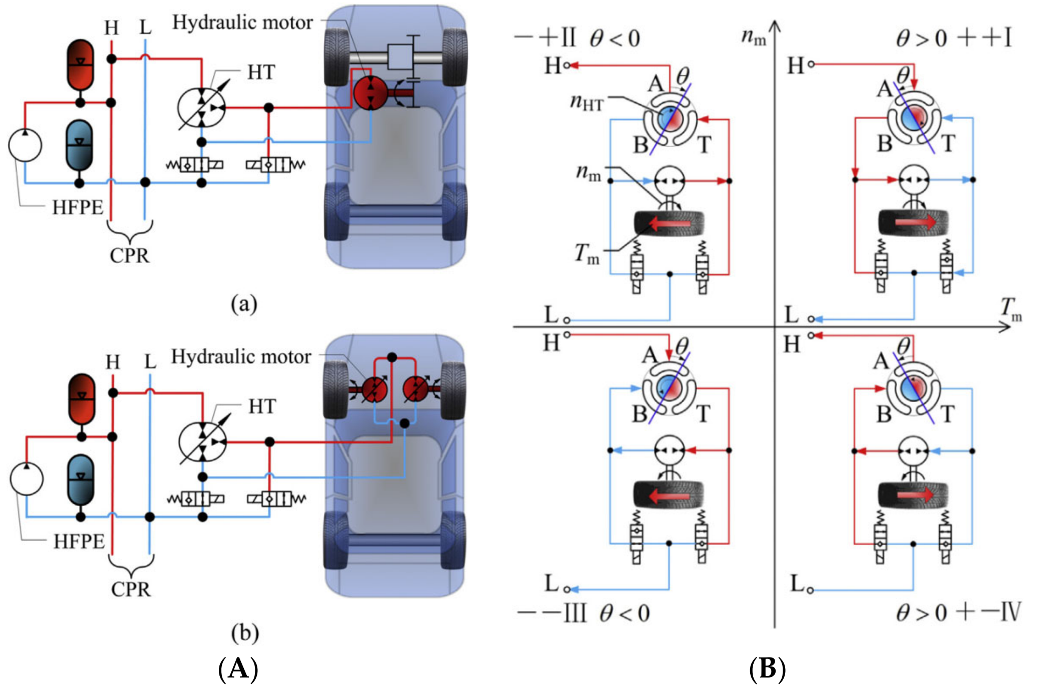


Figure 8. Configuration and principle of the hydraulic vehicle [75]: (**A**) structure of the proposed hydraulic hybrid propulsion system: (**a**) passive type; (**b**) active type; (**B**) working principle.

The authors also simulated and tested the hydraulic hybrid system on a test rig. Ultimately, they concluded that the hydraulic energy recovery efficiency is greatly affected by the overall hydraulic hybrid system efficiency, which is compatible with the conclusion of Ref. [38], and that a higher energy density of accumulator is a very feasible method and has been confirmed to be up to 16% greater than conventional accumulators [76].

Optimizing the drivetrains of a hydraulic hybrid vehicle is another viable approach. To explore the effects of improving fuel efficiency and driving performance of a hydraulic passenger vehicle using a continuously variable transmission, Ref. [68] improved a Hyundai passenger car model by modifying the original with new parts, including planetary gears, hydraulic pump/motors and a two-speed reducer. It was found that, compared with the reference vehicle model, the new structure effectively improved the working efficiency range of the engine, and the overall energy consumption was also remarkably reduced by 16.4%.

Energy optimization and energy management are important ways to conserve energy and decrease the emissions of hydraulic hybrid vehicles. Deppen T O et al. [77] presented a dynamic model of a passenger vehicle and discussed model predictive control to examine the influence of each part's efficiency on overall efficiency and the significance of the dynamic model and control procedure through a hardware-in-the-loop experiment. In this research, the authors found that the presented framework, which utilizes the best balance of each component's efficiency to be easily transferable to other automotive structures, has a 35% improved efficiency compared to results prior to the method that optimizes engine efficiency. The Lagrange multiplier method is an efficient method for designing energy management strategies when ignoring the influence of the accumulator dynamics. Therefore, the objective of Ref. [78] was to propose energy optimization and energy management based on a modification of the Lagrange multiplier. The new findings show that the two methods can reduce fuel consumption by 3–5%.

In addition, other approaches to energy optimization and energy management of vehicles are of great interest. Note that distributed drive electric vehicles are the mainstream direction of future vehicles, so the control methods applied therein can be transferred to hydraulic vehicles [79,80].

Furthermore, Barbosa T P et al. [81] further studied the energy saving possibilities and strengthened the superiority of hydraulic hybrid vehicles over gasoline vehicles. They also optimized the parameters of the hydraulic configuration to make the best use of the fuel by using a pattern search algorithm. The result showed that the energy consumption of the conventional vehicle, SHHV and optimized SHHV are 6.21, 5.11 and 3.89 L/100 km, respectively. Barbosa T P et al. [82] enhanced the research by introducing an ethanol-fueled engine as the primary propulsion mechanism, which is one step closer to zero-carbon vehicles, as shown in Figure 9. It was estimated that the CO_2 and NOx emissions achieved a decrease of 47.2% and 20.7% during the real-world driving cycle, while in the urban cycle, the ethanol-fueled engine exerts an energy-saving efficiency of 30.17–44.14% due to frequent startup and shutdown.

The combination of hydraulic hybrid and battery electric vehicles represents the future development trend. Ref. [83] evaluated the potential of the application of a hydraulic electric vehicle, which is an alternative to overcome the limitations of power batteries. Their simulation results showed that the hydraulic electric vehicle could reach 65% of the electric vehicle over the UDDS cycle and validated that the SOC basically fluctuates around 20%. Therefore, this paper reported that hydraulic electric vehicles are favorable contenders for supercapacitor-battery vehicles, resulting from the current drawbacks of power batteries.

Coincidentally, to effectively improve the shortcomings of electric vehicles in braking energy regeneration, R. Ramakrishnan et al. [73] furthered previous work by developing a novel series of hydraulic/electric synergy systems to find ways to design more energy-efficient and zero-carbon systems. They proposed a control strategy composed of the SOC of the accumulator as input, the power source as output, and then three modes to ameliorate the energy efficiency. The series hydraulic electric vehicle has an overall energy efficiency of 3% and a crystal clear hydraulic regenerative efficiency of 17.3%. Further, a comparative study with Ref. [48] indicated that the series hydraulic electric vehicle is more effective in energy utilization and has a higher output energy and a relatively higher power than HESS because of the electric regenerative braking involved in the recovery of braking energy; more information is given in Table 4. It can be concluded that, in some sense, the series hydraulic-electric hybrids have better potential than the parallel hydraulic–electric hybrids in terms of energy recovery.

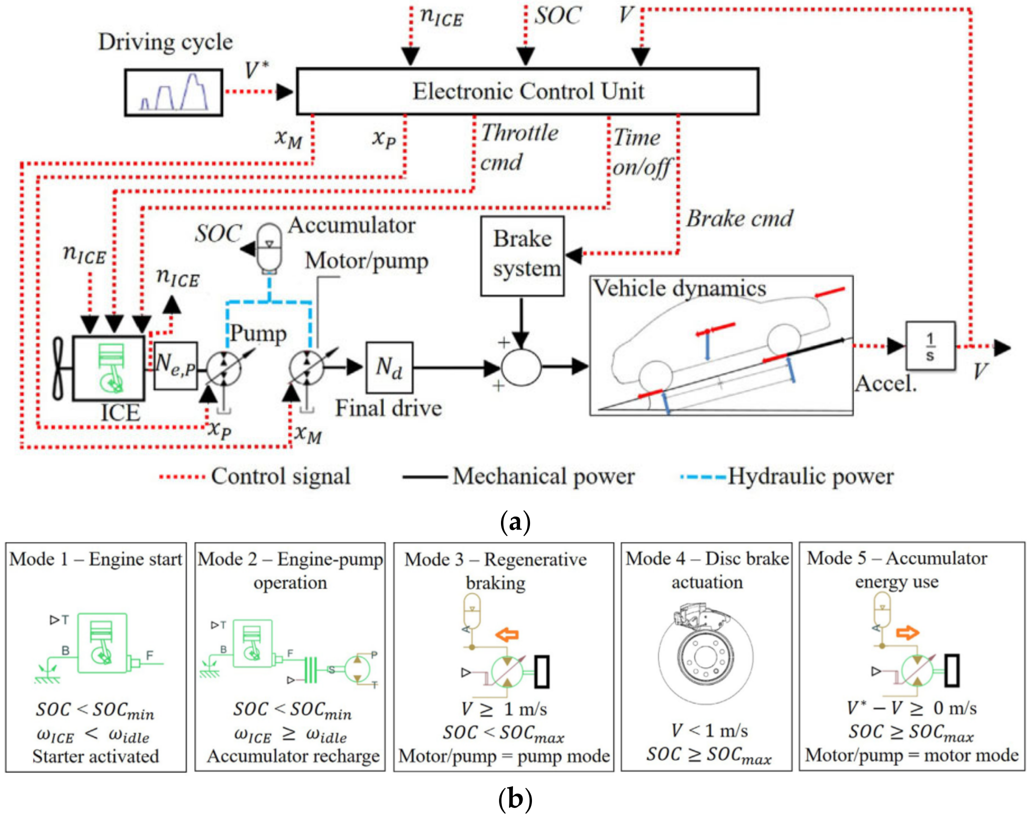


Figure 9. Flowchart and operating modes of hydraulic vehicle with an ethanol-fueled engine [82]: Flowchart and operating modes of hydraulic vehicle with an ethanol-fueled engine: (**a**) HHV flowchart; (**b**) proposed operating modes.

Table 4. Comparison of regenerative energy between HESS and SHESS (kWh).

Types	Recovery Energy Available	Recovery Energy	System Output Energy
HESS	2.7	2.7	28.6
SHESS	4.7	4.6	30.8

3.2. Minibus and Bus

Hydraulic hybrid buses have been studied extensively by researchers because hydraulic hybrid vehicles are very well suited to the frequent start–stop characteristics of buses in urban areas. Pawelski, Z. was one of the first to study hydraulic hybrid buses and also optimized the operating parameters when the accumulator was charging to calibrate the parameters of the control system [84]. There are two ways that were proposed to optimize the system parameters: one-level and two-level methods. Through simulation and experimental studies, the author found the optimal values of the control system, including the work pressure, pump capacity and rotational speed.

Liu G Q et al. [85] improved a conventional bus by implementing a new HPA to make full use of the fuel. In this respect, a methodology of parameter matching and optimization was presented. The simulation results demonstrated that the accumulator capacity and the gear ratio of the hydraulic circuit were the top factors to affect fuel economy and acceleration performance, respectively. The experiment data showed a 25% improvement in fuel consumption. It is worth noting that the prime movement mechanism in the above two studies is still the engine.

It may be that buses are more susceptible to national public policy in China, so researchers also prefer to study hydraulic–electric hybrid vehicles. Niu G et al. [86] introduced a novel parallel hydraulic–electric hybrid (EH2) structure for use in urban trucks and buses, as shown in Figure 10. Further, an upper controller was needed to plan and control the four modes to work properly and efficiently. The simulation results reported that the battery output stress of the city delivery truck could be decreased to 70% on average. Moreover, the range of the city bus could be increased by 50%.

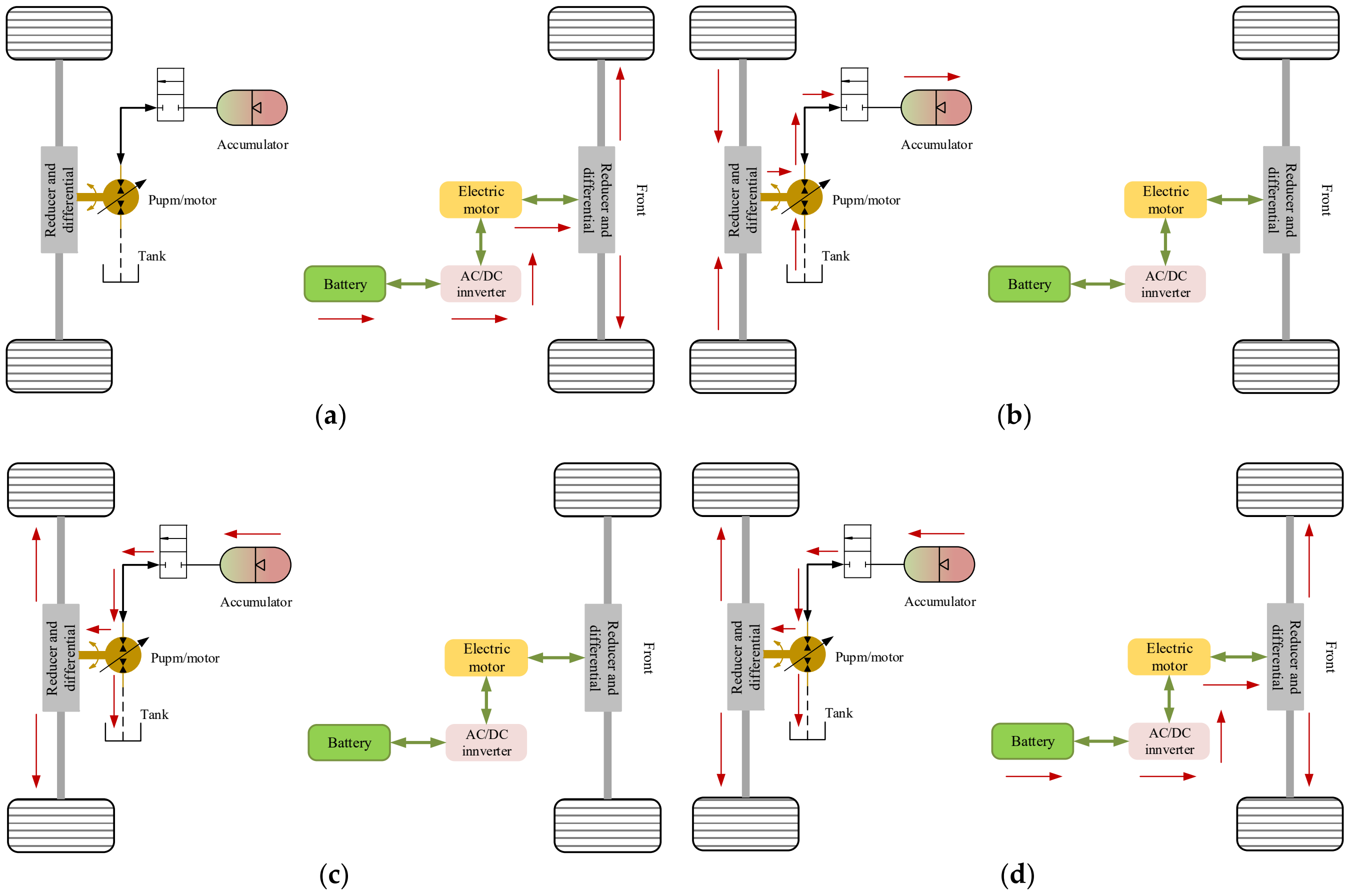


Figure 10. EH2 powertrain operation modes: (**a**) cruising; (**b**) regeneration; (**c**) launch; (**d**) acceleration [86].

Consequently, Chen G and Liu H [87] applied the electro-hydrostatic hydraulic hybrid (EH3) system in a battery-powered bus to reduce peak torque and increase battery lifespan, as shown in Figure 11. In this research, the rule-based dynamic optimal energy control approach is proposed to manage power under special conditions. They also carried out the EH3 simulation model and test rig, which showed that the peak torque and the battery power could reach 63.6% and 66.02% in NEDC. Meanwhile, the peak torque and the battery power could achieve 71.1% and 67.7% in the actual cycle.

However, unlike the other structures mentioned in this paper, one invention was proposed that combined a hydraulic and an electro-hydraulic braking system to make the structure and energy recuperation capacity simpler and higher simultaneously [88]. The fuzzy control of the power administration was implemented in the hydraulic braking regenerative system, and both were verified by a test rig. This study demonstrated that the accumulator volume and initial SOC are the two main factors that determine the efficiency of energy renewal. In addition, this paper reported that the initial speed of braking is a major factor that determines overall energy utilization.

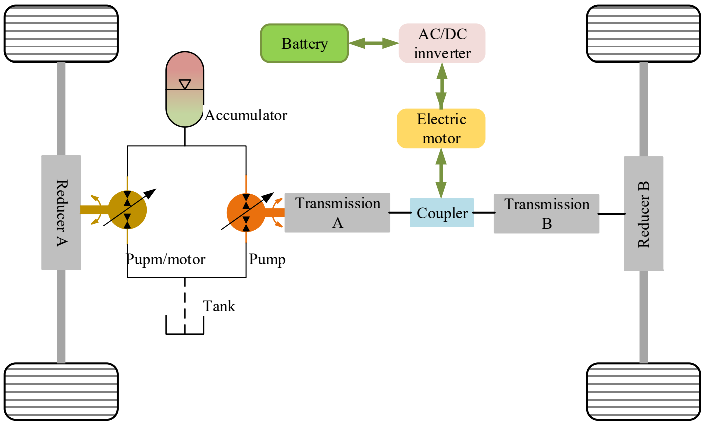


Figure 11. EH3 system in a battery-powered bus [87].

Recently, through the BUSINOVA Evolution project, an in-depth study of intelligent control strategies for hydraulic electric vehicles was conducted in France by Kamal E and Adouane L et al., as shown in Figure 12 [40,89,90]. Figure 11b demonstrates that the parallel configuration added an accumulator to improve energy savings and emission reductions.

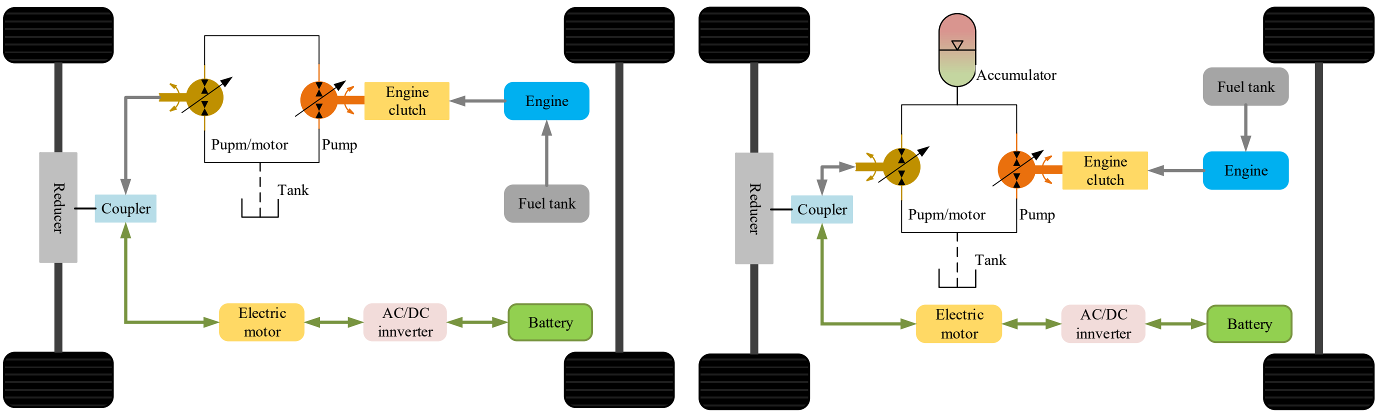


Figure 12. Evolution project of hybrid hydraulic BUSINOVA bus: (**a**) block diagram of the ICE-electric hybrid power flows; (**b**) block diagram of the ICE–electric–accumulator–actuated powertrain power flows [40,89,90].

3.3. Commercial Truck

Hydraulic hybrid systems show great promise for commercial trucks, like buses. At about the same time as the EPA, Filipi Z et al. began their research on hydraulic hybrid propulsion systems to address the open issues at the time through a comprehensive analysis of the parallel hydraulic 6 $\times$ 6 medium truck [91]. The authors developed a method of sequential optimization and power management based on dynamic programming in the process of an advanced first design optimization stage, followed by optimization of the power control stage, and then the second design optimization stage. Their analysis demonstrated that the proposed combined optimization methodology reduced fuel consumption by 32%, and of this, two-thirds of the improvements were accounted for by design optimization and one-third of the improvements were due to the new energy strategy. In addition, Johri R and Filipi Z investigated a series of hydraulic hybrids aimed at supplying a promising method to a city hydraulic vehicle [92], as shown in Figure 13. Through simulation, research reported that an advancement of 52–84% is over the baseline for IMA HEV.

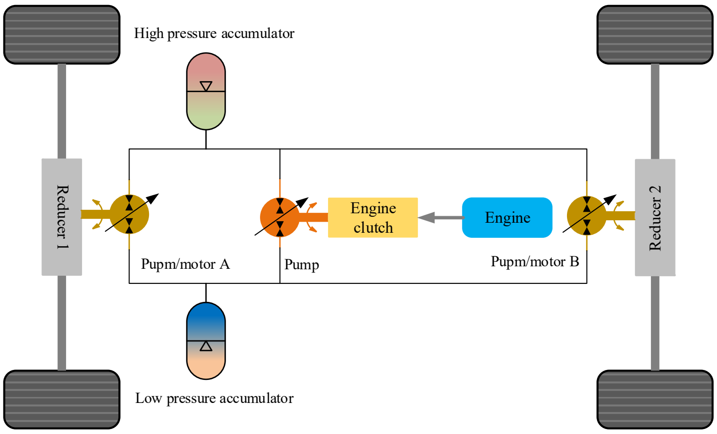


Figure 13. Configuration of the parallel hydraulic 6 × 6 medium truck [91,92].

Later, in another of their papers [44], a comprehensive methodology of supervisory control and an engine-in-the-loop test were set up, and experiment results reported that the fuel economy and particulate emissions of the medium truck were remarkably reduced by 72% and 74%, respectively, compared to the reference truck. Based on the previous 4 × 4 military truck configuration proposed in Ref. [44], the author presented stochastic dynamic programming power management to achieve the fuel economy objective [45]. Subsequently, the drawback of the minimization of transient diesel engine emissions was overcome with stochastic dynamic programming. Therefore, the author suggested novel neuro-dynamic programming to successfully address the problem. Subsequently, the hybrid supervisory control and a baseline rule-based controller were implemented and validated. The data indicated that intelligent multi-objective control exerts excellent performance in energy savings and emission reduction.

Other studies considered different processes than power management. Hui S et al. [93] proposed techniques for the optimization of parameters via dynamic programming and a real-time energy distribution methodology based on a fuzzy torque control strategy considering load change implemented in a parallel hydraulic hybrid heavy vehicle (14.31 t) to develop braking energy regenerative potential. They pointed out that the enactment of fuzzy torque improved fuel economy by 32%. The simulation results of energy storage performance compared with other potential energy storage systems demonstrated that hydraulic hybrid electric vehicles offer an important and viable dual carbon pathway for heavy-duty vehicles. On the basis of the above study, a battery pack was introduced into the same configuration, and a control strategy was proposed to satisfy the requirements for the harmony between energy and power density [48].

Another perspective on energy optimization was examined by Bender F A and Kaszynski M et al. [94]. This paper studied predictive energy optimization to further improve fuel efficiency in a parallel configuration of heavy hydraulic hybrid vehicles, such as refuse vehicles and city buses. Through simulation and test tracking, this paper reported that the heavy hydraulic hybrid vehicle achieved fuel savings of 16.1%, of which an additional 5% can be further saved. Therefore, predictive control is also worthy of further research on energy utilization.

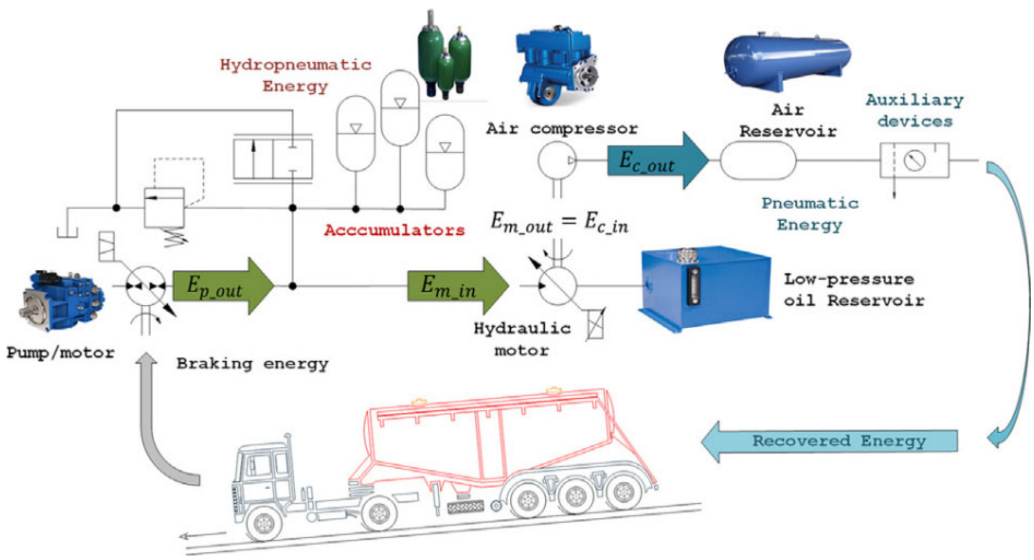
To get the maximum benefit of the high power density of hydraulic and pneumatic energy storage, Bravo R R S et al. [95] explored a new configuration of hydraulic–pneumatic recovery configuration for heavy vehicles to store braking energy used for propulsion or auxiliary systems, as illustrated in Figure 14.

The authors' principle was that the hydraulic system regenerates the braking energy. Then the hydraulic accumulator and air reservoir store the renewed energy. When there is power demand, the hydraulic–pneumatic regenerative system can provide the vehicle propulsion and power auxiliaries effectively. This paper also carried out the modeling, sizing, system integration and control strategy of the proposed hydraulic–pneumatic regenerative system. Further, the simulation and test rig were set up for validation and analysis. Finally, they found that the proposed system recuperates 69% of the available recovery energy during a full stop and 14% on a long downhill slope; more detail can be seen in Figure 14b,c. This study's results indicate that hydraulic and pneumatic systems have remarkable energy efficiency potential in special commercial vehicles, such as delivery trucks and buses. In addition, through this demonstration, we can see the power losses, the nature of the losses and where and when they happen. Therefore, this method is very important in its ease in identifying the components that will be the most rewarding to improve and identifying the best solutions for improving them to reduce even further energy consumption.

Further, the authors went on to propose a component-matching strategy and analyze the sensitivity of the proposed system parameters in order to accelerate the design of a hydro-pneumatic energy recovery braking system [96]. The results demonstrated that it is effective and can also be used in the design of other hydraulic–pneumatic systems.

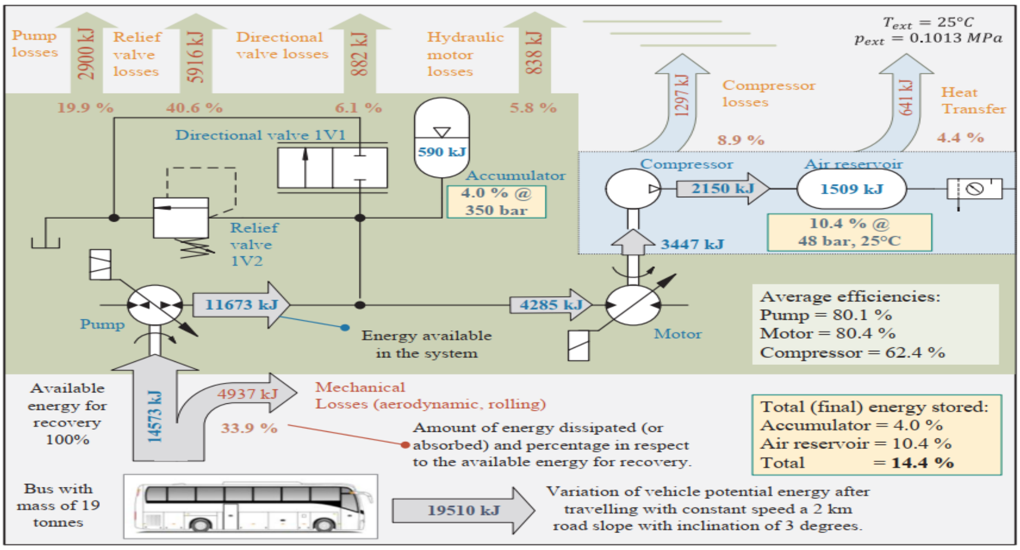
Driven by developments in electric vehicle technology, more and more research into hydraulic hybrid electric vehicles is underway. Some of the relevant Chinese researchers and institutions are mentioned below. Ref. [73] presented a novel electric–hydraulic hybrid vehicle in which the parameters are matched and simulated. Yang J et al. [97] introduced a novel mechanical–electric–hydraulic dynamic coupling drivetrain to enhance the startup acceleration performance and simplify the configuration of the battery electric vehicle, as plotted in Figure 15.

There are five working modes that were selected by the ruling energy management strategies of the MEH-DCDS. The research results showed that the starting performance of MEH-DCDS improved by 40.37%, followed by 23.01% after a PID adjustment, the SOC consumption ratio was reduced to 79.67%, and the driving range was increased by 45.7 m compared to an electric vehicle. The authors then carried out further research in Ref. [98]. They launched the same novel electric vehicle with the newly proposed multiple modes of driving management and fuzzy logic optimization, as shown in Figure 16. Thereafter, the simulation and actual vehicle test rigs were set up, respectively, to verify the feasibility and superiority of MEH-PCEV. The battery's energy consumption decreased by 14.418% and 21.174% under the NEDC and American city cycle, respectively.

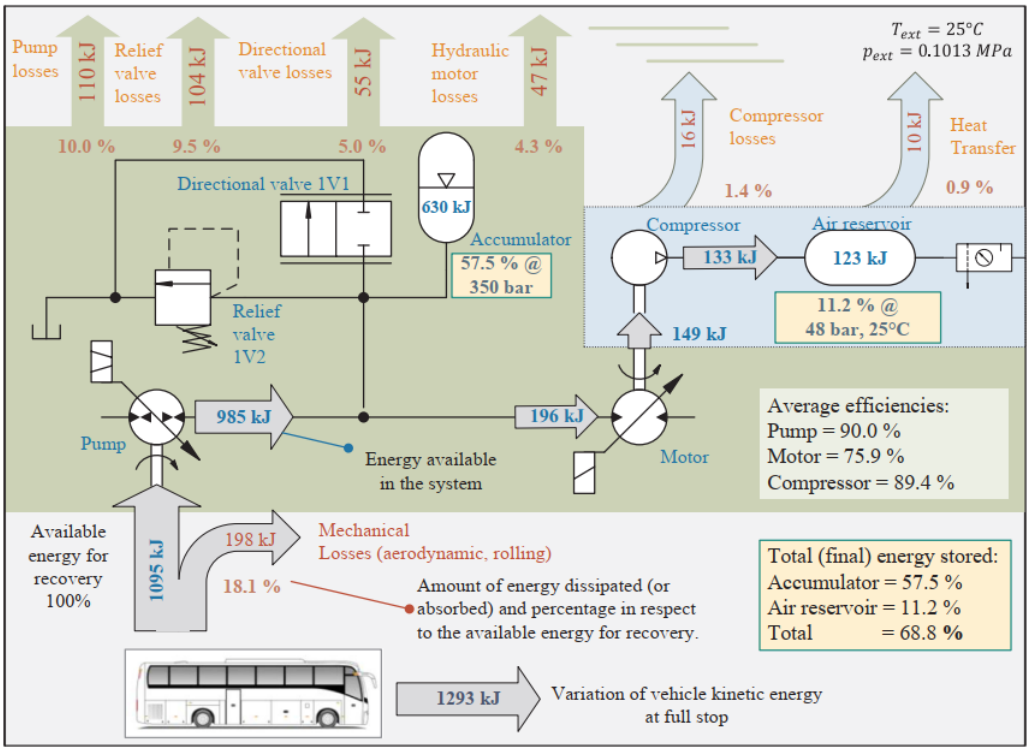


(**a**)

Figure 14. *Cont.*



(b)



(c)

Figure 14. Parallel hydraulic–pneumatic recovery braking system [95]: (**a**) diagram of the configuration used; (**b**) total energy flow at 40 km/h on a 2 km downhill slope with 3°; (**c**) total energy flow after braking to full stop.

It can be concluded that the economy and dynamic performance of hydraulic electric vehicles are significantly affected by important aspects, such as parameter design, parameter optimization and energy management strategies. Therefore, these areas will continue to be active fields of hydraulic hybrid electric vehicle research. Additionally, to improve vehicle power performance and energy consumption, a new hydraulic hybrid vehicle with four-wheel hydraulic motors has been proposed, with the proposed hydraulic control system composed of the upper controller, to determine the gear ratio and power distribution, and the engine controller, to maintain the engine speed using a PID to adjust the pump displacement [99]. Simulation results indicated that acceleration and fuel economy performance improved by about 36.3% and 35.59%, respectively.

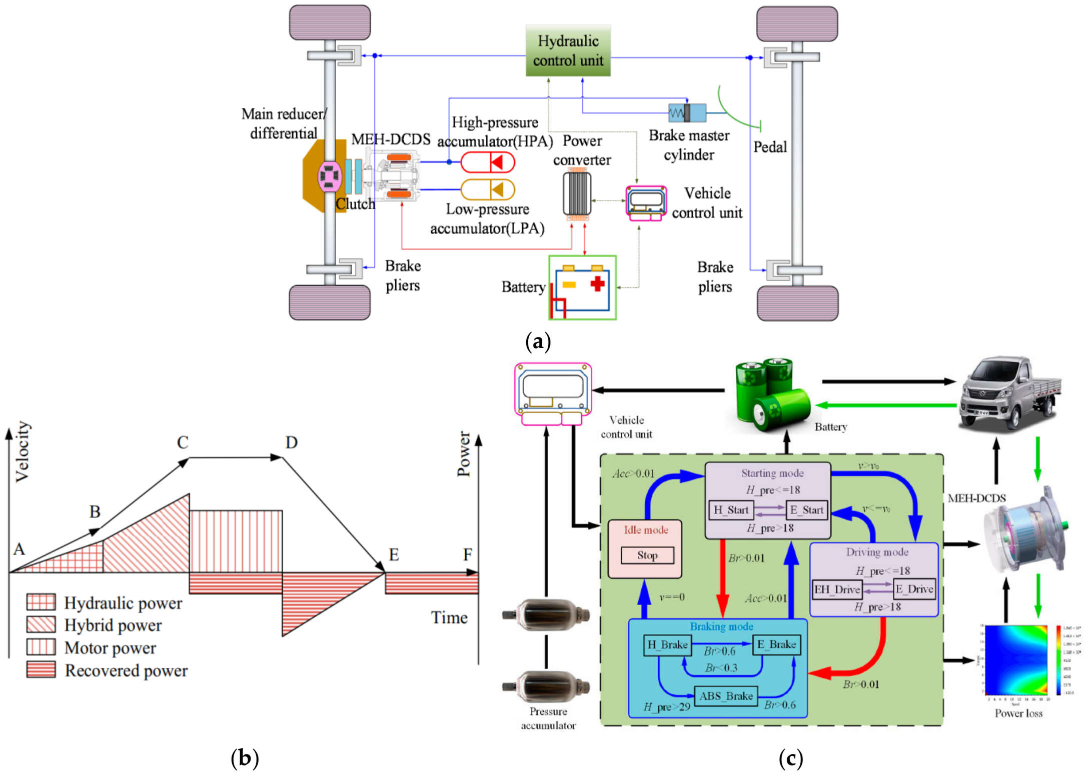


Figure 15. Configuration, working modes and control scheme of proposed MEH-DCDS [97]: (**a**) diagram of the structure; (**b**) working mode diagram; (**c**) energy management strategies.

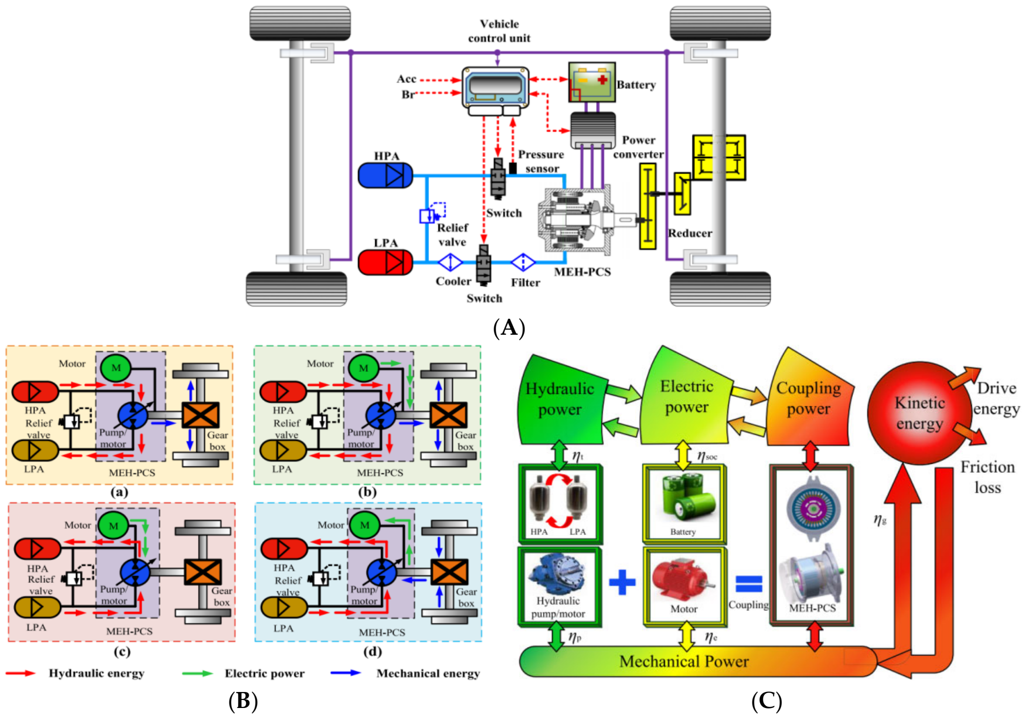


Figure 16. Mechanical–electric–hydraulic dynamic coupling drive system [98]: (**A**) diagram of the structure; (**B**) validation model for the MEH-PCEV, (**a**) energy flow in HD mode, (**b**) energy flow in EHD mode, (**c**) energy flow in Idle mode, (**d**) energy flow in RB mode; (**C**) test rig diagram of MEH-PCS.

Finally, improvements in the components themselves are also key factors in improving vehicle dynamics and economy. For instance, the experimental validation of a hydraulic hybrid truck was conducted by Midgley W J B et al. [100], in which the Danfoss Digital Displacement pump/motor presented 20–50% more than the swashplate in a special scenario [101]. He found that the hydraulic hybrid truck showed savings of 24–43% in fuel economy and savings of 29–95% in terms of engine stop-start under the given driving circle.

3.4. Special Vehicle

The wide range of special-purpose vehicles consists of vehicles that fulfill a specific function in a specific environment. This review mainly focuses on key areas of current interest in the application of hydraulic hybrid vehicles.

3.4.1. Delivery Truck

The first commercial HHV developed by the EPA was a series hybrid hydraulic hybrid driven by an engine applied in a United Parcel Service delivery truck, which had great success due to its good results of energy savings of 60–70% and emission reductions of 40%. More information is in Table 1 and Ref. [9]. Midgley W J B et al. [46] simulated a hydraulic recovery braking system in urban delivery and found that energy savings of 21.7% were obtained. Additionally, this system managed to decrease fuel economy by 12.6% and 5.3%, respectively, when driving in a V-shaped valley and a realistic cycle.

Niu G et al. [102] optimized the system by introducing the electric–hydraulic hybrid (EH2) to improve the original engine fuel economy and dynamic performance, expand the driving range of the electric vehicle and relieve battery discharge current stress. They found the size of hydraulic accumulators plays a notable role in different aspects of different hydraulic electric vehicles, as shown in Table 5. Their work can be applied to city delivery trucks and city buses, and further study is described in Section 3.2. As can be seen from the above studies, there are actually a lot of similarities between medium trucks and buses in cities, which makes them very similar to study.

Table 5. Summary characteristics of evaluations of accumulator size in hydraulic–electric hybrid vehicles.

Items	Types of Hybrid Hydraulic Vehicles		
	Light Hybrid	**Mild Hybrid**	**Heavy Hybrid**
Degree of hybridization	Battery 11%, accumulator 89%	Battery 19%, accumulator 81%	Battery 47%, accumulator 53%
Battery current press	62.5%	60.2%	54.1%
Accumulator usage	72%	62%	5%
Accumulator loss	High	Mild	Low
Hydraulic motor loss	Mild	Low	High
Battery saving	Low	Mild	High
Vehicle weight	Light	Mild	Heavy

3.4.2. Environmental Sanitation Truck

Urban trucks, especially refuse trucks, are one of the important and active areas of hydraulic hybrids and have attracted many researchers. Frank, A et al. [103] first proposed a hybrid hydraulic powertrain in a parallel configuration to study the laws of its energy-saving potential. The results showed an energy savings improvement of about 20%, which gives it a huge advantage in the transport of municipal waste due to its much higher power density.

Zhou S et al. [104] furthered Frank's work by simulating the parallel hydraulic hybrid vehicle, in which a parametric design and corresponding braking control strategy were set up. The results showed that the parameters design and the braking control method have a great effect on the maximum benefits. In 2020, Zhou S et al. used the same parallel hydraulic hybrid vehicle to study the vibration characteristics. They suggested that the natural frequencies of both the parallel hydraulic vehicle and the original vehicle are almost the same. However, the hydraulic driveline response to the engine excitation was over 40% at the first natural frequency. Moreover, there was no need for substantive vibration isolation for the hydraulic pump/motor because the HPM was not exposed to the engine [105].

They furthered the study on drivability and comfortability. The results showed that the faster mode switching gave better drivability, while the slower mode switching gave greater comfort. The solution and balance between the two contradictions were feedforward and feedback control to maintain a stable acceleration during mode switching [106]. After a preliminary study, the author proposed the LQR method to enhance vehicle oscillation [107]. Then, the extended Kalman filter (EKF) was implemented to assess the parameters of the previous hydraulic vehicle. The simulation results showed that the force on the gear transition was successfully executed. However, only the gear shift with lower throttle could be met when the HPA was not full.

Their latest research on all wheel-driven hydraulic hybrids is in Ref. [108]. In this paper, a comparative study was conducted on the energy economy and vertical vibration characteristics of three kinds of vehicle configurations, as shown in Figure 17. Moreover, the author introduced dynamic programming (DP) to optimize the energy utilization of the proposed vehicles. The results demonstrated that the CEV has the best economic performance, followed by the IEV, and the highest is the IHV. It is possible to conclude that the motor efficiency of the CEV is higher and the IHV has the highest energy loss in the hydraulic drivetrain.

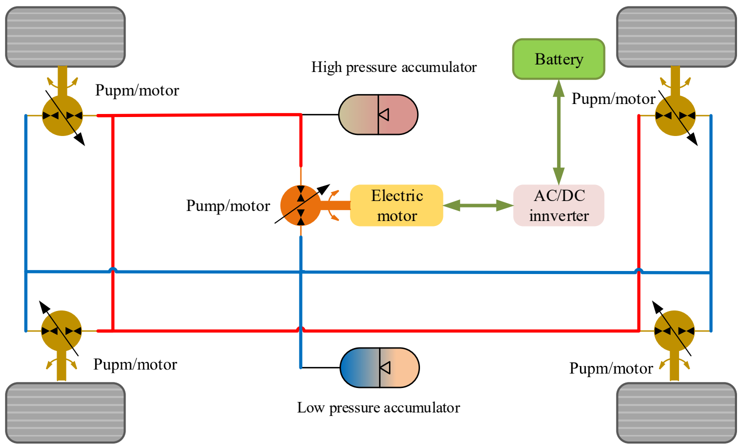


Figure 17. Structure of wheel-drive hydraulic electric vehicles [108].

In another comparative study on refuse trucks, Soriano F et al. [109,110] researched the topological analysis of powertrains to analyze the average energy consumption. In the first part, the hybrid hydraulic vehicle was studied with and without predictive strategies, and results showed that the proposed hybrid hydraulic powertrain without and with neural adaptation had an energy saving of up to 11% and 14% respectively, which implied that the hardware improvement plays a role in the energy economy. In the second part, the paper proposed three different hybrid electric configurations and the overall performances were summarized, from which it can be inferred that the electric structure has a more prominent prospect for energy conservation [110].

3.4.3. Mining Truck

More than one-third of the traction energy can be renewed for mining trucks because of their typical transportation routes, which are ideal for high-power density energy storage systems.

Jin C et al. [111] studied the energy economy of mining trucks by comparing four configurations of trucks. The research showed that the hydraulic ESS under low load and the compressed-air ESS under medium and heavy load work cycles only obtained the best economy when with full capacity. Therefore, it can be concluded that the relationship between HESS and AHESS is not in competition but complementary, and is according to special circumstances, such as typical transportation routes, vehicle parameters, control units, etc.

Subsequently, Yi T et al. [112] further optimized energy storage efficiency for the mining truck with a novel integrated hydro-pneumatic hybrid structure, as shown in Figure 18. The analysis demonstrated that the mass and capacity of the integrated layout are simultaneously improved by 15.4% and 24.8% compared to those of CAESS and by 83.1% and 92.8% compared to those of HESS, respectively. This study indicates that the design of energy recovery devices offers a very promising approach for hydraulic hybrid vehicles.

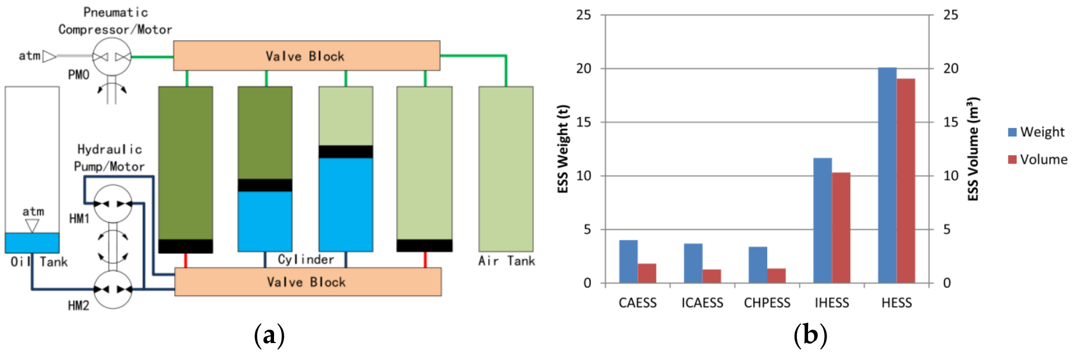


Figure 18. Proposed novel coupled hydro-pneumatic hybrid system [112]: (**a**) coupled layout; (**b**) volume and weight of HMT.

3.4.4. Other Truck

Hydraulic hybrid vehicles are also active in other areas, as described below. Liu H et al. [53] applied the battery-powered electric-hydrostatic in rail vehicles to handle the issues of energy inefficiency and deficient downhill stability, as illustrated in Figure 19.

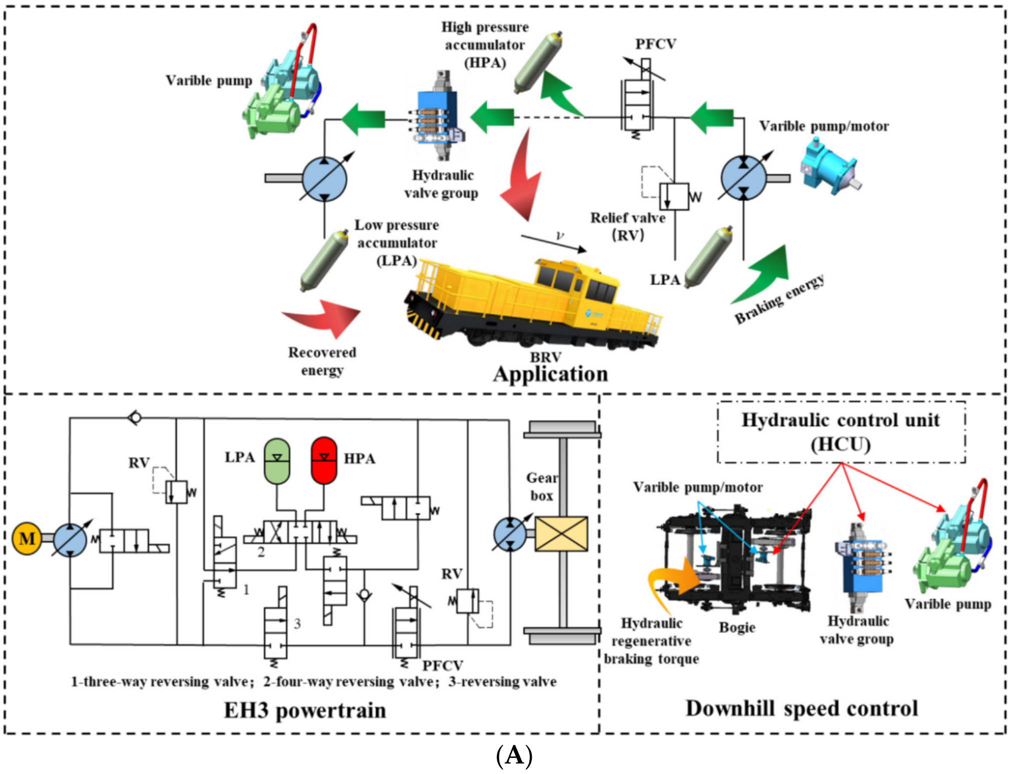


Figure 19. *Cont.*

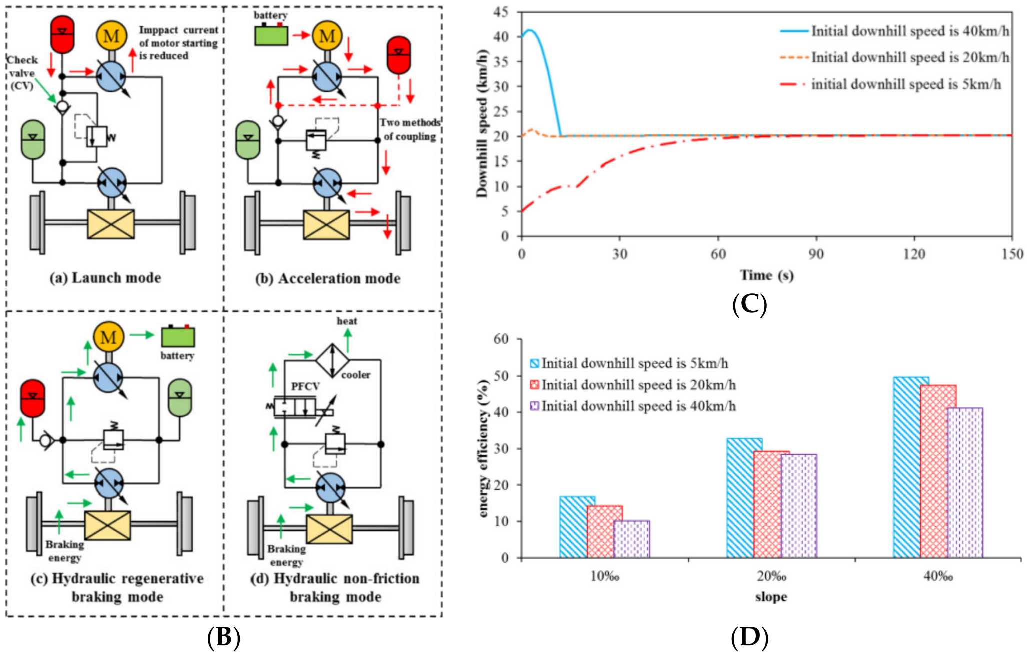


Figure 19. Architecture and characteristics of EH3 [53]: (**A**) EH3 powertrain; (**B**) working modes, (**a**) launch mode, (**b**) acceleration mode, (**c**) hydraulic regenerative braking mode, (**d**) hydraulic non–friction braking mode; (**C**) downhill speed control; (**D**) energy efficiency under different conditions.

Therefore, an EH3 was developed, and the strategy of downslope velocity was offered and validated. The simulation results show the hydraulic average energy recuperation rate could be 50%. In addition, one year later, to manage the weaknesses of low energy efficiency and high power shock when starting or accelerating, Liu H et al. [113] continued optimizing the EH3 and described a novel EH3 configuration, in which three modes, ECOP, ECIP, and TCPM, were designed. Through simulation, the results indicated that this novel EH3 had an energy saving of up to 50% and the battery energy consumption improved to 82.68%. The approach proposed in this paper has implications for energy utilization technologies for hydraulic electric hybrid vehicles.

Consequently, an electro–mechanical–hydraulic electric vehicle was simulated to match electro–mechanical–hydraulic coupling parameters, and the conclusion was drawn that the accumulator capacity can affect the highest working pressure of the accumulator and the battery SOC [114]. Furthermore, along the same lines as [95], Nie et al. implanted the hydraulic transformer into the system [115]. The simulation indicated that the regenerative braking torque fluctuation was improved to 34.39%. It is clear that hydraulic and pneumatic energy storage and combinations of the two show great advantages in compensating for the shortcomings of electric vehicles.

To clearly illustrate the future structure and direction, a summary of mechanical–electric–hydraulic hybrid energy storage systems in vehicle research is listed in Table 6, including the general energy-saving technology in Section 3. Moreover, the method, recycled energy and main findings in mechanical–electric–hydraulic hybrid energy storage systems are summarized in Table 6. Obviously, braking, coasting and coasting on a slope are the primary sources of available energy. Table 6 also shows that the development of hydraulic electric vehicles is a current research hotspot and heralds the integration of hydraulic and electric vehicles as a mainstream direction for the future.

Table 6. Summary of mechanical–electric–hydraulic hybrid energy storage systems in typical vehicles.

No.	Researcher	Method	Recycled Energy	Energy-Saving Technology	Findings
1	Ramakrishnan et al. [38,73]—Series hybrid	Simulation	Braking energy	Match the system parameter and maximize the power output.	Find the factors to enhance energy saving and emission decrease. The output power of the presented object is advanced by 25%.
2	Wu et al. [75]—Series hybrid	Simulation Experiment	Braking energy	Match the components of hydraulic hybrid.	The hydraulic energy recovery efficiency is greatly affected by overall hydraulic hybrid propulsion system efficiency.
3	Ji et al. [68]—Series–parallel hybrid	Simulation	Braking energy	Optimize hydraulic hybrid vehicle drivetrains.	The design effectively enhances the working efficient scope of the drive element and the fuel economy is decreased by 16.4%.
4	Deppen et al. [77]—Series hybrid	HIL experiment	Braking energy	Use the predictive control to improve the energy utilization.	The energy efficiency is 35% prior to the method that optimizes engine efficiency using the additional degrees of freedom.
5	Liu et al. [85]—Hydraulic power-assist system	Simulation Experiment	Braking energy	Methodology of parameter matching and optimization.	The accumulator capacity and the gear ratio as the top factors influencing fuel economy and dynamic performance, respectively. Acquired a 25% improvement in fuel consumption.
6	Niu et al. [86]—Parallel hybrid	Simulation Experiment	Braking energy	Adopt hydraulic–electric hybrid vehicles.	The battery discharging stress could be decreased to 70%. The driving scope of the bus could be expanded by half.
7	Adouane et al. [40,89,90]—Parallel hybrid	Simulation	Braking energy	Design intelligent energy management.	Add an accumulator to improve energy conversation and emission reduction effectively.
8	Filipi et al. [91]—Parallel hybrid	Simulation	Braking energy	Propose sequential optimization and dynamic programming.	Improve the energy conversation by 32%.
9	Bravo et al. [95,96]—Hydraulic–pneumatic regenerative system	Simulation Experiment	Braking energy Low slope	Carry out the sizing, system integration and control strategy.	Retrieve 69% of the available energy of a full stop and 14% of a long downhill slope.
10	Zhou, H et al. [99]—Wheel-driven hydraulic hybrid vehicle	Simulation	Braking energy	Hydraulic hybrid vehicle with four-wheel hydraulic motors.	Indicate accelerating and fuel economy performance is improved by about 36.3% and 35.59%, respectively.
11	Frank et al. [103]—Parallel hybrid	Simulation	Braking energy	Propose a new hybrid hydraulic powertrain.	It is about a 20% energy-saving improvement.
12	Liu et al. [53]—Series hybrid	Simulation	Braking energy	Apply the battery-powered electric-hydrostatic in vehicles.	The hydraulic average energy recuperation rate reached 50%.
13	Yi T et al. [112]—Hydraulic–pneumatic energy storage system	Simulation	Optimized energy storage efficiency	Propose a novel coupled hydro–pneumatic energy storage system.	Enhance by 15.4% and 24.8% compared to those of CAESS and by 83.1% and 92.8% compared to those of HESS, respectively.
14	Zhou et al. [104]—Parallel hybrid	Simulation	Braking energy	Conduct parametric design and braking control strategy.	Have a great effect on the maximum attainable benefits.
15	Soriano et al. [109,110]—Series hybrid	Simulation	Braking energy	Propose analysis of powertrains for refuse-collecting vehicles.	Has an energy saving of up to 14% and 11% without and with neural adaptation, respectively.
16	Jin C et al. [111]—Comparative study	Simulation	Braking energy	Study on the economy of a mining truck of four types.	Show that the relationship between HESS and AHESS is not in competition but complementary.
17	Liu et al. [113]—EH3	Simulation	Braking energy	Optimize the EH3.	This novel EH3 has an energy saving of up to 50%. Improve the battery energy consumption by 17.32%.
18	Chen et al. [114]—Electro–Mechanical–Hydraulic electric vehicles	Simulation	Decelerating and braking energy	Match electro–mechanical–hydraulic coupling parameters.	The accumulator capacity can affect its highest working pressure and the battery SOC. It is confirmed that 35 L is the best volume in the proposed subject.
19	Nie et al. [115]—Parallel hydraulic–pneumatic hybrid	Simulation	Braking energy	Implant the hydraulic transformer into the system.	The recovery braking torque could range from around 14,434 to 169 Nm and its fluctuation can be decreased by 65.61%.

4. Current Research Status of Energy Management Techniques

As can be seen from the aforementioned studies, much attention and research have been directed toward energy management techniques for hydraulic hybrid vehicles and have been proposed, simulated, analyzed and tested in a HIL or an actual vehicle in previous research. The results of the application of these energy management techniques prove that control strategies are vital to enhance energy efficiency and reduce emissions.

Generally, the objectives of the energy control techniques are aligned with the objectives of the whole vehicle, which are primarily: maximum energy economy, minimal emissions or even zero emissions, minimum system cost and good drivability and comfortability, namely, more complete energy utilization for better performance, power and drivability.

Therefore, to pursue such goals, the energy management techniques of hydraulic hybrid vehicles must be designed one-to-one with their configuration and circumstance in the application, where the relationship of the three is constrained and reinforced by each individually. The following is an overview of the current state of the energy strategy. It is true that the current application of hydraulic energy storage technology in vehicles has yet to be significantly developed. Therefore, an overview of the current control technology is highly desirable. Energy management control techniques integrated into hydraulic hybrid vehicles can normally be separated into two primary types: rule-based and optimized control strategies, as shown in Figure 20.

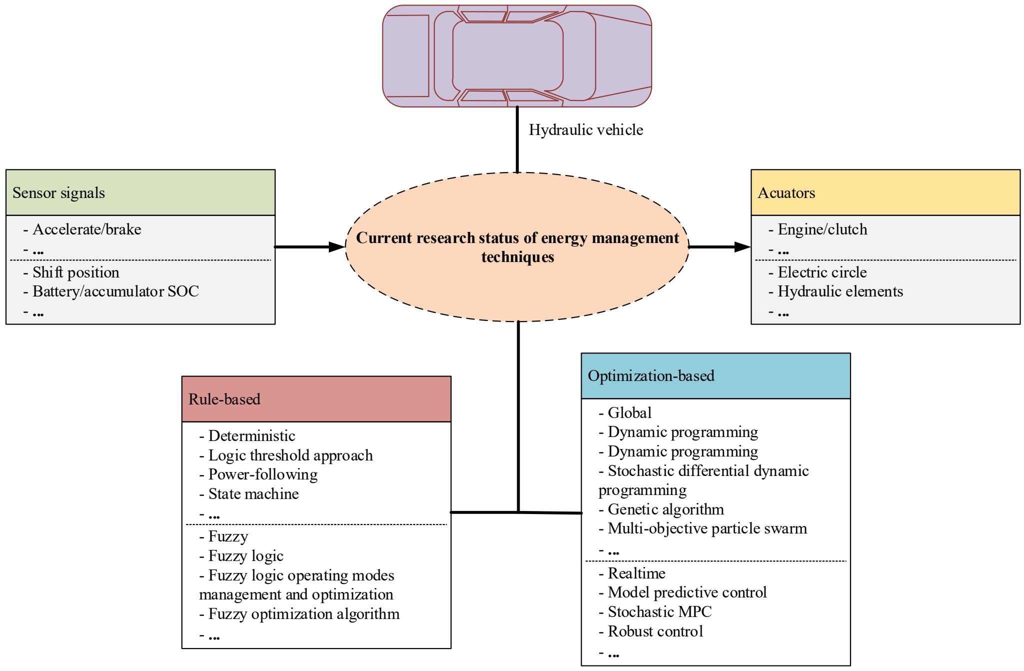


Figure 20. Control strategy classification of hydraulic hybrid vehicle.

4.1. Deterministic Rule-Based Control Strategy

Owing to their simplicity, high computational efficiency and robustness to vehicle uncertainty, deterministic rule-based energy strategies are the most extensively used strategy in hydraulic vehicles.

In order to enhance energy utilization and keep the deviations of the SOC within a high-efficiency range, based on Ref. [48], Hui S et al. [116] studied a logic threshold technique and optimization algorithm for the key parameters. Liu T al. [117] presented a rule-based control method for a recovery braking system. Zhou H et al. [41] suggested a rule-based energy management method to enable the real-time control of the hydraulic vehicle. Moreover, a parameter-match method based on dynamic programming was provided to improve vehicle performance.

A power-following control method was studied by inserting some engine working points in the optimal line [118], as shown in Figure 21. Through the test bench, the results suggested that the control design could enhance energy efficiency by more than 24%. The power-split hydraulic hybrid vehicle characteristics can be expanded to deploy in other vehicles while designing related hydraulic hybrid vehicles [119].

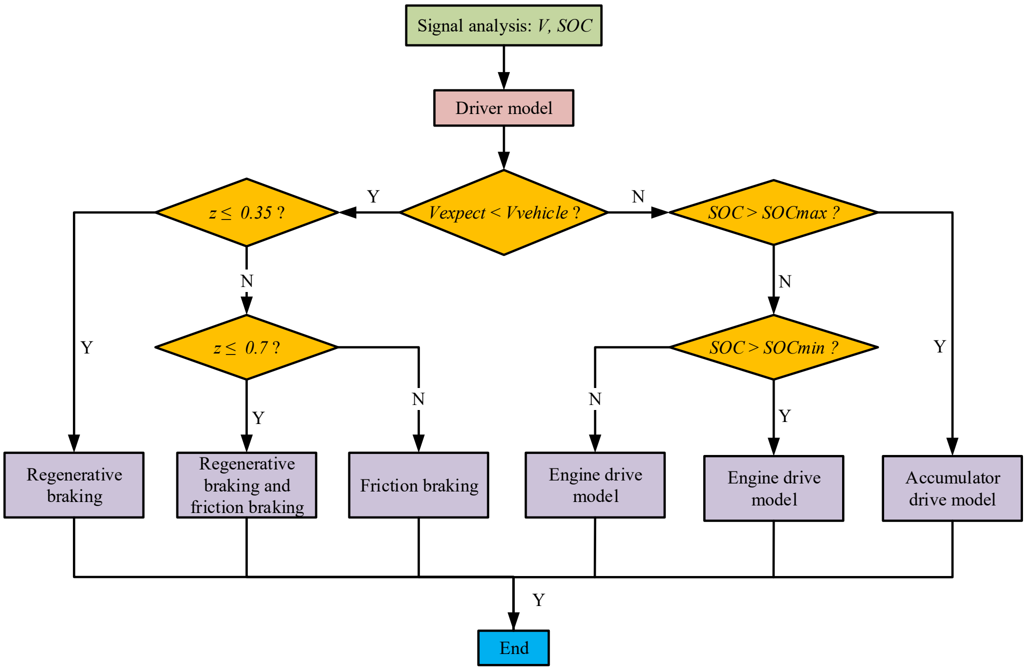


Figure 21. Control method of the wheel-driven hydraulic vehicle [118].

Aimed at investigating the energy-saving potential of a series of hydraulic hybrid systems, Wen Q et al. [120] devised a rule-based tunable energy approach to the trade-off between energy consumption and the dynamic performance of the wheel loader. The results revealed that the series HHWL had fuel savings of up to 18.9%. A rule-based dynamic optimal management approach was provided to address the issue of short battery life [87].

4.2. Fuzzy Rule-Based Control Strategy

Fuzzy rule regulators are another type of rule controller that can solve and adapt to power distribution issues in multi-domain, non-linear and time-varying structures. The main benefit is the robustness to variations in measured values and systems, thus exhibiting better performance than deterministic rule-based control strategies.

Ref. [40] developed a control scheme based on fuzzy control and a neural network to minimize energy consumption to acquire a better battery life. Sarmiento M A D et al. [121] proposed a braking energy renewal system with a control strategy established on fuzzy logic. The simulation results revealed that the fixed and variable displacements showed energy savings of 15.5% and 22.5%, respectively. Other related influential work includes [90].

Zhao Q and Zhang H [122] proposed a regenerative braking energy management system based on the fuzzy optimization method integrated into a novel electro-hydraulic vehicle. This paper reported that the proposed approach can reduce battery energy consumption by 1.22% under NEDC.

4.3. Global Optimal Control Strategy

Rule-based control strategies have rules and thresholds that must be determined in advance, so they do not provide optimal solutions for different driving environments; meanwhile, the performance of such control strategies is greatly affected by changes in vehicle operating conditions. As a result, optimal control strategies have been proposed and are increasingly being studied.

The dynamic programming technique has been employed to address the trouble of the optimal control variable trajectory [123]. Williams K et al. [124] depicted an approximate stochastic differential dynamic programming technique and then integrated it into an MPC framework to optimize energy utilization. Through a HIL experiment, the author evaluated the real-time feasibility of the potential of ASDDP. As to the application of medium and heavy vehicles, Hwang et al. [125] introduced a hydraulic electric vehicle and debated its global optimization approach based on the genetic method. The results demonstrated that the economic performance was improved by 36.51% compared to the battery electric vehicle. Moreover, when adopting a genetic algorithm, the energy economy increased by 43.65%.

For balancing fuel economy and drivability, Wang Z et al. [126] studied a modified multi-objective particle swarm optimization procedure applied in a hybrid hydraulic vehicle. The results showed that the fuel economy of the traditional HHV was substantially enhanced by 18.27%. Moulik B et al. [127] compared the improvement in fuel economy using local and global optimization techniques in a hybrid hydraulic powertrain. The results indicated that global optimization is obviously greater with regard to energy utilization. However, the author pointed out that global optimization techniques are offline. This means that they cannot be employed online, which requires them to be used in conjunction with other methods, such as local optimization methods.

4.4. Real-Time Optimal Control Strategy

Real-time optimal control strategies are the closest to objective reality but are also the most difficult to apply in practice as they are more demanding in terms of computing power. However, there is still much research that has been conducted on real-time optimal control strategies.

Deppen T O et al. [77] presented a predictive management model to optimize energy utilization in a passenger vehicle. In addition, later, a comparative investigation of these strategies was conducted to assist in the choice of which strategy to apply [128]. However, it showed that there is no one energy management method that is most suitable for all scenarios but rather the characteristics of the object and scenarios must be taken into consideration practically so that the most appropriate management strategy is purposefully designed. To employ an online control strategy, Wang et al. [129] further offered a hierarchical MPC scheme to enhance the energy economy and application of various scenarios. The results indicated that the proposed approach enhances performance, on average, by 7.3% and 5.9% in the simulation and experiment, respectively. For hydraulic electric hybrid vehicles, Yang Y et al. [130] reported a real-time global energy control method to optimize energy utilization. Through simulation, the results proved that the suggested strategy is feasible and has an energy saving of 32.14%.

As mentioned above, a control method generally does not meet the problem requirements of the target object. Therefore, the synthesis of methods becomes the best way to address energy management and optimization problems. Kamal E and Adouane L et al. conducted an in-depth study of smart energy control for hydraulic electric vehicles.

Firstly, the same authors in Ref. [89] provided a novel intelligent controller (IHHCS = ISSMC + IPDOC + LFPIDC) for the same hydraulic electric vehicle as previously mentioned to enhance the overall energy efficiency and minimize the total energy use, as shown in Figure 22a. The new results highlighted that the IHHCS control strategy makes the optimal energy consumption of 3732 kJ, while the SF is 3835 kJ and the OFLC strategy is 3800 kJ. In a word, compared to OFLC and SF, this paper presented a strategy that significantly optimizes fuel economy, enhances energy efficiency and is adaptable to a wider range of scenarios.

Secondly, a hybrid hydraulic–electric intelligent vehicle with a reliable and robust energy control strategy (IRHHCS = ISSMBMC + REMS + SRFTC) was designed to minimize fuel consumption and extend battery lifespan [40], as shown in Figure 22b. The simulation findings demonstrated that the IRHHCS algorithm optimized the lowest energy consumption of 43,223 kJ, while the HCSF was 51,809 kJ and the FBS strategy was 47,115 kJ.

Moreover, the proposed control strategy was proven to be feasible when current and/or voltage sensors are deficient. In the third Ref. [90], the hybrid electric urban bus was modified by introducing hydraulics to control the tri-hybrid powertrain smoothly and efficiently; the other components were the same as the previous structure, as shown in

Figure 23. There are four working modes: the electric mode, the hydraulic via ICE mode and degraded mode, the hydraulic via accumulator mode and the hybrid mode, which is somewhat complex to control. Therefore, the author designed an EMS that managed to overcome the uncertainties during the driving modes controlled.

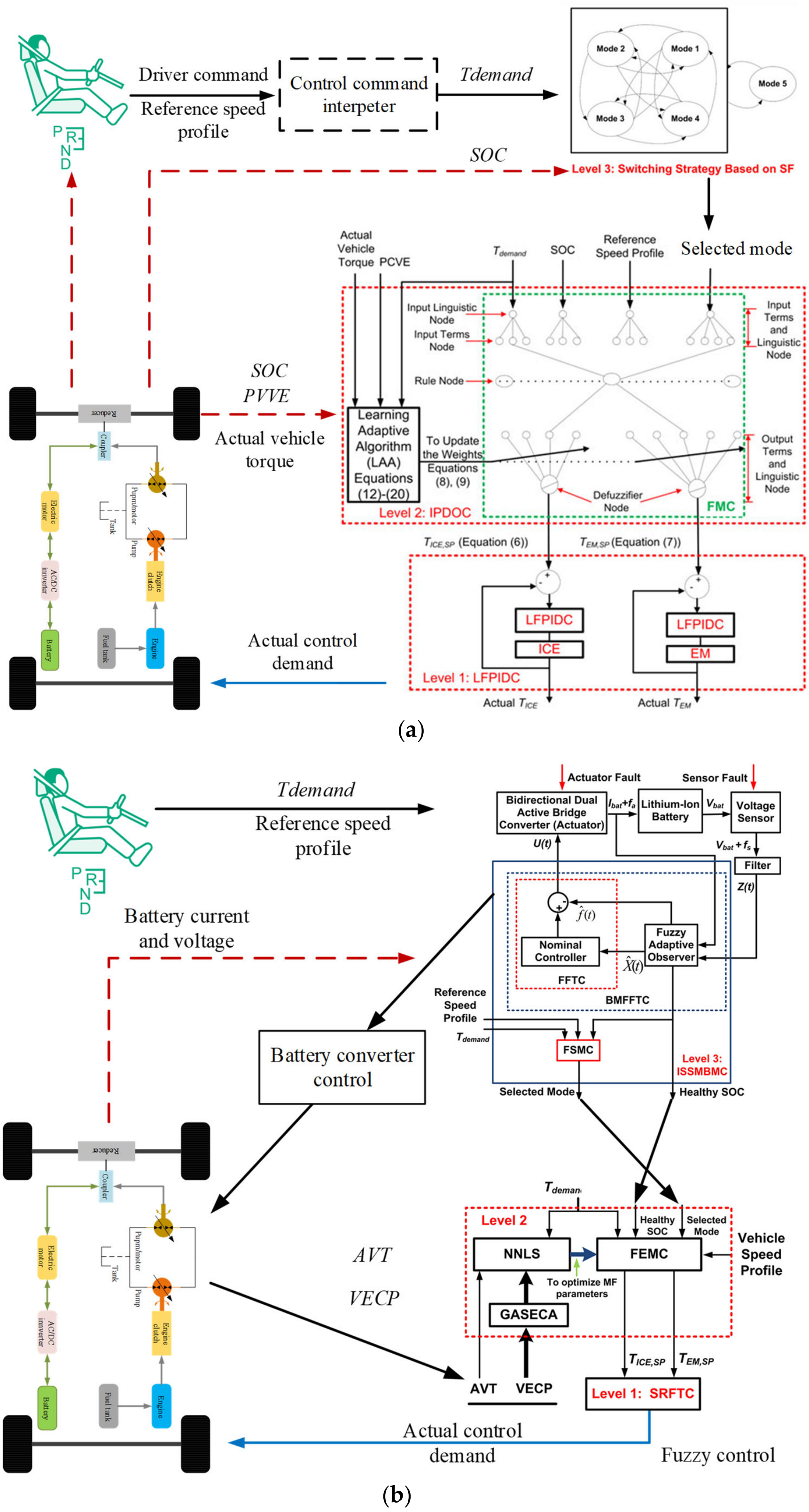


Figure 22. IHHCS and IRHHCS of hydraulic–electric buses [40,89]: (a) IHHCS; (b) IRHHCS.

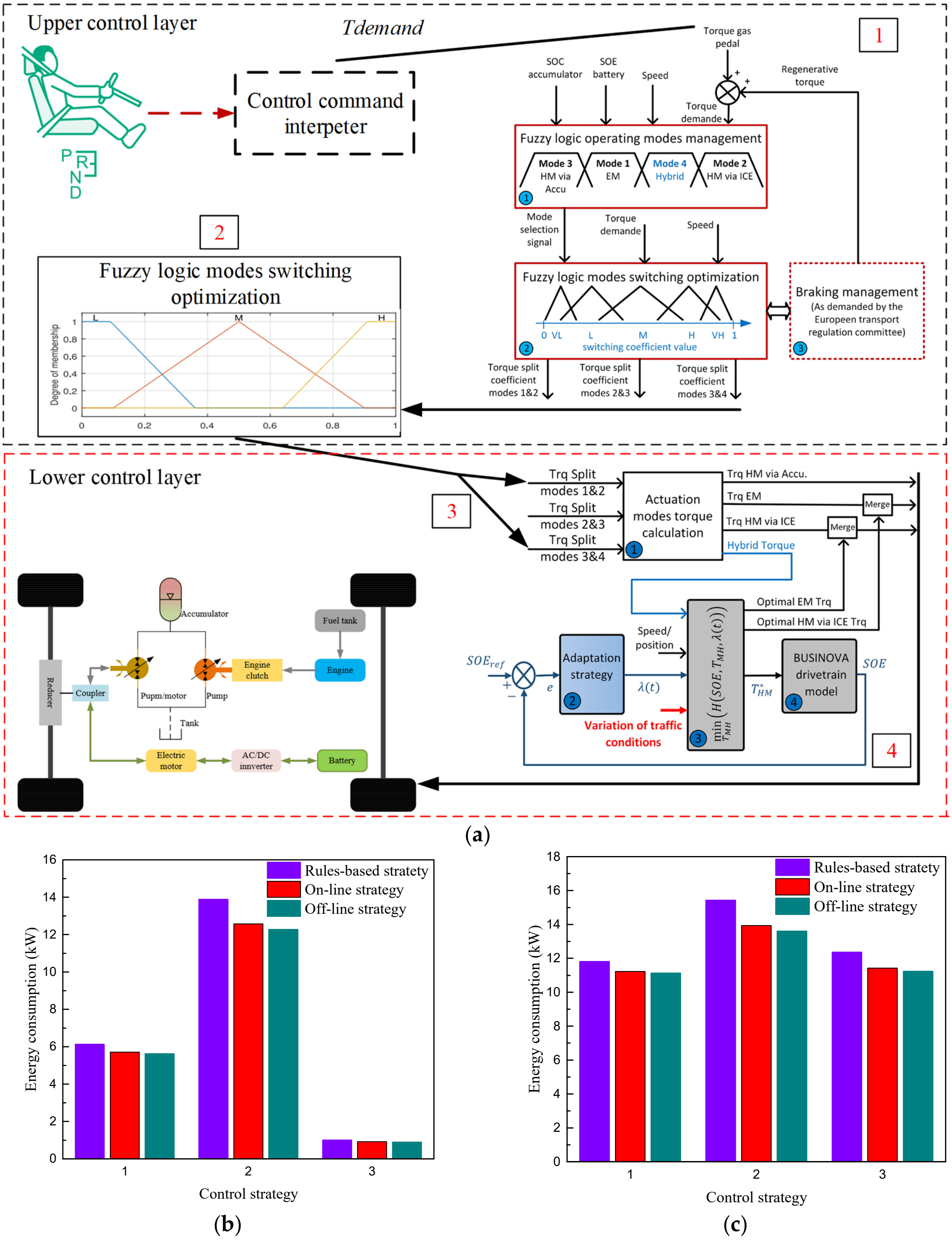


Figure 23. Proposed control strategy and results of the hybrid hydraulic–electric system [90]: (**a**) control strategy for BUSINOVA bus; (**b**) comparison of three strategies under UDC; (**c**) comparison of three strategies under FTP-75.

Finally, the author succeeded to report that both the abrupt transitions during mode switching and hybrid operation phases are better thanks to the optimization of the hybrid torque split by the optimal control algorithm.

Although during battery electric or hydraulic working, the fuel consumption is relatively similar, the entire growth of the energy economy is around 8.7% in UDC and 7.6% in FTP-75, respectively. Moreover, global minimum energy consumption corresponds to 2.1% in UDC and 1.6% in FTP-75, respectively. Therefore, as advanced control methods gradually begin to be applied to electric vehicles (especially hybrid electric vehicles, such as the learning-based method [131]), energy management and optimization methods for hydraulic vehicles will be enriched and refined.

Powertrain structures, major findings and control approaches used for mechanical–electric–hydraulic hybrid energy storage systems in typical vehicles are listed in Table 7. It can be concluded from Section and Table 7 that the level of energy optimization gradually increases as the control method progresses. However, at present, the more real-time and flexible the control method, the more difficult it is to use it in the application. Therefore, the following points can be inferred.

Table 7. Summary of control approaches used for mechanical–electric–hydraulic hybrid energy storage systems in typical vehicles.

No.	Powertrain Structure	Control Strategy	Major Findings	Ref.
1	Power-split hydraulic hybrid vehicle	Deterministic rule-based strategy	Improve the fuel economy by over 24%.	[118]
2	Series hydraulic hybrid vehicle	Rule-based tunable energy management	Has a fuel saving of up to 18.9% in the short loading cycle.	[120]
3	Parallel hydraulic hybrid vehicle	Control strategy based on fuzzy logic	Yield an energy saving of 15.5% and 22.5% for fixed and variable displacement of the hydraulic elements, respectively.	[121]
4	Parallel hydraulic electric hybrid vehicle	Global optimization based on the genetic algorithm	Improve the economic performance and energy consumption after genetic algorithm optimization by 36.51% and 43.65%, respectively.	[125]
5	Series hydraulic hybrid vehicle	Hierarchical model predictive control	Improve by 7.3% and 5.9% in simulation and experiment, respectively.	[129]
6	Series–parallel hydraulic electric vehicle	Real-time global optimization strategy	Have an energy saving of 32.14% more than original vehicle.	[130]
7	Parallel hydraulic electric hybrid vehicle	Novel intelligent controller	Make the optimal energy consumption of 3732 kJ, while the SF is 3835 kJ and the OFLC strategy is 3800 kJ.	[89]
8	Parallel hydraulic electric hybrid	Intelligent robust hierarchical hybrid controller strategy	Optimize the lowest energy consumption of 43,223 kJ, while the HCSF is 51809 kJ and the FBS strategy is 47,115 kJ.	[40]
9	Parallel hydraulic electric hybrid	Fuzzy logic and optimal control	Achieve energy saving of about 8.7% (UDC) and 7.6% (FTP-75).	[90]
10	Series–parallel hybrid electric vehicle	Taguchi method optimization	Reduce motor and hydraulic torque. Improve the battery SOC.	[132]
11	Series–parallel hybrid electric vehicle	Fuzzy logic method	Acquire a 9.57% reduction in the ratio of driveline cost to driving range.	[133]
12	Series–parallel hybrid vehicle	Optimum fuzzy logic controller	Reduce by 13.07% *HC* and by 10.55% *CO* with 35.67% fuel savings.	[134]
13	Series–parallel hybrid electric vehicle	Rule-based and thinking fuzzy logic optimization strategy	Decrease the energy consumption rate by 24.42%.	[135]
14	Series–parallel hybrid vehicle	Dynamic programming strategy with improved rules	Save fuel by 11.84% and 5.96% compared to that of traditional contemporary with single and compound accumulators, respectively.	[136]
15	Series–parallel hybrid electric vehicle	Rule-based dynamic strategy	Reduce the battery power consumption to 85.3%. Boost the energy recuperation rate of the hydraulic accumulator by around 94.3%.	[137]
16	Series–parallel hybrid electric vehicle	Entropy-based torque strategy	Integrate entropy and Z-score with torque control firstly.	[138]

Firstly, as a whole, the energy control strategies used in hydraulic vehicles show a significant increase in the level of energy optimization as they progress from lower to higher levels [116,118,123].

Secondly, the advantages of energy control strategies are based on the matching and optimization of drive system parameters, as concluded from the mentioned reference in this paper, and can also be deduced from Table 7.

Thirdly, more advanced control methods require more advanced hardware support, which therefore tends to increase costs. So, it is not the case that more advanced control methods mean that the control is more effective.

Last but not least, the suitability of an energy management method is judged by the application scenario of the control object. There is no best method, but only the most suitable energy management method, which is the best overall. It is believed that this problem will eventually be solved with the progress of control theory and technology.

5. Future Prospects and Challenges

The energy regeneration and conversion technologies based on mechanical–electric–hydraulic hybrid energy storage systems in vehicles are used in a wide scope of vehicles, from passenger to commercial vehicles, and applied in a variety of scenarios with or without a road. They also have a number of features that distinguish them from a typical vehicle, particularly in their hydraulic hybrid configuration, characteristics of each component, weight range, corresponding control strategy, etc. These differences and characteristics make energy regeneration and conversion technologies based on mechanical–electric–hydraulic hybrid energy storage systems in vehicles challenging.

(1) In view of the general principle and operation of hydraulic energy regeneration and conversion, the intrinsic drive of the dual carbon scheme and electric vehicle technology calls for hydraulic hybrid vehicles to move towards electrification and intelligence. Moreover, innovations in hydraulic-powered energy recovery systems and components will be an important direction for future efforts [96,112,113].

(2) For the different kinds of hydraulic vehicles, current hydraulic hybrid vehicle research is still primarily based on a gasoline or diesel engine as the central power source and the hydraulic accumulator only as the supplemental energy, which only reduces the emission of detrimental gases but does not satisfy the requirements of zero carbon vehicles. However, considering that there is no perfect powertrain, it is not wise to simply choose only one power source. Obviously, different hydraulic vehicles need to be selected due to dual carbon schemes and scenarios. A small-size or load vehicle can use an FC or battery electric system, while a large-size or load vehicle can equip the hydraulic vehicle with an engine, fuel cell or hybrid of them, which will provide a trade-off between the dynamics and economy of the vehicle.

Buses, delivery vehicles and refuse trucks are widely researched in the urban area, on which hydraulic vehicle research is mainly concentrated. However, this research rarely considers municipal construction vehicles, sanitation vehicles, urban logistics vehicles, urban mini-buses, etc. Therefore, a hydraulic hybrid vehicle of more types of urban commercial vehicles is worthy of our attention.

Accordingly, we believe that mechanical–electric–hydraulic hybrid energy storage systems based on a wide-range-capacity battery, a hydraulic and pneumatic accumulator, a fuel cell or a combination of them may be the best choice for the future primary propulsion mechanism for vehicles, with the choice of power form ultimately dependent on the combination between its characteristics and the application scenario [139,140].

(3) As to energy management techniques, the energy management method is a primary part of mechanical–electric–hydraulic hybrid energy storage system research. Recently, the energy-saving design for hydraulic hybrid vehicles has mainly concentrated on the rule-based control strategy in the application. Although it is relatively easier and more straightforward to control, more energy-saving developments call for more advanced and closer-to-reality control methods. Therefore, the application and research of the intelligent energy control strategy will be the focus of the next phase of hydraulic hybrid vehicle research.

6. Conclusions

The need for a reduction in fossil fuels and the carbon peaking plan is moving the vehicle energy system toward alternative energy sources. Among the many alternative energy options, mechanical–electric–hydraulic hybrid energy storage systems have become a hot topic of research because of their high power density, non-polluting nature, smaller engine and low emissions. With the development of hydraulic storage, power battery technology, control strategy technology and government policy support, we believe that hydraulic hybrid vehicles will have a brighter future.

This research investigates the current status of energy recovery and conversion technology for hydraulic-powered vehicles based on mechanical–electric–hydraulic hybrid energy storage systems. Moreover, it can be concluded that energy recovery and conversion technology for hydraulic energy storage has different applications in different models. In passenger vehicles, the hybrid power of electric and hydraulic modes will become a hot topic; buses will also move towards electric and hydraulic modes. The direction of the trucks and special vehicles will be dominated by fuel and hydraulic hybrid technology in the short run, but the engine will become smaller and smaller and even disappear, as is determined by the application scenario and the characteristics of the energy storage system, such as a hydraulic accumulator, a multi-energy system based on the hydraulic accumulator, a fuel cell, etc. In addition, this paper provides a more detailed review of relevant energy management methods. It is worth noting that the issue of energy management is a crucial aspect of the development of hydraulically powered vehicles. Therefore, the integrated intelligent energy control strategy with the hydraulic vehicle is an important research direction now and in the long run.

Finally, the research in this paper will have a significant impact on helping to look forward to the prospects and challenges of energy recovery and conversion technology based on mechanical–electric–hydraulic hybrid energy storage systems for vehicles and explore the coping strategies of hydraulic energy recovery and conversion technology in vehicles in the future.

Author Contributions: Conceptualization, B.F.; methodology, B.F.; formal analysis, A.W.; investigation, B.F.; resources, H.X.; data curation, H.X.; writing—original draft preparation, B.F.; writing—review and editing, B.F. and H.X.; visualization, L.G.; supervision, X.Z.; project administration, A.W.; funding acquisition, Y.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Xingtai City Key Research and Development Plan of China, grant number 2020ZC017.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The authors declare no data available of interest.

Acknowledgments: The authors would like to thank Yunze Li for his careful guidance and selfless help.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liu, L.; Wang, Y.; Wang, Z.; Li, S.; Li, J.; He, G.; Li, Y.; Liu, Y.; Piao, S.; Gao, Z.; et al. Potential contributions of wind and solar power to China's carbon neutrality. *Resour. Conserv. Recycl.* **2022**, *180*, 106155. [CrossRef]
2. Luo, Y.; Chen, X.; Fang, F.; Zhang, X.; Guo, N. A trust-enhanced and preference-aware collaborative method for recommending new energy vehicle. *Environ. Sci. Pollut. Res. Int.* **2021**, *28*, 7901–7917. [CrossRef] [PubMed]
3. Kılkış, Ş.; Krajačić, G.; Duić, N.; Rosen, M.A.A. Advances in integration of energy, water and environment systems towards climate neutrality for sustainable development. *Energy Convers. Manag.* **2020**, *225*, 113410. [CrossRef]
4. Zhao, X.; Shang, Y.; Song, M. Industrial structure distortion and urban ecological efficiency from the perspective of green entrepreneurial ecosystems. *Socio-Econ. Plan. Sci.* **2020**, *72*, 100757. [CrossRef]
5. Earth System Science Data. Available online: https://essd.copernicus.org/articles/11/1783/2019/essd-11-1783-2019.pdf (accessed on 1 September 2022).

6. Jackson, R.B.; Friedlingstein, P.; Andrew, R.M.; Canadell, J.G.; Le Quéré, C.; Peters, G.P. Persistent fossil fuel growth threatens the Paris Agreement and planetary health. *Environ. Res. Lett.* **2019**, *14*, 121001. [CrossRef]
7. Peters, G.P.; Andrew, R.M.; Canadell, J.G.; Friedlingstein, P.; Jackson, R.B.; Korsbakken, J.I.; Le Quéré, C.; Peregon, A. Carbon dioxide emissions continue to grow amidst slowly emerging climate policies. *Nat. Clim. Change* **2019**, *10*, 3–6. [CrossRef]
8. IEA. Available online: https://www.iea.org/articles/global-co2-emissions-in-2019 (accessed on 1 September 2022).
9. IEA. Available online: https://iea.blob.core.windows.net/assets/17fc0c1d-7fff-4ca6-af39-7f6e6f1c33fc/EnhancingChinasETSforCarbonNeutrality_FocusonPowerSector.pdf (accessed on 1 September 2022).
10. Le Quéré, C.; Jackson, R.B.; Jones, M.W.; Smith, A.J.P.; Abernethy, S.; Andrew, R.M.; De-Gol, A.J.; Willis, D.R.; Shan, Y.; Canadell, J.G.; et al. Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nat. Clim. Change* **2020**, *10*, 647–653. [CrossRef]
11. Mallapaty, S. How China could be carbon neutral by mid-century. *Nature* **2020**, *586*, 482–483. [CrossRef]
12. He, J.; Li, Z.; Zhang, X.; Wang, H.; Dong, W.; Chang, S.; Ou, X.; Guo, S.; Tian, Z.; Gu, A.; et al. Comprehensive report on China's Long-Term Low-Carbon Development Strategies and Pathways. *Chin. J. Popul. Resour. Environ.* **2020**, *18*, 263–295. [CrossRef]
13. He, J.; Li, Z.; Zhang, X.; Wang, H.; Dong, W.; Du, E.; Chang, S.; Ou, X.; Guo, S.; Tian, Z.; et al. Towards carbon neutrality: A study on China's long-term low-carbon transition pathways and strategies. *Environ. Sci. Ecotechnol.* **2022**, *9*, 100134. [CrossRef]
14. Solaymani, S. CO_2 emissions patterns in 7 top carbon emitter economies: The case of transport sector. *Energy* **2019**, *168*, 989–1001. [CrossRef]
15. Xie, R.; Fang, J.; Liu, C. The effects of transportation infrastructure on urban carbon emissions. *Appl. Energy* **2017**, *196*, 199–207. [CrossRef]
16. Shahzad, U.; Doğan, B.; Sinha, A.; Fareed, Z. Does Export product diversification help to reduce energy demand: Exploring the contextual evidences from the newly industrialized countries. *Energy* **2021**, *214*, 118881. [CrossRef]
17. Xiong, L.; Xia, X.; Lu, Y.; Liu, W.; Gao, L.; Song, S.; Yu, Z. IMU-Based Automated Vehicle Body Sideslip Angle and Attitude Estimation Aided by GNSS Using Parallel Adaptive Kalman Filters. *IEEE Trans. Veh. Technol.* **2020**, *69*, 10668–10680. [CrossRef]
18. Liu, W.; Xia, X.; Xiong, L.; Lu, Y.; Gao, L.; Yu, Z. Automated vehicle sideslip angle estimation considering signal measurement characteristic. *IEEE Sens. J.* **2021**, *21*, 21675–21687. [CrossRef]
19. Liu, W.; Xiong, L.; Xia, X.; Lu, Y.; Gao, L.; Song, S. Vision-aided intelligent vehicle sideslip angle estimation based on a dynamic model. *IET Intell. Transp. Syst.* **2020**, *14*, 1183–1189. [CrossRef]
20. Liu, W.; Hua, M.; Deng, Z.; Huang, Y.; Hu, C.; Song, S.; Gao, L.; Liu, C.; Xiong, L.; Xia, X. A Systematic Survey of Control Techniques and Applications: From Autonomous Vehicles to Connected and Automated Vehicles. *arXiv* **2023**, arXiv:2303.05665.
21. Xiong, R.; Sun, W.; Yu, Q.; Sun, F. Research progress, challenges and prospects of fault diagnosis on battery system of electric vehicles. *Appl. Energy* **2020**, *279*, 115855. [CrossRef]
22. Hong, J.; Wang, Z.; Yao, Y. Fault prognosis of battery system based on accurate voltage abnormity prognosis using long short-term memory neural networks. *Appl. Energy* **2019**, *251*, 113381. [CrossRef]
23. Wang, X.; Chen, J.; Quan, S.; Wang, Y.-X.; He, H. Hierarchical model predictive control via deep learning vehicle speed predictions for oxygen stoichiometry regulation of fuel cells. *Appl. Energy* **2020**, *276*, 115460. [CrossRef]
24. Guo, H.; Wang, X.; Li, L. State-of-charge-constraint-based energy management strategy of plug-in hybrid electric vehicle with bus route. *Energy Convers. Manag.* **2019**, *199*, 111972. [CrossRef]
25. Bi, J.; Wang, Y.; Zhang, J. A data-based model for driving distance estimation of battery electric logistics vehicles. *EURASIP J. Wirel. Commun. Netw.* **2018**, *2018*, 251. [CrossRef]
26. Andwari, A.M.; Pesiridis, A.; Rajoo, S.; Martinez-Botas, R.; Esfahanian, V. A review of Battery Electric Vehicle technology and readiness levels. *Renew. Sustain. Energy Rev.* **2017**, *78*, 414–430. [CrossRef]
27. Kim, S.; Lee, J.; Lee, C. Does driving range of electric vehicles influence electric vehicle adoption? *Sustainability* **2017**, *9*, 1783. [CrossRef]
28. Li, Q.; Yang, H.; Han, Y.; Li, M.; Chen, W. A state machine strategy based on droop control for an energy management system of PEMFC-battery-supercapacitor hybrid tramway. *Int. J. Hydrogen Energy* **2016**, *41*, 16148–16159. [CrossRef]
29. Hou, S.; Gao, J.; Zhang, Y.; Chen, M.; Shi, J.; Chen, H. A comparison study of battery size optimization and an energy management strategy for FCHEVs based on dynamic programming and convex programming. *Int. J. Hydrogen Energy* **2020**, *45*, 21858–21872. [CrossRef]
30. Kim, N.; Rousseau, A. *A Comparative Study of Hydraulic Hybrid Systems for Class 6 Trucks*; No. 2013-01-1472; SAE Technical Paper; SAE International: Warrendale, PA, USA, 2013.
31. Huang, C.J.; Du, M.S.; Tsai, G.L. Comparison of fuel economy between hydraulic hybrids and hybrid electric vehicles. *Manuf. Sci. Technol.* **2015**, *3*, 57–65. [CrossRef]
32. Kim, H.; Yoo, S.; Cho, S.; Yi, K. Hybrid control algorithm for fuel consumption of a compound hybrid excavator. *Automation in Construction* **2016**, *68*, 1–10. [CrossRef]
33. Krithika, V.; Subramani, C. A comprehensive review on choice of hybrid vehicles and power converters, control strategies for hybrid electric vehicles. *Int. J. Energy Res.* **2018**, *42*, 1789–1812. [CrossRef]
34. He, X.; Xiao, G.; Hu, B.; Tan, L.; Tang, H.; He, S.; He, Z. The applications of energy regeneration and conversion technologies based on hydraulic transmission systems: A review. *Energy Convers. Manag.* **2020**, *205*, 112413. [CrossRef]

35. EPA. Available online: https://archive.epa.gov/otaq/technology/web/html/partners-milestones.html (accessed on 1 September 2022).
36. Sabri, M.F.M.; Danapalasingam, K.A.; Rahmat, M.F. A review on hybrid electric vehicles architecture and energy management strategies. *Renew. Sustain. Energy Rev.* **2016**, *53*, 1433–1442. [CrossRef]
37. Tran, D.-D.; Vafaeipour, M.; El Baghdadi, M.; Barrero, R.; Van Mierlo, J.; Hegazy, O. Thorough state-of-the-art analysis of electric and hybrid vehicle powertrains: Topologies and integrated energy management strategies. *Renew. Sustain. Energy Rev.* **2020**, *119*, 109596. [CrossRef]
38. Ramakrishnan, R.; Hiremath, S.S.; Singaperumal, M. Theoretical investigations on the effect of system parameters in series hydraulic hybrid system with hydrostatic regenerative braking. *J. Mech. Sci. Technol.* **2012**, *26*, 1321–1331. [CrossRef]
39. Mensing, F.; Li, P.Y. Sizing and Optimal Operation of a Power Split Hydraulic Hybrid Drive Train. In Proceedings of the International Fluid Power Exhibition, Las Vegas, NV, USA, 23–25 March 2011; Volume 2226.
40. Kamal, E.; Adouane, L. Hierarchical energy optimization strategy and its integrated reliable battery fault management for hybrid hydraulic-electric vehicle. *IEEE Trans. Veh. Technol.* **2018**, *67*, 3740–3754. [CrossRef]
41. Zhou, H.; Xu, Z.; Liu, L.; Liu, D.; Zhang, L. A rule-based energy management strategy based on dynamic programming for hydraulic hybrid vehicles. *Math. Probl. Eng.* **2018**, *2018*, 9492026.
42. Zhang, Z.; Chen, J.; Wu, B. The control strategy of optimal brake energy recovery for a parallel hydraulic hybrid vehicle. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2012**, *226*, 1445–1453. [CrossRef]
43. Li, H.; Zhu, D.; Shang, L.; Fan, P. Collaborative optimization and energy management of hydraulic hybrid mining trucks. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2022**, *236*, 2773–2791.
44. Filipi, Z.; Kim, Y.J. Hydraulic hybrid propulsion for heavy vehicles: Combining the simulation and engine-in-the-loop techniques to maximize the fuel economy and emission benefits. *Oil Gas. Sci. Tech. Nology-Rev. Del'institut Français Du Pétrole* **2010**, *65*, 155–178. [CrossRef]
45. Johri, R.; Filipi, Z. Optimal energy management of a series hybrid vehicle with combined fuel economy and low-emission objectives. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2014**, *228*, 1424–1439. [CrossRef]
46. Midgley, W.J.B.; Cathcart, H.; Cebon, D. Modelling of hydraulic regenerative braking systems for heavy vehicles. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2013**, *227*, 1072–1084. [CrossRef]
47. Paswan, R.; Das, J.; Kumar, N.; Kumar, A.; Mishra, S.K.; Sujit, K. Simulation study on different energy efficient hydraulic system: An overview. *Appl. Mech. Mater.* **2014**, *592*, 2234–2238. [CrossRef]
48. Hui, S.; Lifu, Y.; Junqing, J. Hydraulic/electric synergy system (HESS) design for heavy hybrid vehicles. *Energy* **2010**, *35*, 5328–5335. [CrossRef]
49. Wasbari, F.; Bakar, R.A.; Gan, L.M.; Tahir, M.M.; Yusof, A.A. A review of compressed-air hybrid technology in vehicle system. *Renew. Sustain. Energy Rev.* **2017**, *67*, 935–953. [CrossRef]
50. Niu, G.; Arribas, A.P.; Salameh, M.; Krishnamurthy, M.; Garcia, J.M. Hybrid energy storage systems in electric vehicle. In Proceedings of the 2015 IEEE Transportation Electrification Conference and Expo (ITEC), Dearborn, MI, USA, 14–17 June 2015.
51. Macor, A.; Benato, A.; Rossetti, A.; Bettio, Z. Study and simulation of a hydraulic hybrid powertrain. *Energy Procedia* **2017**, *126*, 1131–1138. [CrossRef]
52. Zhang, H.; Wang, F.; Stelson, K.A. Modeling and design of a hydraulic hybrid powertrain for passenger vehicle. In *Fluid Power Systems Technology*; American Society of Mechanical Engineers: New York, NY, USA, 2017; Volume 58332, p. V001T01A075.
53. Liu, H.; Jiang, Y.; Li, S. Design and downhill speed control of an electric-hydrostatic hydraulic hybrid powertrain in battery-powered rail vehicles. *Energy* **2019**, *187*, 115957. [CrossRef]
54. Sill, J.; Molla, S.; Ayalew, B. Modelling and control of handling dynamics for a hydrostatically driven vehicle. *Int. J. Heavy Veh. Syst.* **2011**, *18*, 322–340. [CrossRef]
55. Chen, Y.L.; Liu, S.A.; Jiang, J.H.; Shang, T.; Zhang, Y.K.; Wei, W. Dynamic analysis of energy storage unit of the hydraulic hybrid vehicle. *Int. J. Automot. Technol.* **2013**, *14*, 101–112. [CrossRef]
56. He, X.; Liu, H.; He, S.; Hu, B.; Xiao, G. Research on the energy efficiency of energy regeneration systems for a battery-powered hydrostatic vehicle. *Energy* **2019**, *178*, 400–418. [CrossRef]
57. Nguyen, T.; Elahinia, M.; Wang, S. Hydraulic hybrid vehicle vibration isolation control with magnetorheological fluid mounts. *Int. J. Veh. Des.* **2013**, *63*, 199–222. [CrossRef]
58. Kitanovic, M.; Popovic, S.; Miljic, N.; Mrdja, P. Numerical analyses of a hydraulic hybrid powertrain system for a transit bus. *Therm. Sci.* **2020**, *24*, 159–170. [CrossRef]
59. Panchal, S.; Dincer, I.; Agelin-Chaab, M. Thermodynamic analysis of hydraulic braking energy recovery systems for a vehicle. *J. Energy Resour. Technol.* **2016**, *138*, 011601. [CrossRef]
60. Nikolaus, H. Antriebssystem mit hydrostatischer Kraftubertragung Patent-anmeldung. *Hydraul. Und Pneum.* **1977**, *968*, 27–39.
61. Shen, W.; Huang, H.; Pang, Y.; Su, X. Review of the energy saving hydraulic system based on common pressure rail. *IEEE Access* **2017**, *5*, 655–669. [CrossRef]
62. Shen, W.; Jiang, J. Analysis and development of the hydraulic secondary regulation system based on the CPR. In Proceedings of the Proceedings of 2011 International Conference on Fluid Power and Mechatronics, Beijing, China, 17–20 August 2011; pp. 117–122.

63. Wu, W.; Di, C.; Hu, J. Dynamics of a hydraulic-transformer-controlled hydraulic motor system for automobiles. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2016**, *230*, 229–239. [CrossRef]
64. Zang, F.Y.; Wang, Y. Performance Research on the Secondary Hydraulic Transmission System Under Variable Pressure Rail. *Appl. Mech. Mater.* **2014**, *602*, 1064–1068. [CrossRef]
65. Zang, F.; Kong, X. Energy-saving research of the bus secondary hydraulic transmission system under variable pressure rail. In *2016 International Conference on Advanced Electronic Science and Technology (AEST 2016)*; Atlantis Press: Amsterdam, The Netherlands, 2016; pp. 432–437.
66. Kwon, H.; Sprengel, M.; Ivantysynova, M. Thermal modeling of a hydraulic hybrid vehicle transmission based on thermodynamic analysis. *Energy* **2016**, *116*, 650–660. [CrossRef]
67. Liu, T.; Jiang, J.; Sun, H. Investigation to Simulation of Regenerative Braking for Parallel Hydraulic Hybrid Vehicles. In Proceedings of the 2009 International Conference on Measuring Technology and Mechatronics Automation, Zhangjiajie, China, 11–12 April 2009; pp. 242–245.
68. Ji, C.; Zhu, Y.; Liang, C.; Liu, X. Simulation study on the operating characteristics of a hybrid hydraulic passenger car with a power split transmission. *Veh. Syst. Dyn.* **2013**, *51*, 1518–1532. [CrossRef]
69. Chen, J.S. Energy efficiency comparison between hydraulic hybrid and hybrid electric vehicles. *Energies* **2015**, *8*, 4697–4723. [CrossRef]
70. Baseley, S.; Ehret, C.; Greif, E.; Kliffken, M.G. *Hydraulic Hybrid Systems for Commercial Vehicles*; No. 2007-01-4150; SAE Technical Paper; SAE International: Warrendale, PA, USA, 2007.
71. Ramakrishnan, R.; Hiremath, S.S.; Singaperumal, M. Modeling, simulation and design optimization of a series hydraulic hybrid vehicle. *Appl. Mech. Mater.* **2014**, *541*, 727–731.
72. Mykola, K.; Olegas, P.; Šarūnas, Š. Research on high-pressure hose with repairing fitting and influence on energy parameter of the hydraulic drive. *Eksploat. I Niezawodn.-Maint. Reliab.* **2022**, *24*, 25–32.
73. Ramakrishnan, R.; Hiremath, S.S.; Singaperumal, M. Design strategy for improving the energy efficiency in series hydraulic/electric synergy system. *Energy* **2014**, *67*, 422–434. [CrossRef]
74. Meng, Z.; Zhang, H.; Yang, J.; Zhao, Q. Research on matching of power transmission system of electro-hydraulic hybrid electric vehicle. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *632*, 032007. [CrossRef]
75. Wu, W.; Hu, J.; Jing, C.; Jiang, Z.; Yuan, S. Investigation of energy efficient hydraulic hybrid propulsion system for automobiles. *Energy* **2014**, *73*, 497–505. [CrossRef]
76. Van de Ven, J.D. Constant pressure hydraulic energy storage through a variable area piston hydraulic accumulator. *Appl. Energy* **2013**, *105*, 262–270. [CrossRef]
77. Deppen, T.O.; Alleyne, A.G.; Stelson, K.A.; Meyer, J.J. Optimal Energy Use in a Light Weight Hydraulic Hybrid Passenger Vehicle. *J. Dyn. Sys. Meas. Control* **2012**, *134*, 041009. [CrossRef]
78. Du, Z.; Cheong, K.L.; Li, P.Y. Energy management strategy for a power-split hydraulic hybrid vehicle based on Lagrange multiplier and its modifications. *Proc. Inst. Mech. Eng. Part I J. Syst. Control Eng.* **2018**, *233*, 511–523. [CrossRef]
79. Hua, M.; Chen, G.; Zhang, B.; Huang, Y. A hierarchical energy efficiency optimization control strategy for distributed drive electric vehicles. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2018**, *233*, 605–621. [CrossRef]
80. Chen, G.; Hua, M.; Zong, C.; Zhang, B.; Huang, Y. Comprehensive chassis control strategy of FWICpre based on sliding mode control. *IET Intell. Transp. Syst.* **2019**, *13*, 703–713. [CrossRef]
81. Barbosa, T.P.; da Silva, L.A.R.; Pujatti, F.J.P.; Gutiérrez, J.C.H. Hydraulic hybrid passenger vehicle: Fuel savings possibilities. *Mech. Based Des. Struct. Mach.* **2020**, *50*, 135–153. [CrossRef]
82. Barbosa, T.P.; Eckert, J.J.; Roso, V.R.; Pujatti, F.J.P.; da Silva, L.A.R.; Horta Gutiérrez, J.C. Fuel saving and lower pollutants emissions using an ethanol-fueled engine in a hydraulic hybrid passengers vehicle. *Energy* **2021**, *235*, 121361. [CrossRef]
83. Honey, E.; Suh, I.-S. A feasibility study of an electric–hydraulic hybrid powertrain for passenger vehicles. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2015**, *229*, 1894–1906. [CrossRef]
84. Pawelski, Z.; Wittich, S. Optimisation of operating parameters during the accumulator charging process. *Int. J. Veh. Des.* **2005**, *38*, 150–161. [CrossRef]
85. Liu, G.Q.; Yan, Y.C.; Chen, J.; Xu, F.F. Parameter matching and optimization for a hydraulic power-assistant system. *Int. J. Automot. Technol.* **2010**, *11*, 573–580. [CrossRef]
86. Niu, G.; Shang, F.; Krishnamurthy, M.; Garcia, J.M. Design and Analysis of an Electric Hydraulic Hybrid Powertrain in Electric Vehicles. *IEEE Trans. Transp. Electrif.* **2017**, *3*, 48–57. [CrossRef]
87. Chen, G.; Liu, H. Design and energy utilization of electro-hydrostatic hydraulic hybrid system for battery bus. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2020**, *235*, 759–772. [CrossRef]
88. Ma, B.; Lin, M.; Chen, Y.; Wang, L.-X. Investigation of energy efficiency for electro-hydraulic composite braking system which is based on the regenerated energy. *Adv. Mech. Eng.* **2016**, *8*, 1687814016666449. [CrossRef]
89. Kamal, E.; Adouane, L. Intelligent Energy Management Strategy Based on Artificial Neural Fuzzy for Hybrid Vehicle. *IEEE Trans. Intell. Veh.* **2018**, *3*, 112–125. [CrossRef]
90. Ouddah, N.; Adouane, L. Hybrid Energy Management Strategy Based on Fuzzy Logic and Optimal Control for Tri-Actuated Powertrain System. *IEEE Trans. Veh. Technol.* **2019**, *68*, 5343–5355. [CrossRef]

91. Filipi, Z.; Louca, L.; Daran, B.; Lin, C.C.; Yildir, U.; Wu, B.; Chapp, R. Combined optimisation of design and power management of the hydraulic hybrid propulsion system for the 6 × 6 medium truck. *Int. J. Heavy Veh. Syst.* **2004**, *11*, 372–402. [CrossRef]
92. Johri, R.; Filipi, Z. Low-cost pathway to ultra efficient city car: Series hydraulic hybrid system with optimized supervisory control. *SAE Int. J. Engines* **2010**, *2*, 505–520. [CrossRef]
93. Hui, S.; Ji-Hai, J.; Xin, W. Torque control strategy for a parallel hydraulic hybrid vehicle. *J. Terramech.* **2009**, *46*, 259–265. [CrossRef]
94. Bender, F.A.; Kaszynski, M.; Sawodny, O. Drive cycle prediction and energy management optimization for hybrid hydraulic vehicles. *IEEE Trans. Veh. Technol.* **2013**, *62*, 3581–3592. [CrossRef]
95. Bravo, R.R.S.; De Negri, V.J.; Oliveira, A.A.M. Design and analysis of a parallel hydraulic–pneumatic regenerative braking system for heavy-duty hybrid vehicles. *Appl. Energy* **2018**, *225*, 60–77. [CrossRef]
96. Bravo, R.R.d.S.; Gama, A.T.d.C.; Oliveira, A.A.M.; De Negri, V.J. Component sizing and sensitivity analysis of design parameters of a hydraulic-pneumatic regenerative braking system for heavy duty vehicles. *Energy* **2023**, *264*, 126021. [CrossRef]
97. Yang, J.; Zhang, T.; Zhang, H.; Hong, J.; Meng, Z. Research on the Starting Acceleration Characteristics of a New Mechanical–Electric–Hydraulic Power Coupling Electric Vehicle. *Energies* **2020**, *13*, 6279. [CrossRef]
98. Yang, J.; Zhang, T.; Hong, J.; Zhang, H.; Zhao, Q.; Meng, Z. Research on driving control strategy and Fuzzy logic optimization of a novel mechatronics-electro-hydraulic power coupling electric vehicle. *Energy* **2021**, *233*, 121221. [CrossRef]
99. Zhou, H.; Xu, Z.; Liu, L.; Liu, D.; Zhang, L. Design and validation of a novel hydraulic hybrid vehicle with wheel motors. *Sci. Prog.* **2020**, *103*, 36850419878024. [CrossRef]
100. Midgley, W.J.B.; Abrahams, D.; Garner, C.P.; Caldwell, N. Modelling and experimental validation of the performance of a digital displacement®® hydraulic hybrid truck. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2021**, *236*, 594–605. [CrossRef]
101. Caldwell, N. Review of early work on Digital Displacement®® hydrostatic transmission systems. In *Fluid Power Systems Technology*; American Society of Mechanical Engineers: New York, NY, USA, 2018; Volume 51968, p. V001T01A061.
102. Niu, G.; Shang, F.; Krishnamurthy, M.; Garcia, J.M. Evaluation and selection of accumulator size in electric-hydraulic hybrid (EH2) powertrain. In Proceedings of the 2016 IEEE Transportation Electrification Conference and Expo (ITEC), Dearborn, MI, USA, 27–29 June 2016; pp. 1–6.
103. Bender, F.A.; Bosse, T.; Sawodny, O. An investigation on the fuel savings potential of hybrid hydraulic refuse collection vehicles. *Waste Manag.* **2014**, *34*, 1577–1583. [CrossRef]
104. Zhou, S.; Walker, P.; Zhang, N. Parametric design and regenerative braking control of a parallel hydraulic hybrid vehicle. *Mech. Mach. Theory* **2020**, *146*, 103714. [CrossRef]
105. Zhou, S.; Walker, P.D.; Xiao, B.; Zhang, N. Modelling and Vibration Analysis of a Parallel Hydraulic Hybrid Vehicle. *IEEE Trans. Veh. Technol.* **2020**, *69*, 10710–10723. [CrossRef]
106. Zhou, S.; Walker, P.; Tian, Y.; Zhang, N. Mode switching analysis and control for a parallel hydraulic hybrid vehicle. *Veh. Syst. Dyn.* **2020**, *59*, 928–948. [CrossRef]
107. Zhou, S.; Walker, P.; Wu, J.; Zhang, N. Power on gear shift control strategy design for a parallel hydraulic hybrid vehicle. *Mech. Syst. Signal Process.* **2021**, *159*, 107798. [CrossRef]
108. Zhou, S.; Walker, P.; Tian, Y.; Nguyen, C.T.; Zhang, N. Comparison on Energy Economy and Vibration Characteristics of Electric and Hydraulic in-Wheel Drive Vehicles. *Energies* **2021**, *14*, 2290. [CrossRef]
109. Soriano, F.; Moreno-Eguilaz, M.; Alvarez, J.; Riera, J. Topological analysis of powertrains for refuse-collecting vehicles based on real routes–Part I: Hybrid hydraulic powertrain. *Int. J. Automot. Technol.* **2016**, *17*, 873–882. [CrossRef]
110. Soriano, F.; Moreno-Eguilaz, M.; Alvarez, J.; Riera, J. Topological analysis of powertrains for refuse-collecting vehicles based on real routes–Part II: Hybrid electric powertrain. *Int. J. Automot. Technol.* **2016**, *17*, 883–894. [CrossRef]
111. Jin, C.; Yi, T.; Shen, Y.; Khajepour, A.; Meng, Q. Comparative study on the economy of hybrid mining trucks for open-pit mining. *IET Intell. Transp. Syst.* **2018**, *13*, 201–208. [CrossRef]
112. Yi, T.; Ma, F.; Jin, C.; Huang, Y. A novel coupled hydro-pneumatic energy storage system for hybrid mining trucks. *Energy* **2018**, *143*, 704–718. [CrossRef]
113. Liu, H.; Chen, G.; Xie, C.; Li, D.; Wang, J.; Li, S. Research on energy-saving characteristics of battery-powered electric-hydrostatic hydraulic hybrid rail vehicles. *Energy* **2020**, *205*, 118079. [CrossRef]
114. Chen, Y.; Zhang, T.; Zhang, H.; Zhang, Z.; Jia, Q.; Chen, H.; Xu, H.; Zhang, Y. Study on the Effect of Hydraulic Energy Storage on the Performance of Electro-Mechanical-Hydraulic Power-Coupled Electric Vehicles. *Electronics* **2022**, *11*, 3344. [CrossRef]
115. Nie, C.; Shao, Y.; Mechefske, C.K.; Peng, D.; Yang, X. Pipe architecture optimization of the parallel Hydraulic-pneumatic hybrid system using a hydraulic transformer. *Energy Convers. Manag.* **2022**, *266*, 115858. [CrossRef]
116. Hui, S.; Lifu, Y.; Junqing, J.; Yanling, L. Control strategy of hydraulic/electric synergy system in heavy hybrid vehicles. *Energy Convers. Manag.* **2011**, *52*, 668–674. [CrossRef]
117. Liu, T.; Zheng, J.; Su, Y.; Zhao, J. A Study on Control Strategy of Regenerative Braking in the Hydraulic Hybrid Vehicle Based on ECE Regulations. *Math. Probl. Eng.* **2013**, *2013*, 208753. [CrossRef]
118. Zhang, T.; Wang, Q.; He, X.H.; Li, S.S.; Shen, X.M. Power-Following Control Strategy of a Wheel-Drive Hydraulic Hybrid Vehicle. *Stroj. Vestn./J. Mech. Eng.* **2020**, *66*, 193–202. [CrossRef]
119. Kwon, H.; Ivantysynova, M. System Characteristics Analysis for Energy Management of Power-Split Hydraulic Hybrids. *Energies* **2020**, *13*, 1837. [CrossRef]

120. Wen, Q.; Wang, F.; Xu, B.; Sun, Z. Improving the Fuel Efficiency of Compact Wheel Loader with a Series Hydraulic Hybrid Powertrain. *IEEE Trans. Veh. Technol.* **2020**, *69*, 10700–10709. [CrossRef]
121. Sarmiento, M.A.D.; Valdés, L.A.D.P.; Ordoñez, Y.J.R.; Pinilla, C.B.; Diaz, D.C.D. Modeling and simulation of a braking energy regeneration system in hydraulic hybrid vehicles in the Colombian topography. *Period. Eng. Nat. Sci.* **2021**, *9*, 755–766. [CrossRef]
122. Zhao, Q.; Zhang, H.; Xin, Y.; Saleem, S. Research on Control Strategy of Hydraulic Regenerative Braking of Electrohydraulic Hybrid Electric Vehicles. *Math. Probl. Eng.* **2021**, *2021*, 5391351. [CrossRef]
123. Shen, W.; Jiang, J.; Su, X.; Reza Karimi, H. Control strategy analysis of the hydraulic hybrid excavator. *J. Frankl. Inst.* **2015**, *352*, 541–561. [CrossRef]
124. Williams, K.; Ivantysynova, M. Approximate Stochastic Differential Dynamic Programming for Hybrid Vehicle Energy Management. *J. Dyn. Syst. Meas. Control* **2019**, *141*, 051003. [CrossRef]
125. Hwang, H.-Y.; Lan, T.-S.; Chen, J.-S. Optimization and Application for Hydraulic Electric Hybrid Vehicle. *Energies* **2020**, *13*, 322. [CrossRef]
126. Wang, Z.; Jiao, X. Optimization of the powertrain and energy management control parameters of a hybrid hydraulic vehicle based on improved multi-objective particle swarm optimization. *Eng. Optim.* **2020**, *53*, 1835–1854. [CrossRef]
127. Moulik, B.; Prakash, A.; Ganguly, A. Improvement in fuel economy of hybrid hydraulic powertrain by conducting a comparative study of two different optimization strategies. In Proceedings of the 2020 10th International Conference on Cloud Computing, Data Science & Engineering (Confluence), Noida, India, 29–31 January 2020; pp. 828–833.
128. Deppen, T.O.; Alleyne, A.G.; Meyer, J.J.; Stelson, K.A. Comparative Study of Energy Management Strategies for Hydraulic Hybrids. *J. Dyn. Syst. Meas. Control* **2015**, *137*, 041002. [CrossRef]
129. Wang, Z.; Jiao, X. Hierarchical Model Predictive Control for Hydraulic Hybrid Powertrain of a Construction Vehicle. *Appl. Sci.* **2020**, *10*, 745. [CrossRef]
130. Yang, Y.; Zhong, Z.; Wang, F.; Fu, C.; Liao, J. Real-time energy management strategy for oil-electric-liquid hybrid system based on lowest instantaneous energy consumption cost. *Energies* **2020**, *13*, 784. [CrossRef]
131. Yan, F.; Wang, J.; Du, C.; Hua, M. Multi-Objective Energy Management Strategy for Hybrid Electric Vehicles Based on TD3 with Non-Parametric Reward Function. *Energies* **2022**, *16*, 74. [CrossRef]
132. Chen, H.; Zhang, T.; Zhang, H.; Tian, G.; Liu, R.; Yang, J.; Zhang, Z. Power Parametric Optimization of an Electro-Hydraulic Integrated Drive System for Power-Carrying Vehicles Based on the Taguchi Method. *Processes* **2022**, *10*, 867. [CrossRef]
133. Eckert, J.J.; Barbosa, T.P.; da Silva, S.F.; Silva, F.L.; Silva, L.C.A.; Dedini, F.G. Electric hydraulic hybrid vehicle powertrain design and optimization-based power distribution control to extend driving range and battery life cycle. *Energy Convers. Manag.* **2022**, *252*, 115094. [CrossRef]
134. Eckert, J.J.; Barbosa, T.P.; Silva, F.L.; Roso, V.R.; Silva, L.C.A.; da Silva, L.A.R. Optimum fuzzy logic controller applied to a hybrid hydraulic vehicle to minimize fuel consumption and emissions. *Expert. Syst. Appl.* **2022**, *207*, 117903. [CrossRef]
135. Yang, J.; Liu, B.; Zhang, T.; Hong, J.; Zhang, H. Multi-parameter controlled mechatronics-electro-hydraulic power coupling electric vehicle based on active energy regulation. *Energy* **2023**, *263*, 125877. [CrossRef]
136. Tang, X.; Xie, Y.; Wang, B.; Shi, L.; Wu, X. Energy management strategy for hydraulic hybrid system with compound accumulator based on dynamic programming. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2022**, 095440702211020. [CrossRef]
137. Li, L.; Zhang, T.; Hong, J.; Zhang, H.; Yang, J.; Zhang, Z.; Wu, K. Energy management strategy of a novel mechanical–electro–hydraulic power coupling electric vehicle under smooth switching conditions. *Energy Rep.* **2022**, *8*, 8002–8016. [CrossRef]
138. Zhang, Z.; Zhang, T.; Hong, J.; Zhang, H.; Yang, J. Entropy-based torque control strategy of Mechanical–Electric–Hydraulic Power Coupling Vehicles. *Control Eng. Pract.* **2023**, *133*, 105437. [CrossRef]
139. Balali, Y.; Stegen, S. Review of energy storage systems for vehicles based on technology, environmental impacts, and costs. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110185. [CrossRef]
140. Li, L.; Zhang, T.; Sun, B.; Wu, K.; Sun, Z.; Zhang, Z.; Lin, L.; Xu, H. Research on electro-hydraulic ratios for a novel mechanical-electro-hydraulic power coupling electric vehicle. *Energy* **2023**, *270*, 126970. [CrossRef]