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Alternative and Transitional Energy Sources for Urban Transportation

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Abstract In urban areas, the transportation sector is one of the principal sources of substantial energy consumption and carbon emission. Although diesel and gasoline are still the main energy sources used in urban transportation, alternative and transitional energy sources have been introduced. The alternative and transitional energy sources include electricity (used in hybrid, electric, and fuel-cell vehicles), biofuels, gaseous fuels from other sources (hydrogen, natural gas, and liquefied petroleum gas [LPG]), alcohols, and ethers. Alternative and transitional energy sources can be used to promote the development of sustainable transportation systems because these sources are renewable and have a lower environmental impact than diesel and gasoline. However, various technical, economic, and policy factors can prevent the successful application of alternative energy sources. In this review, we summarize the latest literature regarding alternative and transitional energy sources in order to understand the current applications of these energy sources in urban transportation and their future applications.

Keywords Alternative energy · Transitional energy · Urban transportation · Electricity · Biofuels

Introduction

In urban areas, the transportation sector is one of the principal sources of substantial energy consumption. Although public modes of transportation have greater passenger capacity and a lower environmental impact than private motorized vehicles, people in many cities still prefer owning and using their private cars. In most American cities, more than 90 % of trips are made using private vehicles [1]. Currently, because most private vehicles consume diesel or gasoline, a high reliance on private vehicles causes higher consumption of non-renewable energy sources and greater carbon dioxide (CO_2) emissions. With the rapid urbanization and motorization in China, CO_2 emissions from road transportation rose from 3.10 Mt in 1980 to 270.9 Mt in 2009, 90 % of which was caused by urban transportation, making urban transportation the source of approximately 80 % of the total transportation-related CO_2 emissions [2]. Worldwide, the transportation sector accounted for 27 % of the global fuel consumption in 2010, with 97 % of the energy sources used being fossil fuels, thereby producing 22 % of the total global CO_2 emissions [3]. Today, technological advancements have enabled the development of alternative and transitional energy sources. Vehicles using energy sources such as liquefied petroleum gas (LPG), electricity, and biofuels are becoming more widely used. By using alternative and transitional energy sources instead of traditional diesel and gasoline, the reliance on non-renewable energy can be reduced and the impact on the environment can be minimized. However, there are still multiple challenges in applying these new technologies at a large scale. In the USA, even though the government has heavily promoted electric vehicles (EVs), the sales of such vehicles only accounted for 3.38 % of the country's national automotive market in 2012 [4]; however, they are predicted to account for 62 % of the total vehicles driven in the USA by 2050 [5]. Given the existing trends, fossil fuels (including coal, oil, and natural gas) will remain the dominant sources of energy for transportation at least up to 2030 [6].

Substituting diesel and gasoline with alternative and transitional energy sources in both private vehicles and public transportation vehicles is challenging because multiple obstacles are involved. The obstacles not only involve the technological complexities of vehicle design and infrastructure construction but also the lack of political and public support. It

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was argued that only when alternative energy sources compete with the efficiency of fossil fuels in all aspects, such as cost, convenience, and reliability [7•], can they be widely applied in sustainable urban transportation systems. Therefore, to understand the current and future status of alternative and transitional energy sources for urban transportation, acquiring knowledge regarding the types of alternative energy sources available and the obstacles hindering their application in urban transportation is necessary.

Types of Alternative and Transitional Energy Sources

Alternative and transitional energy sources are derived from sources other than diesel and gasoline. For urban transportation, the main alternative and transitional energy sources are electricity, biofuels (e.g. vegetable oil and biodiesel), other gaseous fuels (natural gas, hydrogen, and LPG), alcohols (methanol and ethanol), and ethers (Fig. 1) [8]. Since the world energy crisis in the 1970s, alternative and transitional energy sources have received much attention. Among these, the use of natural gas in forms such as compressed natural gas (CNG) and LPG has increased rapidly over the past decades [9]. Nowadays, there are more than 11.3 million natural gas-fueled vehicles on the road and 16,500 natural gas refueling stations worldwide [10]. Natural gas is widely used because it is available in large quantities, relatively cheap, and has a well-developed distribution infrastructure [11]. However, as its potential to reduce emissions is limited, it can only be adopted as a transitional energy source [12]. Most current studies focus on electricity and biofuels, which may become the main long-term sustainable energy sources for urban transportation. Regarding the application of hydrogen, alcohols, and ethers, the new trend is to use them in fuel-cell vehicles instead of as primary fuels or to use them in combination with fossil fuels [9].

Electricity

The applications of electricity in urban transportation include plug-in hybrid EVs (PHEVs), battery EVs (BEVs), and fuel-cell EVs (FCEVs). PHEVs depend on both diesel/gasoline and electricity and have been used for about half a century; more recently, BEVs and FCEVs have been receiving increased attention. In 2012, the global EV stock reached 180,000, accounting for only 0.02 % of total passenger cars, but the percentage is projected to be 2 % by 2020 [13]. The USA and Japan are currently the leading users of EVs, with definite EV sales and stock targets and incentives promoted by their respective governments [13]. However, some challenges remain. For example, simultaneously charging tens of thousands of EVs may threaten the stability of a power system. Thus, battery technologies such as nickel-metal hydride (Ni-MH) and lithium-ion (Li-Ion), intelligent energy management systems, and vehicle-to-grid (V2G) technology were introduced [5]. V2G technology enables EVs to deliver power back to the grid, and a study conducted in Norway showed that a smart charge approach can further reduce the strain of large-scale EV charging on the grid [14]. Compared with plug-in EVs, FCEVs can produce electricity by refilling with fuels such as hydrogen [15, 16], alcohols, or ethers [8] instead of recharging. However, the performance of FCEVs is limited by the energy storage system technology, such as storing hydrogen in the vehicle, and the high cost of energy storage and fuel cells limits commercial application.

Biofuels

Biomass conversion can be used to produce biofuels using wood residues, bagasse, rice husks, agro-residues, animal manure, and municipal and industrial waste [17•]. Biofuels have near-carbon neutrality, and the various resources used for producing them are abundant [18]; therefore, they are considered one of the most promising alternative energy sources. It was estimated that 38 % of the world's direct fuel use will be derived from biomass by 2050 [19]. Nowadays, biofuel is usually used as a diesel additive only. The biodiesel blends have a short ignition delay, high ignition temperature, pressure, and peak heat release, as well as low emissions. Based on the production technology used, biofuels can be divided into four generations: the first generation is produced from sugar, starch, vegetable oils, or animal fats by using traditional technology; the second generation is produced from non-food crops, wheat straw, corn, wood, solid waste, and energy crops by using advanced technology; the third generation is produced from algae; and the fourth generation involves producing biogasoline from vegetable oil and biodiesel by using highly advanced technology [19]. Many studies focus on bioethanol as a substitute for gasoline and biodiesel as a substitute for diesel. The gasification of biomass into hydrogen, synthetic gasoline, or diesel fuel is a new trend that has become technologically feasible [20]. The use of biofuels could be widely adopted around the world, and the resources used for making these fuels vary by region. The USA, France, Brazil, India, Indonesia, Malaysia, and Australia are the main producers of biodiesel. Cooking oil is used in the USA and the European Union (EU); palm oil and coconut oil are used in Malaysia, Indonesia, and Thailand [10]. Another recent study recommended that China, India, Indonesia, and other rice-producing countries can benefit from using biofuels by producing it using the leftover rice husks and rice straw from the rice industry [18].

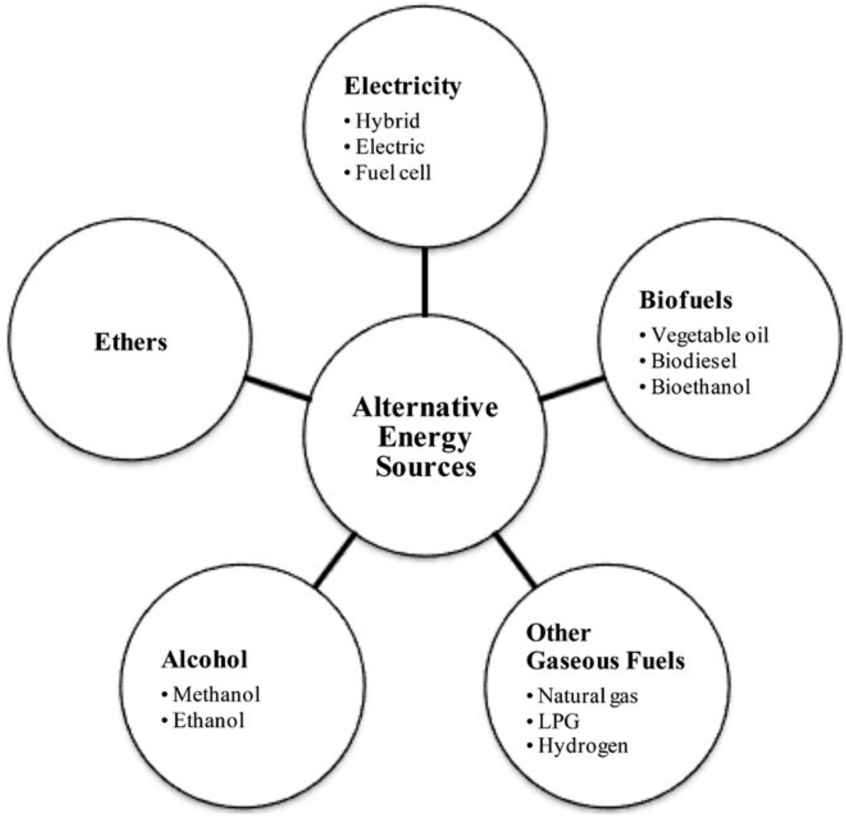

Fig. 1 Type of alternative and transitional energy sources in urban transport

Application Obstacles

Technology

Technological immaturity and the high cost of new technologies are major obstacles for the widespread application of alternative and transitional energy sources in transportation. The technologically complex problems not only include vehicle and engine design but also the design of fuel storage systems and refueling and recharging infrastructure. Specifically, different types of alternative and transitional energy sources involve different technological obstacles. For electricity, the battery performance and recharging system are the main obstacles [21–23]. The widespread adoption of EVs requires the establishment of intelligent grids and an EV charging infrastructure; however, an empirical study conducted in a Danish residential area revealed that voltage limits restricted the integration of EVs in the local grid [24]. Fuel-cell vehicles require additional space and weight for battery and storage tank installation, which increases the production cost. Other obstacles regarding electricity applications include range limitation, safety, and reliability [13]. For biofuels, the high costs of production, transportation, and storage are some notable obstacles. For example, commercializing microalgal biodiesel requires the optimization of microalgae harvesting and the selection of suitable microalgae species; therefore, devising a new and efficient oil-extraction method that yields the most oil from existing algae strains, or selecting new algae strains with high oil contents is necessary, all of which cost companies money [25]. For countries lacking rich biomass resources, the transportation costs of importing should be considered [17•]. For example, Germany must import ethanol from other countries, such as Brazil (sugarcane), the USA (corn), and France (wheat and sugar beets) [26].

Policy

In addition to technological problems, one other obstacle preventing the widespread application of alternative energy sources in urban transportation is the industrial commercialization of these energy sources, which often requires the support of government policies. First, numerous new technologies, such as FCEVs and new-generation bioethanol and biodiesel, are not yet market ready and have high production costs. Thus, without the help of government policies (such as tax exemptions, price controls, and direct subsidies) to attract new investors, it is difficult to promote these technologies [25]. Second, different regions may approve different policies for different alternative and transitional energy sources because production costs also depend on the regional characteristics, such as the availability of resources. For example, in Paraguay, the use of hydrofuel cell buses is an economically feasible alternative for diesel fuel buses [27]; however, the high price of EVs still limits its applications [28]. It is more difficult to reduce CO_2 emissions than it is to reduce reliance on diesel and gasoline consumption because the electricity used in hybrid EVs, PHEVs, and pure EVs (PEVs) in some regions is produced by using a high share of coal power [29]. The key point is to consider both the direct emissions reduction and various indirect impacts, which we shall elaborate in the next section. Third, consumer acceptance is also critical because consumers tend to resist new technologies that are immature; even technology enthusiasts are highly uncertain about EVs and are more concerned about the cost and performance than sustainability [30]. A study on hydrogen showed that the acceptability of hydrogen technology depends on people's knowledge and awareness of hydrogen's benefits toward the environment and human life; however, people still do not have sufficient information on hydrogen [15, 31].

New and Future Directions

Traditional studies regarding alternative and transitional energy sources for urban transportation have focused on the technologies for applying these energy sources, including the technical feasibility of vehicle design, fuel production, and storage, as well as the potential of using alternative fuels for reducing greenhouse gas (GHG) emissions [7•]. Some new and future directions of research include, among others, the quantification/modelling of the benefits of alternative and transitional energy sources, and studies on promoting the commercialization of these more sustainable technologies.

Quantifying the Benefits of Alternative and Transitional Energy Sources

To emphasize the value of alternative and transitional energy sources, some recent studies have attempted to quantify the benefits of alternative energy sources in transportation using the life-cycle assessment (LCA) approach [32]. LCA is a method for quantifying the relevant energy and material flow as well as the emissions and waste that are generated throughout the life cycle of a product. By using LCA, it was discovered that, compared with using diesel and gasoline, using alternative and transitional energy sources can yield a more favorable performance in several aspects, including carbon emission [33] and energy efficiency [34, 35]. However, the performance of the various alternative and transitional energy sources differs in different contexts.

For instance, the degree to which electricity can actually reduce GHG emissions is uncertain, and depends on the percentage of renewable energy sources used in electricity generation [14, 28]. A case study conducted in Portugal used LCA to examine the energy use and emissions of different light-duty vehicle technologies: conventional gasoline and diesel (internal combustion engine; ICE), PEVs, fuel-cell hybrid EVs (FCHEVs), and fuel-cell PHEVs (FC-PHEVs). It was revealed that the energy supply infrastructures of the new vehicle technologies are more carbon and energy intensive per unit of supplied energy than are conventional energy supply infrastructures [36]. Therefore, integrating wind power with plug-in EVs [37] or promoting V2G [36] and Vehicle-Infrastructure Integration (VII) communication technologies [38] in EVs was suggested. The electricity generation emission of biofuels is 14–90 % less than the electricity generated from fossil fuels [17•]. Using wood to displace fossil fuel-intensive materials is much more effective in reducing GHG emissions than using biofuels to directly replace diesel and gasoline [33]. A case study conducted in Greece also proved that using biodiesel resulted in a substantial reduction of GHG emissions compared with using gasoline and diesel; however, biodiesel combustion increased the emissions of PM_{10}, nitrous oxide, nitrogen oxides (NO_x), as well as elements such as nitrogen and phosphorus [32]. Another case study conducted in Denmark also supported these findings, revealing that using residual domestically available biomass materials instead of diesel and gasoline can reduce GHG emissions [39]. However, the energy efficiency of biomass is not necessarily higher [40]. Hydrogen, which can be used in several transportation modes, can also be a promising source of alternative energy because it produces zero carbon emissions. A case study conducted in Ontario, Canada showed that the benefits of using hydrogen are greater in automobile and rail applications than in air and marine applications [41]. In comparison, the potential of using CNG and LPG to reduce emissions is limited. For alcohols and ethers, a study suggests that the life-cycle emissions are generally higher for ethanol than for gasoline, but ethanol exhibits different spatial and temporal patterns than gasoline [42]. Some well-to-tank studies have indicated that hydrogen-derived methanol is a viable alternative to liquid or compressed hydrogen, both in production cost and energy efficiency [43]. When quantifying the life-cycle GHG emissions of using bioethanol, it was observed that changing from corn to sugarcane, and then to cellulosic biomass helps to substantially increase the reductions in energy use and GHG emissions. Relative to petroleum gasoline, using ethanol made from corn, sugarcane, corn stover, switchgrass, and miscanthus can reduce the life-cycle GHG emissions by 19–48 %, 40–62 %, 90–103 %, 77–97 %, and 101–115 %, respectively [44].

It is debatable whether financial incentives should be given to encourage the application of alternative and transitional energy sources in urban transportation. One study applied an economic model to evaluate the costs and benefits of diesel–electric hybrid vehicles in the USA from 2012 to 2030 and concluded that promoting the technology could lead to positive economic benefits with a 3 % discount rate from a societal perspective [23]. Another study of European policies on vehicle carbon emissions revealed that using hybrid vehicles, BEVs, PHEVs, and FECVs can decrease CO_2 emissions from passenger transportation by 35–57 % in the EU (EU-27) until 2050 compared with 2010 [21]. To assist decision making, the analytic hierarchy process (AHP) was used to evaluate alternative and transitional fuels based on economic, technical, social, and policy criteria. The study found that, among the various new-generation biofuels, bio-substitute natural gas and electricity produced from biomass incineration are the most suitable fuels [45].

Identifying and Overcoming Technological Barriers

Research is needed to identify and overcome the technological barriers of applying various alternative and transitional energy sources in transportation. Some new but promising technologies include V2G [5, 46], vehicle-to-home [14], and smart charging for EVs, atomic layer deposition for electrochemical energy generation and storage [47], using highway right-of-ways for energy production [48], and bioenergy derived from rice [18], wood [22], residual biomass, and waste biomass [49]. As mentioned previously, one challenge of applying renewable energy sources (e.g., solar and wind energy and hydropower) in vehicles is energy storage; therefore, by using electrochemical processes, including those found in photoelectrochemical devices, batteries, fuel cells, and supercapacitors, the storage and distribution of energy can be simplified. An energy management system is a computer-aid tool used for the operation of electric utility grids to monitor, control, and optimize the performance of the power system [50]. However, further research is required to reduce the cost of V2G power and smart charging [51]. In addition, future improvements in battery pack energy density, operating temperature range, and life cycle are required to reduce costs and increase the driving range and battery life of EVs [13]. Because feedstock accounts for 75 % of the production cost of biodiesel, selecting suitable economical feedstock is key for reducing the cost. Moreover, the oil percentage and the yield per hectare are crucial factors. Compared with the first-generation edible feedstock oils, using non-edible oil resources (*Jatropha curcas*, *Calophyllum inophyllum*, *Dipteryx odorata*, *Aleurites moluccana*) has the advantages of low impact to food crops, low land clearing requirements, as well as low GHG emissions. Recently, microalgae and genetically engineered plants, such as poplar and switchgrass, were considered as new feedstocks for biodiesel. In addition to exploring new feedstocks, researchers have also focused on new production technologies. For example, transesterification is a low-cost and simple technology for producing biofuels [52]. For hydrogen supplies, some scholars tried to build a cost-effective central hydrogen supply system using a transportation model [53]. Generally, the production of synthetic gaseous fuels is 45 % more efficient than that of synthetic liquid fuels; however, compression affects the thermal efficiency in the lower engine, which reduces the efficiency of gaseous fuels [54].

Policy and Behavioral Research

Government policies that may improve the market share of alternative and transitional fuel vehicles can be classified into regulatory or ‘technology-forcing’ instruments such as fuel mandates; economic instruments, including subsidies, tax incentives, and discounted loans; procurement instruments, such as mandatory green public procurement; collaborative instruments, such as public–private partnerships; and communication and diffusion instruments, such as vehicle labelling, education, awareness campaigns, and publicity [55••]. Many scholars have conducted case studies regarding the transportation and energy policies in regions such as China [56, 57], Japan [58], Germany [12], the USA [59], Turkey [60], Canada [61], and Brazil [62], providing multiple points of view because energy policies differ substantially among nations, reflecting their own circumstances and national objectives. Many studies analyzed the opportunities and challenges involved in these different policies, including standards, technology-supporting programs, and legal regulations regarding energy, and strategies for further energy and transportation development.

Cost can be a major obstacle to the widespread use of alternative and transitional energy sources in transportation. Hence, the reduction of the first registration tax, sales tax, exemption from import duty, and other forms of subsidies have been made to encourage the replacement of diesel and gasoline vehicles with vehicles using alternative or transitional fuels. One study conducted in Sweden shows that transportation fuel taxation can effectively affect the application of alternative transportation fuels, but the nature of the impact of fuel taxation is largely dependent on the way in which the taxes are applied [63]. Public awareness and desire toward cleaner fuel vehicles can also be improved by emphasizing the convenience of using such vehicles and providing free parking. By broadcasting new reports, advertisements, educational materials, and documentaries, the public acceptance of clean fuel vehicles may be improved [4].

In different regions, policies may differ (Table 1). In Taiwan, policies on clean fuel were proposed to increase the use of EVs and biodiesel vehicles [64]. In Turkey, policies for developing alternative energy sources include laws concerning renewable energy, feed-in tarrifs, purchase obligations, connection priority, reduced license fees, reduced fees for project preparation, and land acquisition [60]. In the USA, because of the Renewable Fuel Standard (RFS), renewable fuel use in vehicles has increased from nearly zero to 10 % annually since 2005, and fuel blends contain up to 15 %

Table 1 Policies about alternative and transitional energy sources in urban transport in different countries

Country	Targets	Strategy
China	• Developing electric vehicles • Blending gasoline with 10 % ethanol in 9 provinces by 2015	• Support R&D and production of clean-fuel vehicles by grants • Promote clean-fuel vehicles by purchase subsidy and tax reduction • Import duty reduction for ethanol
USA	• Blending gasoline with 10 % ethanol in 3 states by 2015 • The volume of renewable fuel increased to 36 billion gallons by 2022 • Reduce petroleum consumption by 2.5 billion gallons by 2020 • 75 % of new light-duty vehicles acquired by covered state fleets must be alternative fuel vehicles	• Fund for technology commercialization • Producer tax credit for cellulosic biofuel and tax credit for ethanol • Grants for production of advanced biofuels and renewable fuel infrastructure • Requirement of federal agencies to use plug-in hybrid vehicles • National biodiesel education
Japan	• Large-scale supply of gasoline containing 3 % ethanol in large cities	• Large clean fuel R&D budget
UK	• 10 % of energy demand met by renewable energy sources by 2020	• Transport fuel suppliers are required to ensure a set percentage of their sales from a renewable source, with 5 % in 2013–2014. • A reduction of excise duty rate for biodiesel and bioethanol • Financial schemes to support R&D of technologies
Sweden	• 14 % of energy demand met by renewable energy sources by 2020 • Vehicle stock independent of fossil fuels by 2030	• Biofuel-based motor fuels are exempted from energy and carbon dioxide taxes • Encourage converting vehicles to ethanol by reduced tax and buying low-emission vehicle by eco car subsidy • Larger petrol stations are required to sell renewable motor fuels
Italy	• 10 % of energy demand met by renewable energy sources by 2020	• An obligation for all traditional fuel producers to supply a minimum quota of biofuels, with 5 % by 2014 • Excise duty reduction and tax relief for biofuels • Financial support to R&D

Source: IEA/IRENA Joint Policies and Measures database [70].

R&D research and development

ethanol [4]. In the UK, targets of 40 and 90 % market penetrations of electric and hybrid vehicles have been established for 2030 and 2050. Policies including purchase taxes, graduated vehicle road taxes, vehicle scrappage schemes, and fuel taxation have been adopted [65]. In Italy, like the other EU countries subject to the terms of the Renewable Energy Directive, the Government has aimed to reach 10 % renewable energy use in transportation by 2020, which is constituted by 65 % biodiesel, 21 % bioethanol, and 13 % renewable electricity, as well as a minor percentage of other biofuels [66]. In Sweden, the Government has the ambitious goal of eliminating the use of fossil fuel-operated vehicles by 2030. The main strategy is to make public transportation attractive by improving both the infrastructure and fare subsidies of public transportation and offering economic incentives such as fuel taxation and parking fees for private cars. The basis for these changes is that the public transportation system in Sweden has to change from vehicles operated on fossil fuels to vehicles using biofuels and electricity [67]. In China, it is recommended to use new energy vehicle technology with "oil-electric hybrid pure electric, improved hybrid-hydrogen fuel cell, rechargeable hybrid" as the main line, according to the considerations of technology maturity, cost, energy resources, pollution, energy efficiency, and technical characteristics [68]. Specifically, a range of monetary incentives can be implemented: governments can support vehicle research and development and manufacturing by offering grants, loans, and tax credits; resources from different government levels can be consolidated to provide grants and loans for the establishment of charging facilities; and provincial- and municipal-level financial incentives can be provided in the form of tax credits, free or discounted parking spaces, free or discounted transfers to other transportation modes, and exemption from on-the-road charging to help stimulate the EV-buying market. Non-monetary incentive options include designating the use of superior lanes for EVs to promote vehicle purchases; strengthening the monitoring and evaluation component of the demonstration program; and reducing self-interest and enhancing cooperation in pilot cities [69].

Conclusion

Currently, alternative and transitional fuels are increasingly applied in urban transportation. According to some studies that used LCA, alternative and transitional fuels generally have lower carbon emissions and higher energy efficiencies than traditional diesel and gasoline. However, their applications are still limited because the technologies are immature, expensive, and unrecognized by consumers. Recently, numerous studies have provided new technological and political strategies for improving the application of alternative and transitional energy sources. In the future, research should not only focus on the technical aspects but also the wider political, economic, and social contexts in which these technologies are adopted.

Compliance with Ethics Guidelines

Conflict of Interest Linna Li and Becky P.Y. Loo declare no conflicts of interest.

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- • Of importance
- •• Of major importance

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